RUNOFF QUALITY INDEX FOR AREA UNDER MAIZE CULTIVATION

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ABSTRACT

Land development activities contribute to water quality impairment. The resulting runoff from rainfall from different land use areas carries a wide range of pollutants that find their ways to the surface and ground waters. The use of models plays an important role in the assessment of diffuse pollution sources and their delivery to the receiving water bodies. The current Water Quality Index (WQI) used by the Department of Environmental (DOE) Malaysia has limitations when applied to agricultural areas. The important parameters do not include those pollutants particular to agricultural areas. This research project was carried out on sandy clay loam soil grown with maize (Zea Mays). The experimental plot was isolated from the surrounding areas with perimeter bunds to protect from runoff from adjacent areas. Thirty seven rainfall events in three seasons were monitored to evaluate the parameters that contributed most to the Non-point Source (NPS) pollution. A Runoff Quality Index (RQI) was proposed to assess runoff quality. The quality parameters include Total Kjeldhal Nitrogen (TKN) and Total Phosphorous (TP). It must be mentioned that the results of this experimental study is limited specifically to an agricultural area that was cultivated in maize only.

Keywords: *Agricultural Pollution, Diffuse Pollution, Runoff Quality Index (RQI)*

1.0 INTRODUCTION

The environmental sustainability of agricultural systems has been discussed worldwide and the degradation of water is among the main environmental concerns related to agriculture. High risk of flooding, dead fish, and contamination by pesticides and nutrients in surface and groundwater are considered the main impacts of agriculture. The quality and quantity of water resources decrease over time. The degradation of water resources is caused by a lot of activities such as land conversion from forest to farmland, shifting cultivation, plantation, residential and industrial development. Those activities involving earthworks cause soil erosion, sedimentation of rivers and consequently flooding that threatens human beings and properties.

Water resources are degraded due to addition of pollutants from the point and non-point sources (NPS). Point source pollution are usually noticeable, confined and is comparatively easy to estimate its pollutant loads into the rivers and other water bodies. On the contrary, non-point sources pollution is not confined and therefore is difficult to be estimated and to be captured to reduce water pollution problems. Non-point source pollution is directly governed by storm runoff. Runoff from agricultural areas is the main conveyance of non-point sources pollution to the downstream river system.

Malaysia receives an annual average rainfall that varies from 1700 to 4000 mm depending on location. The resulting runoff can be substantial and can carry a wide range of pollutants from different land uses that find their ways to the surface and ground waters. The runoff may contribute as high as 60% of the total pollutants coming into the rivers [7]. Malaysia covers an area of about 32.86 million hectares, consisting of Peninsular Malaysia and the states of Sabah and Sarawak and the island Federal Territory of Labuan in northern Borneo Island. Over 10 million hectares, or 31% of Malaysia's total land area, is considered suitable for agricultural practices. Of this, some 5.4 million hectares have been cultivated, constituting a very large potential area to generate NPS pollution.

