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Water Quality Status of Selected Rivers in Kota Marudu, Sabah, Malaysia and its Suitability for Usage

(Status Kualiti Air Beberapa Sungai Terpilih di Kota Marudu, Sabah, Malaysia dan Kesesuaian Penggunaannya)

AHMAD ZAHARIN ARIS*, WAN YING LIM, SARVA MANGALA PRAVEENA, MOHD KAMIL YUSOFF, MUHAMMAD FIRUZ RAMLI & HAFIZAN JUAHIR

ABSTRACT

The water chemistry of selected rivers in Kota Marudu, Sabah was studied based on the major ion chemistry and its suitability for drinking and irrigation purposes. Ten sampling stations were selected and water samples were collected from each station to assess its chemical properties. The physico-chemical variables including temperature, electrical conductivity (EC), total dissolved solids (TDS), salinity, dissolved oxygen (DO), pH, turbidity, ammoniacal-nitrogen (NH_3-N), biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS) were measured. The cations (K, Mg, Ca, Na) were analyzed by ICP-MS. Most of the variables were within the drinking water quality standards stipulated by the World Health Organization (WHO) and the Ministry of Health (MOH), Malaysia except for turbidity. Sodium adsorption ratio (SAR) and salinity hazard were calculated to identify the suitability of the water as irrigation water. The Wilcox diagram classifies that only 10% of samples are not suitable for the purpose of irrigation. The overall results showed that most of the rivers in Kota Marudu are still in a clean condition and suitable for drinking and irrigation purposes except for Sumbilingan River, which is considered as slightly polluted. The results are supported by the hierarchical cluster analysis as the stations were grouped into two groups; low and high pollution intensities. This preliminary result can update the baseline data of selected water quality parameters in the Kota Marudu and could serve as tool for assisting relevant government bodies in regulating the water resources policies in the future.

Keywords: Guideline; hydrochemistry variation; Kota Marudu; water quality

ABSTRAK

Ciri kimia air bagi beberapa sungai terpilih di Kota Marudu, Sabah telah dikaji berdasarkan ciri kimia utama ion dan kesesuaiannya bagi tujuan air minuman dan pengairan saliran. Sepuluh stesen persampelan telah dipilih dan sampel air telah diambil dari setiap stesen persampelan terbabit untuk menguji sifat kimianya. Pembolehubah kimia-fizikal yang disukat termasuklah suhu, kekonduksian elektrik (EC), jumlah pepejal terlarut (TDS), kemasinan, oksigen terlarut (DO), pH, kekeruhan, nitrat-ammoniaka (NH_3-N), permintaan oksigen biologi (BOD), permintaan oksigen kimia (COD) dan juga jumlah pepejal terampai (TSS). Kation (K, Mg, Ca, Na) telah dianalisis menggunakan ICP-MS. Kebanyakan pemboleh ubah ini didapati berada dalam julat piawaian kualiti air minuman (DWQS) yang telah ditetapkan oleh Organisasi Kesihatan Dunia (WHO) serta Kementerian Kesihatan Malaysia (MOH), kecuali nilai bagi kekeruhan. Kadar penyerapan natrium (SAR) dan risiko kemasinan telah dikira bagi mengenal pasti kesesuaian air itu bagi tujuan pengairan saliran. Gambaran Wilcox telah mengklasifikasikan hanya 10% daripada sampel itu tidak sesuai bagi tujuan pengairan saliran. Keseluruhan keputusan menunjukkan hampir kesemua sungai di Kota Marudu masih berada dalam keadaan bersih dan sesuai untuk tujuan minuman dan pengairan kecuali air dari Sungai Sumbilingan kerana ia telah dikesan sebagai sedikit tercemar. Keputusan ini telah dikukuhkan lagi dengan analisis kelompok hierarki, memandangkan kesemua stesen persampelan telah dibahagikan kepada dua kumpulan; tahap pencemaran rendah dan tinggi. Keputusan awal ini didapati mampu mengemaskini data sedia ada bagi ciri kualiti air terpilih di Kota Marudu dan seterusnya dapat dijadikan sebagai satu alat untuk membantu badan kerajaan yang berkenaan dalam mengatur polisi sumber air pada masa akan datang.