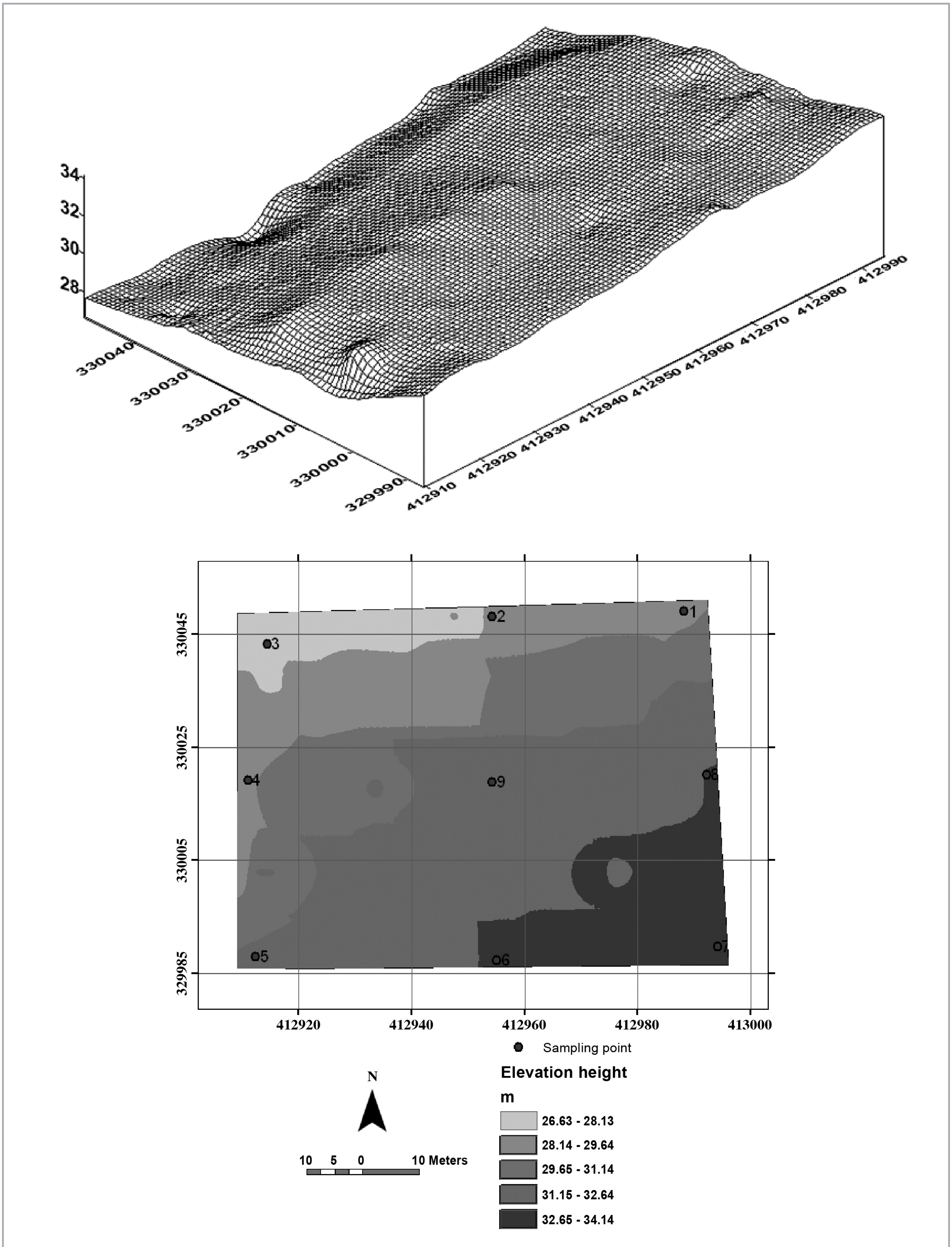


Figure 1: Elevation Height of the Study Area above Mean Sea Level (MSL)

The existing Water Quality Index (WQI) proposed by the Department of Environmental (DOE) Malaysia was reviewed and found to have limitations when applied to agricultural areas. In view of the issues and problems discussed above, the objective of the study was to develop a Runoff Quality Index (RQI) based on the dominant pollutants in runoff specifically from a tropical cultivated agricultural area.

2.0 METHODOLOGY

2.1 The Study Area

The research project was carried out at the Precision Agriculture Experimental Plot in Universiti Putra Malaysia (UPM). Maize (Zea Mays variety) was planted in the study area the size of about 0.56 ha located at latitude 3° 02' N and longitude 101° 42' E, at 31 m above mean sea level. The soil in the study area is the Malayan Serdang series. The study plot was isolated from the surrounding areas by building bunds to prevent runoff produced from the adjacent areas. The area has 7 % slope in the direction sloping down from south to north (Figure 1). Water quality study was conducted during three consecutive seasons from March to June2004 (Crop season I), August to October 2005 (Crop Season II) and November 2005 to February 2006 (Crop season III). Normal agricultural practices were implemnented. For each season, fertilisers were spread three times. The first time being 15 days after seeding with Nitrophoska Green, (15% N, 15% P_2O_5 and 15% K_2O). The second and third spreads were done 30 and 45 days after seeding resepctively, using Nitrophoska Blue TE which contains 12% N, 12% P_2O_5, 17% K_2O, and 2% MgO and trace elements: Boron (B), Manganese (Mn), Zinc (Zn) and Iron (Fe). I all a total of twenty rain events in crop season I, nineteen events in crop season II and eight events in crop season II were monitored. It must be mentioned that the results of this experimental study is limited specifically to an area that was cultivated in maize only.

2.2 Collection of Samples

The following equipment and instruments were installed at the site to collect water samples: automatic rain gauge, auto-sampler for water collection [6], automatic water level recorder. Water samples were collected by the auto-sampler (ISCO 6712 Portable Sampler, Teledyne Isco Inc.) with a built-in peristaltic pump following recommended procedures [2].