Kata kunci: Garis panduan; Kota Marudu; kualiti air; variasi hidrokimia

INTRODUCTION

Freshwater ecosystems are one of the important assets in the environment based on their immense biological diversity. The high economical value possessed by this ecosystem makes its suitable for aquaculture activity, as a source of food for sustaining food security, recreation, nature tourism and as genetic resources (Alkarkhi et al. 2009). Due to the scarcity of freshwater such as river, water pollution has become a global concerns; furthermore, water quality depletion will lead to unhealthy natural resources and affect the overall environment (Ujang et al. 2008). The World Health Organization estimates that about 3.4 million people died every year from waterborne disease including cholera, typhoid fever, hepatitis A and cancer due to the lack of access to safe drinking water and adequate sanitation (Water Quality and Health Council 2003). Consequently, access to clean river water becomes a critical issue to overcome by the government.

A parallel increase between the human population and water demand is one of the many concerns related to water quality and quantity. Malaysia is one of the renowned ongoing developing countries in South East Asia and the major water demand comes from agriculture, industry as well as domestic sector (DOE 2007). Although the growth in these sectors has undoubtedly generated economic benefit to the society, it has led to deterioration in water quality and quantity (Muyibi et al. 2008). As a result, the study and management of freshwater resources is becoming more challenging in this country. Considerable efforts have been made in the past to study the environmental conditions of the freshwater ecosystem in Malaysia. Several studies have focused on the assessment of the hydrological properties and water quality (Fulazzaky et al. 2010; Gasim et al. 2007; Mokhtar et al. 1994, 2009; Shuhaimi-Othman et al. 2007; Suratman et al. 2005, 2009a; Yusof et al. 2001). Researchers found that the unsustainable development could result in environmental damage to its surrounding areas as well as the biodiversity of benthic macroinvertebrates (Al-Shami et al. 2010; Azrina et al. 2006). In addition, Muyibi et al. (2008) proved that the development activities had induced the water pollution problem in Malaysia. The wastewater discharged from the manufacturing industry, agro-based industry, domestic sewage, animal husbandry, mining activity as well as surface runoff from land clearing and earthworks activity has led to the problem of freshwater pollution in Malaysia (DOE 2007, 2010; Ebrahimpour & Mushrifah 2008; Mokhtar et al. 1994; Muyibi et al. 2008; Suratman et al. 2009b; Yusof et al. 2001). Most of these studies proved that freshwater contamination mostly dominated at areas close to industrial sites and estuaries. A water quality monitoring program is necessary to protect the continuity of freshwater resources (Fulazzaky et al. 2010; Mokhtar et al. 2009). In order to protect the valuable water resource, understanding of the natural evolution of water chemistry under the natural water circulation process combined with knowledge about the background of the study area are necessary (Mokhtar et al. 2009). Hence, a holistic approach for water quality monitoring and resources management is crucial in order to find adequate supplies and maintaining water quality to maintain a high quality of freshwater in the required quantity at selected places (Radojević & Bashkin 2007).