Table 1: Proposed runoff quality index for the agricultural area (planted in maize)

RQI = 0.14SITKN + 0.18SIBOD + 0.18SICOD + + 0.17SINH3-N + 0.19SITSS + 0.14SITP (1)

Where,
RQI= Runoff quality index for agricultural area; SITKN= Sub-index of TKN; SIBOD= Sub-index of BOD;
SIBOD= Sub-index of BOD; SINH3-N= Sub-index of NH3-N; SITSS= Sub-index of TSS and SITP= Sub-index of TP.

Sub-index of TKN for 0.5 mg/L ≤ TKN ≤ 5 mg/L:
SITKN = 0.559 TKN3 – 3.8857 TKN2 – 14.786 TKN + 101.83 (2)

Sub-index of BOD for 1 mg/L ≤ BOD ≤ 15 mg/L:
SIBOD = 0.0063 BOD3 – 0.2427 BOD2 – 4.4215 BOD + 100.32 (3)

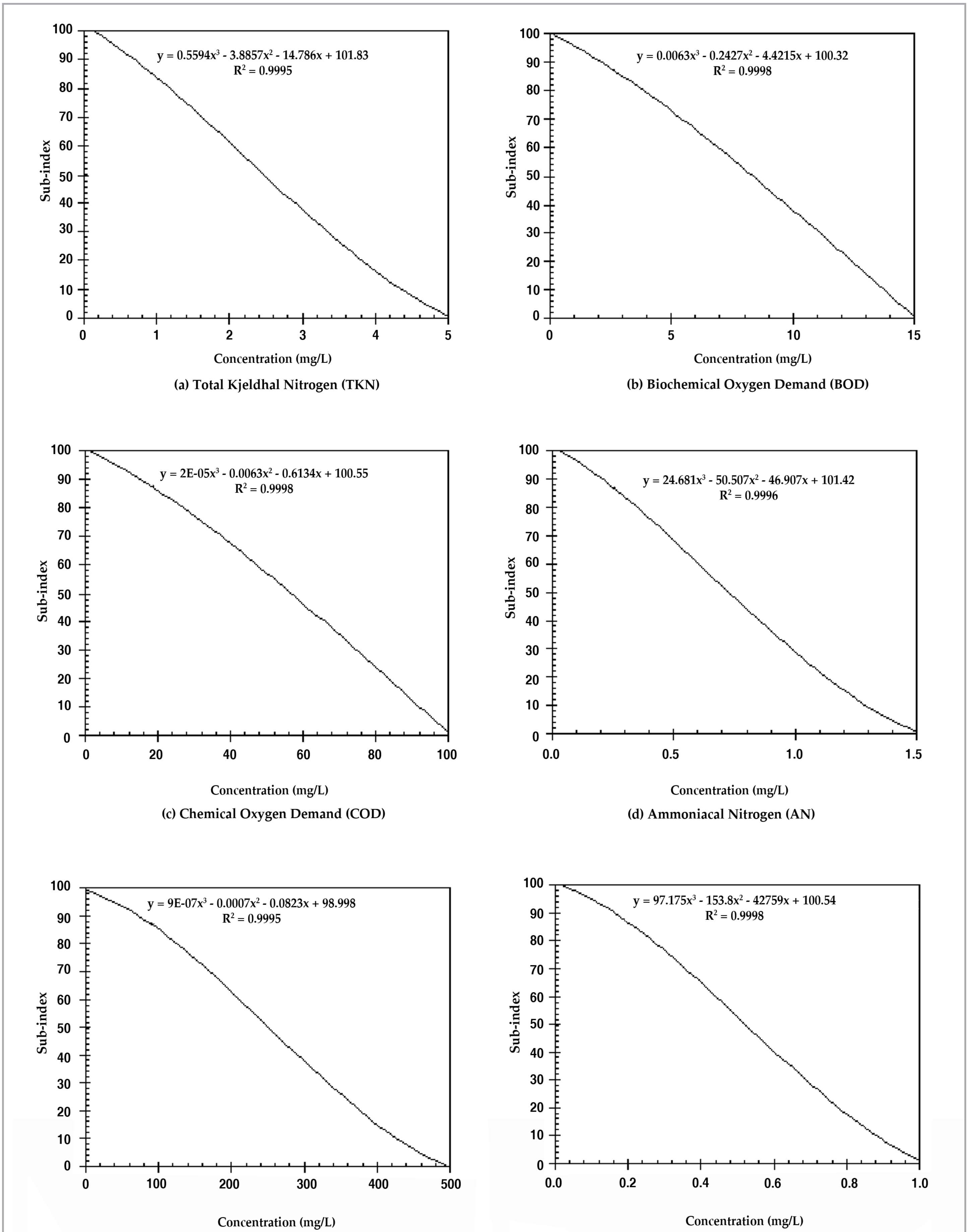
Sub-index of COD for 10 mg/L ≤ COD ≤ 100 mg/L:
SICOD = 2E-05 COD3 - 0.0063 COD2 – 0.6134 COD + 100.55 (4)