In this study, Kota Marudu, Sabah, Malaysia, was chosen, which is surrounded by an estuary exposed to pollution issue posed by human interference. Moreover, Kota Marudu is the major producer of crops especially paddy and timber (Yap et al. 2009). Like most parts of Malaysia, in recent decades, human activities, such as excessive forest cutting, crop cultivation and waste dumping, have had a considerable impact on Sabah's rivers. Kota Marudu is not exempted, with Marudu Bay being an example regional pollution from the discharge of nutrient and pollutants from the terrestrial area of Kota Marudu. In addition, Kota Marudu has a history of being a former Mn mining area, late 1902 while the dispersion of other metals might come from the former railway that has been damaged several times during heavy flooding. The side tank of train locomotives were used to transport manganese ores to the industrial area and been scrapped during 1954 (Muda & Tongkul 2008). Previous study has also emphasized on the importance of the quality of river water to wildlife, as the population of proboscis monkey is abundant in Sabah including Marudu Bay (Sha et al. 2008). Since majority of the community relies on the water resources to support their livelihood, there is a need to understand both the natural evolution of water chemistry under the natural water cycle process and the background information of the study area. This understanding is to improve the condition of water resources and minimize threats to its ecological balance (Mokhtar et al. 2009). Thus, the water quality is an issue of great concern since river water is an important source for the citizens in Kota Marudu.

This study focused on the assessment of the river water quality status of selected rivers at Kota Marudu. It attempted to identify the critical parameters affecting the water chemistry and its variation. It also attempted to determine the spatial distribution and concentration of cations (Na, Ca, Mg and K) in the river water. Finally, the data presented in this study aimed to provide or update the baseline data of selected water quality parameters in the Kota Marudu river water for future references.

MATERIALS AND METHODS

STUDY AREA

Kota Marudu is located at the southern end of Marudu Bay in the north of Sabah and lie within the latitude of 6° 15" to 6° 45" N and a longitude of 116° to 117° E (Figure 1). It is situated in the Kudat Division with an area of 1917km^2 and along with Kudat and Pitas as one of the main towns. Kota Marudu is supportive of the nation's economic and commercial development, with the plantation and agricultural sectors being the major economic contributors. Many commercial projects have been initiated making this district the economic and agricultural hub of northern Sabah. The sampling stations are located adjacent to residential area, which are dominated by agricultural and aquaculture activities. The current types of agricultural activity are predominantly timber, oil palm, paddy and coconut and rubber plantations. Light and small medium industries only play minor roles within the study area. The sand dredging is another main activity that is operating in the vicinity of the study area.

Kota Marudu is made up of three distinct areas which is valley, coastal area and mountainous terrain with the major portion being situated in the mountainous area. The study area is located within the Crocker Range with two mountains known as Mount Tambayukum (8462 m) and Mount Tendok Sirong (3315 m). In fact, Kota Marudu District is a sedimentary formation made up of sandstone and mudstone. In general, Sabah has an equatorial climate with uniform temperature, high humidity and copious rainfall due to its proximity to the equator (Malaysian Meteorological Department 2011). On average, Sabah receives about 2500–3500 mm of rainfall annually in most parts of the State. The chosen study area is influenced by two monsoon periods; the northeast monsoon blows approximately from November to April and the southwest monsoon that usually occurs between May and September. Heavy rainfall generally occurs during the northeast monsoon.

FIELD SAMPLING AND PRESERVATION

Ten sampling stations were chosen within the study area (Figure 1) with exact coordinate of sampling locations were recorded using a Global Positioning System (GPS) device (Table 1). The selections of these ten sampling stations were based upon the observed possibility of contamination from domestic waste discharge and on the practicability of collecting samples. The sampling campaigns were carried out on August and November 2009 and continued between February and March 2010 representing different sampling periods. Before sampling, all the laboratory apparatuses and polyethylene bottles were pre-cleaned with acid washed by soaking overnight in 5% (v/v) nitric acid before rinsing thoroughly first with distilled water. This procedure is very crucial in order to ensure any contaminants and traces of cleaning reagent were removed before the analysis (APHA 2005). It was performed in clean laboratory to minimize the potential risk of contamination. For BOD analysis, water samples were stored in the BOD bottle and wrapped with aluminum foil. Afterwards, the collected samples were stored in the cooler box at approximately 4°C to minimize the microbial activity in the water (APHA 2005). During sampling, the polyethylene bottles were normalized with river water