Sub-index of NH3-N for 0.20 mg/L ≤ NH3-N ≤ 1.50 mg/L:
SINH3-N = 24.681 NH3-N3 – 50.507 NH3-N2 – 46.907 NH3-N + 101.42 (5)

Sub-index of TP for 0.15 mg/L ≤ TP ≤ 1.0 mg/L:
SITP = 97.175 TP3 – 153.8 TP2 - 42.759 TP + 100.54 (6)

Sub-index of TSS for 25 mg/L ≤ TSS ≤ 500 mg/L:
SITSS = 9E-07 TSS3 - 0.0007 TSS2 - 0.0823 TSS + 98.998 (7)

Pollutant concentrations are in mg/L for all parameters. The sub-index value cannot be negative.
These equations (from 1 to 7) are graphically represented in Figure 2.



(a) Total Kjeldhal Nitrogen (TKN)

(b) Biochemical Oxygen Demand (BOD)

(c) Chemical Oxygen Demand (COD)

(d) Ammoniacal Nitrogen (AN)

(e) Total Suspended Solids (TSS)

(f) Total Phosphorus (TP)

Figure 2: Variation of Sub-indices with Pollutant Concentrations for the Parameters Required for the Proposed RQI

Table 2: Existing water quality index (WQI) and classes

Parameter	Class I	Class II	Class III	Class IV	Class V
Ammoniacal Nitrogen (NH3-N)	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
Biochemical Oxygen Demand (BOD)	< 1	1 - 3	3 - 6	6 - 12	> 12
Chemical Oxygen Demand (COD)	< 10	10 - 25	25 - 50	50 - 100	> 100
Dissolved Oxygen (DO)	< 7	5 - 7	3 - 5	1 - 3	< 1
pH	> 7	6 - 7	5 - 6	< 5	< 5
Suspended Solids (SS)	< 25	25 - 50	50 - 150	150 - 300	> 300
Water Quality Index (WQI)	> 92.7	76.5-92.7	51.9-76.5	31.0-51.9	< 31.0

The sampler had a maximum of 24 bottles of 1 L capacity and the unit was programmed to collect samples at various time intervals. For each storm event, a maximum of 24 samples were collected from the drainage outlet. Non-uniform time intervals of sampling were chosen to plot the runoff hydrographs covering the storm events. For all 3 seasons, the first 10 samples were collected at 2-minute intervals and the other 14 samples at 5-minute intervals making a 90-minute rainfall satisfactorily sampled. Available laboratory facilities were used to analyse the pollutants in the samples collected.

2.3 Laboratory Testing

The most important and sensitive component of water quality study is the method of laboratory testing and analysis. Adequate attention was given to maintain acceptable level of accuracy in laboratory testing. The water quality parameters were tested using standard methods [1], calibrated sensors and instruments, which are accepted and practiced internationally (YSI, HACH, Oreon, *etc*.).

2.4 Pollutants Studied

Initially, the first crop season samples were analysed for eleven parameters that affect water quality. They were pH, Dissolved Oxygen (DO), Temperature, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3-N), Nitrate (NO_3), Total Kjeldhal Nitrogen (TKN), Total Phosphorous (TP), Total Suspended Solid (TSS) and Turbidity. For the second season, however, only parameters that exceeded the limits of Class III water (which is considered suitable for general usage) were analysed. Seven parameters namely BOD, COD, NO_3, TKN, TP. TSS and Turbidity were found to have exceeded those of Class III water. Consequently, only these seven parameters were analyzed during the second and third seasons.