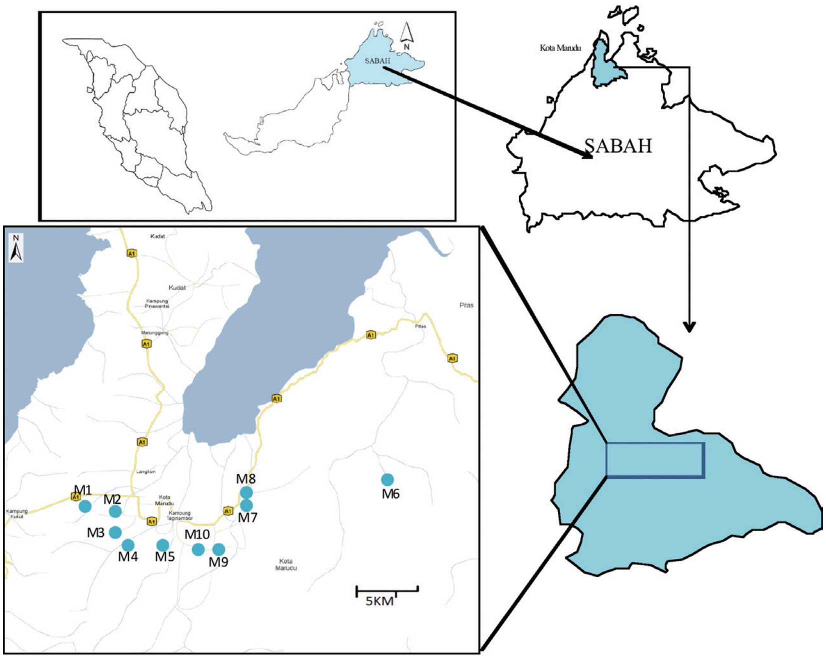

FIGURE 1. Map of sampling stations in Kota Marudu

TABLE 1. The longitude and latitude of the sampling stations

Station	Location	Latitude	Longitude
M1	Manggaris River	06°31.842'N	116°41.252'E
M2	Langkon River	06°31.703'N	116°42.869'E
M3	Sungoi River	06°30.479'N	116°42.744'E
M4	Ragaroh River	06°29.886'N	116°43.314'E
M5	Bongan Rakit River	06°29.770'N	116°45.359'E
M6	Taritipan River	06°33.345'N	116°57.290'E
M7	Rasak River	06°31.409'N	116°50.837'E
M8	Tandek River	06°31.693'N	116°50.584'E
M9	Rakit River	06°29.649'N	116°48.373'E
M10	Sumbilingan River	06°29.704'N	116°47.201'E

and then filled up with running river water facing the direction of flow. Triplicate samples were collected and homogenized from each sampling station in order to obtain an average value for the analysis. Each bottle was labeled with its corresponding sampling station and the time of sampling was recorded.

WATER ANALYSIS

Basic water quality parameters included *in situ* parameters (temperature, conductivity, total dissolved solids (TDS), salinity, dissolved oxygen (DO) and pH, turbidity, ammoniacal-nitrogen (NH_3-N), biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS)) were taken into account for measurement. The measurement of *in situ* parameters was done immediately during each fieldwork by using multiparameters probe (Orion Star Series Portable Meter) except the measurement of turbidity, which was carried out using a potable turbidity meter. The NH_3-N was determined using spectrophotometer at a specified wavelength (Hach Method 8038) while COD was measured in accordance with the APHA 5220B open reflux technique and TSS in accordance with the APHA 2540D method. For cation analysis, approximately 500 mL water samples were filtered through 0.45 µm cellulose nitrate membrane filter paper and acidified with nitric acid (HNO_3) to pH<2 and stored in high density polyethylene (HDPE) containers (APHA 2005). This process is crucial to obtain dissolved metal that is always smaller than 0.45 µm and also to avoid the occurrence of clogging during analysis with the spectrometry instrument. The samples were analyzed for Potassium (K), Magnesium (Mg), Calcium (Ca) and Sodium (Na) using inductively couple plasma mass spectrometry (ICP-MS, ELAN DRC-e, Perkin Elmer). The average values of three replicates were taken for each analysis. Standard calibration solutions and blank sample were prepared with Milli-Q water. The cation concentrations in the water are expressed as microgram per liter (µg/L). An accuracy check was performed on each 10 samples analysed with the injection of a certified standard solution. The RSD of the samples analysed were within ± 5%.

DATA ANALYSIS

Further data analyses were conducted using the raw data obtained from the sample analysis. The obtained data were analyzed using PASW Statistics 18 (formerly known as SPSS Statistics 18 or SPSS Base) in order to describe the descriptive statistic and also verify the relationship between various environmental matrices. This provides useful generalization about water quality for both either physical parameter or cations analysis, such as the mean and average concentration of the water sample. Correlation coefficient and one-way ANOVA were applied in order to indicate the sufficiency of one variable to predict to another and also to split the selected variables and sampling points into a finite number of groups with similar hydrogeochemical composition (Davis 1986). River water quality data sets were subjected to hierarchical cluster analysis (HCA), In this case, HCA was performed on the standardized dataset (mean of observations over the whole period) using the Ward's method with squared Euclidean distances (Singh et al. 2005). The similarity in the relationship between any one sample and the entire data set is illustrated by a dendrogram with a dramatic reduction in dimensionality of the original data (Najar & Khan 2012; Shrestha & Kazama 2007). All obtained results were compared with the permissible limit of drinking water quality recommended by the Ministry of Health (MOH 2004) and the World Health organization (WHO 2004).

RESULTS AND DISCUSSION

The descriptive statistics for physico-chemical parameters of water samples during the sampling period are presented in Table 2. Table 3 compares physico-chemical parameters and analyzed metals concentration data with the drinking water quality standard by the World Health Organization (WHO 2004) and the Malaysian national standard for drinking water quality (NSDWQ) by the Ministry of Health (MOH 2004). The correlation coefficients of various water variables are tabulated in Table 4.

Overall, the pH values during the study period ranged from 6.87 to 7.66 (Table 3) and there is no significant difference (p>0.05) among the sampling stations. All analyzed water samples were well within the limits prescribed by the WHO (6.50-9.20) and MOH (6.50-9.0). The results showed that most of the river water in different sampling station was slightly acidic to slightly alkaline condition. The alkaline condition normally indicates the presence of carbonate magnesium and calcium in water (Begum et al. 2009; Connell & Miller 1984; Reza & Singh 2010). The weathering reactions between carbonate rocks and water are naturally delivering these elements into the river. These two elements are found to be abundant in the earth's crust and normally, their concentration is indeed higher than other element such as Pb and Mn. In addition, the acidity in river waters could be attributed to the photosynthetic processes and decomposition of organic matter in the river (Mokhtar et al. 2009; Radojević & Bashkin 2007).

The surface water temperature varies between different sampling stations and ranged between 27.6 and 30.3°C. The temperatures recorded among stations were slightly high regardless of hot weather throughout the sampling periods. The influence of heat exchange with the earth surface also contributed to the river water circulation (Mokhtar et al. 2009). The COD values varied significantly between sampling stations (p<0.05) and ranged between 2.00 and 25.25 mg/L with the mean concentration being 11.45 mg/L. The high COD value in station M10 (Sumbilingan River) was attributed to the organic decomposition resulting from human activities as the river is in close proximity to a village. The dissolved oxygen (DO) fluctuated between 4.24 and 6.34 mg/L. It was noticed that the DO concentration

TABLE 2. Statistical variation (minimum, maximum, range, mean and standard deviation) among various water matrices according to different sampling period