Table 3: Proposed runoff quality index (RQI) and classes

Parameter	Class I	Class II	Class III	Class IV	Class V
Ammoniacal Nitrogen (NH3-N)	< 0.1	0.1 - 0.3	0.3 - 0.5	0.5 - 1.1	1.1 - 1.5
Biochemical Oxygen Demand (BOD)	< 1	1 - 3	3 - 6	6 - 12	12 - 15
Chemical Oxygen Demand (COD)	< 10	10 - 25	25 - 50	50 - 75	75 - 100
Total Kjeldhal Nitrogen (TKN)	< 0.5	0.5 - 1.5	1.5- 2.5	2.5 - 3.5	3.5 - 5.0
Total Phosphorous (TP)	< 0.15	0.15 - 0.3	0.3- 0.5	0.5 - 0.75	0.75 - 1.0
Total Suspended Solids (TSS)	< 25	25 - 50	50 - 150	150 - 300	300 - 500
Runoff Quality Index (RQI)	> 94.6	82.8-94.6	62.1-82.8	26.5-62.1	< 26.5

Table 4: Statistical Summary of the case study WQI and RQI Values Obtained

Parameter	RQI	WQI	RQI - WQI	Class RQI	Class WQI
Mean	32.3	46.3	-14.0	IV	IV
Median	28.6	48.0	-18.0	IV	IV
Minimum	21.9	32.5	-25.7	IV	IV
Maximum	54.2	57.7	5.9	III	III
10%tile	23.6	36.5	-23.3	IV	IV
90%tile	50.0	50.9	2.2	IV	IV

3.0 RESULTS AND DISCUSSIONS

Runoff Quality Index (RQI) shown in Table 1 for the agricultural area was proposed based on statistical analysis of primary data collected from the site. The proposed RQI parameters and their rankings were selected to suit the local water quality problems and objectives. The convenience in water quality sampling and testing was another factor considered in selecting the parameters for the proposed RQI of an agricultural area. The RQI is proposed considering the potential important physical, chemical and nutrient parameters from maize cultivation activities.

The proposed RQI given in Equation 1 also consists of six parameters. However, their relative weightage is different from those of the existing WQI equations (DOE). In addition, the pH and DO terms were replaced with Total Kjeldhal Nitrogenand Total Phosphorous. Ammoniacal Nitrogen NH_3-N was included to evaluate the toxicity of the runoff to the aquatic fauna. BOD and COD will represent the biochemically and chemically oxidiseable elements in the runoff from the maize field. There was strong correlation between TSS and turbidity of runoff data. In view of this only TSS was considered in the RQI, which indirectly also represents the clarity of runoff from the study area. The parameters were selected such that the water quality was assessed based on the common and important physical and chemical parameters of surface water. The RQI was also proposed in relation to the five (5) classes of river water as recommended for the existing WQI (Table 2). However, uniformity was maintained in dividing the ranges of water quality classes (from I to V in Table 3), which was not considered in the existing WQI guidelines established for the evaluation of river water quality.

It was observed that the average value of RQI at the site was less by some 14.0 points from the WQI values as shown in in the Table 4. This indicated that the proposed runoff quality index (RQI) was slightly more stringent compared to those derived from the the existing WQI equations. The big difference in WQI values also indicted that the proposed RQI equations are more sensitive to the non-point source pollution, which has been identified as the main source of river pollution in Malaysia [3], [4], [5].

This preliminary RQI for the evaluation of overall water quality discharged from an agricultural area would of course benefit from require further in-depth analyses in different solid types and locality and detailed discussion with the relevant Authorities before implementation in the country. The proposed modifications for the determination of water quality index is necessary to assure good river water quality to enhance the Malaysian government's mission to increase aquatic tourism and river related activities in the country.

4.0 CONCLUSION

The existing Water Quality Index (WQI) guidelines as adopted by the Department of Environmental (DOE) Malaysia was reviewed and found to have a few limitations when applied to Non Point Source pollution common in agricultural practices. It was established that the existing WQI procedure is not suitable for the evaluation of runoff quality from agricultural areas. The main pollutants from the study area were identified and a runoff quality index (RQI) was proposed to assess the runoff quality from the maize field. This modification is necessary to ensure good river water. Further studies on its application throughout the Malaysian agricultural landscape would further enhance is applicability.

5.0 ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

RQI	runoff quality index
TKN	total Kjeldhal nitrogen
TP	total phosphorus
BOD	biochemical oxygen demand
COD	chemical oxygen demand
TSS	total suspended solids
NH_3-N	ammonical nitrogen
DO	dissolved oxygen
NO	nitrate
SI	sub-index
WQI	water quality index
DOE	Department of Environment
MOSTI	Ministry of Science Technology and Innovation
IRPA	Intensive Research for Priority Areas
UPM	Universiti Putra Malaysia
MACRES	Malaysia Centre for Remote Sensing