Parameter	Unit		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Temp	°C	Min	26.29	27.53	23.26	26.26	27.19	26.25	26.86	27.45	28.14	27.69
		Max	33.01	31.56	32.90	29.71	34.69	28.94	30.19	28.60	29.79	30.75
		Mean	30.25	29.51	28.24	27.84	30.29	27.55	28.35	27.93	28.85	28.98
		SD	2.830	2.086	3.952	1.647	3.225	1.136	1.548	0.496	0.818	1.285
EC	mS/cm	Min	0.19	0.26	0.18	0.17	0.00	0.22	0.15	0.24	0.15	0.16
		Max	0.32	0.44	0.23	0.21	0.23	0.28	0.19	0.66	0.17	3.32
		Mean	0.24	0.33	0.21	0.18	0.14	0.25	0.17	0.37	0.16	1.08
		SD	0.055	0.084	0.024	0.020	0.101	0.025	0.018	0.200	0.007	1.509
TDS	mg/L	Min	0.11	0.16	0.11	0.10	0.09	0.14	0.09	0.15	0.10	0.10
		Max	0.18	0.28	0.14	0.31	0.13	0.17	0.11	0.40	0.97	2.02
		Mean	0.14	0.20	0.12	0.16	0.11	0.16	0.10	0.22	0.32	0.65
		SD	0.028	0.055	0.014	0.104	0.016	0.014	0.010	0.120	0.435	0.920
Salinity	o/oo	Min	0.08	0.11	0.08	0.07	0.06	0.10	0.06	0.11	0.07	0.07
		Max	0.13	0.20	0.10	0.10	0.09	0.12	0.08	0.30	0.70	1.61
		Mean	0.10	0.14	0.09	0.08	0.08	0.11	0.07	0.17	0.23	0.51
		SD	0.021	0.042	0.010	0.014	0.014	0.010	0.010	0.090	0.315	0.739
DO	mg/L	Min	3.80	3.96	3.91	3.39	5.57	3.47	3.72	3.14	3.62	2.47
		Max	8.39	6.09	6.37	5.09	7.16	5.77	6.56	6.80	6.78	7.26
		Mean	6.34	5.10	5.34	4.24	6.00	4.43	5.25	4.55	4.99	4.24
		SD	1.956	1.149	1.167	0.697	0.776	0.973	1.452	1.570	1.334	2.133
pH	-	Min	7.15	7.12	7.09	6.73	6.86	6.93	6.83	6.60	7.23	6.58
		Max	8.39	7.79	7.79	7.79	7.55	7.37	7.16	7.12	7.80	7.45
		Mean	7.66	7.38	7.35	7.22	7.19	7.15	7.04	6.87	7.43	7.08
		SD	0.539	0.293	0.319	0.436	0.326	0.196	0.147	0.263	0.264	0.394
Turbidity	NTU	Min	5.78	5.11	5.35	11.40	4.57	4.65	21.20	9.11	19.70	18.80
		Max	16.40	12.50	16.10	17.10	24.50	59.20	69.90	52.70	61.20	219.00
		Mean	9.92	8.40	10.74	14.25	10.20	19.81	39.25	28.05	46.53	80.00
		SD	4.581	3.208	4.412	2.649	9.607	26.299	21.174	19.080	18.959	93.273
NH_3-N	mg/L	Min	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
		Max	0.04	0.08	0.03	0.36	0.04	0.14	0.07	0.23	0.08	0.12
		Mean	0.02	0.03	0.01	0.13	0.01	0.04	0.02	0.07	0.03	0.06
		SD	0.023	0.034	0.015	0.168	0.020	0.067	0.034	0.109	0.038	0.049
COD	mg/L	Min	0.00	1.00	0.00	6.00	1.00	2.00	2.00	0.00	7.00	7.00
		Max	13.00	9.00	5.00	20.00	25.00	25.00	24.00	31.00	17.00	42.00
		Mean	3.50	4.00	2.00	12.00	10.75	16.50	15.00	13.50	12.00	25.25
		SD	6.351	3.559	2.449	5.831	11.087	10.214	9.309	14.617	4.761	14.408
BOD	mg/L	Min	0.15	0.03	0.69	0.16	0.14	0.09	0.01	0.16	0.13	0.79
		Max	1.12	0.80	0.90	2.34	1.07	2.28	1.92	0.95	1.65	3.36
		Mean	0.69	0.48	0.77	1.01	0.57	0.90	0.83	0.58	0.78	2.09
		SD	0.493	0.403	0.112	1.169	0.468	1.199	0.982	0.397	0.784	1.285
TSS	mg/L	Min	4.62	4.09	4.28	9.12	3.66	3.72	16.96	7.29	15.76	15.08
		Max	13.12	10.00	12.88	13.68	19.60	47.36	55.92	42.16	48.96	175.20
		Mean	8.44	6.72	8.59	11.40	8.16	15.85	31.40	22.44	37.22	64.01
		SD	4.314	2.567	3.529	2.119	7.685	21.040	16.939	15.264	15.167	74.609

(Min, Minimum; Max, Maximum; SD, standard deviation; Temp, temperature; EC, electrical conductivity; TDS, total dissolved solid; DO, dissolved oxygen; NH3-N, ammoniacal-nitrogen; COD, chemical oxygen demand; BOD, biological oxygen demand; TSS, total suspended solid)

TABLE 3. Descriptive statistic of water matrices by comparing with WHO and MOH drinking water quality standard

Parameter	Unit	Minimum	Maximum	Mean ± SD	WHO (2004)	MOH (2004)
Temp	°C	27.55	30.29	28.78 ± 14.62	NA	NA
EC	mS/cm	0.14	1.08	0.31 ± 0.23	1.50	NA
TDS	mg/L	0.10	0.65	0.22 ± 0.15	1000	1000
Salinity	o/oo	0.07	0.51	0.16 ± 34.18	NA	NA
DO	mg/L	4.24	6.34	5.05 ± 1.24	NA	NA
pH	-	6.87	7.66	7.23 ± 18.69	6.5-9.2	6.5-9.0
Turbidity	NTU	8.40	80.00	26.71 ± 20.90	NA	5.00
NH_3-N	mg/L	0.01	0.13	0.04 ± 0.53	NA	NA
BOD	mg/L	0.48	2.09	0.87 ± 7.27	NA	NA
COD	mg/L	2.00	25.25	11.45 ± 14.51	NA	NA
TSS	mg/L	6.33	64.01	21.21± 18.50	NA	NA
Na	μg/L	5882.50	63250.00	14353.0± 17906.69	200 000	200 000
Ca	μg/L	2220.00	16626.00	5453.00 ± 4112.96	200 000	NA
Mg	μg/L	4095.00	23480.00	9038.00 ± 5744.05	150 000	150 000
K	μg/L	1510.00	10901.50	3232.00 ± 2812.12	200 000	NA

(SD, standard deviation; NA, no available; Temp, temperature; EC, electrical conductivity; TDS, total dissolved solids; DO, dissolved oxygen; BOD, biological oxygen demand; COD, chemical oxygen demand; TSS, total suspended solid)

significantly decreased with an increase in temperature (Figure 2). The microorganism activity and domestic wastewater contributes to the factors in controlling the DO concentration in river water as well as the temperature factor (Clark 1996; Yang et al. 2007). In addition, DO was found to be significant and negatively correlated with both NH_3-N (r=-0.719, p<0.05) and COD (r=-0.643, p<0.05). Therefore, the decomposition rate of organic matter (COD and ammoniacal-nitrogen) as well as hot weather (temperature) depleted the DO constituents in the river water.

The turbidity values ranged from 8.40 to 80.00 NTU. The highest value of turbidity (80.00 NTU) was recorded at station M10 (Sumbilingan River). Sand dredging activities may be the possible factor that caused high turbidity value. Ashraf et al. (2011) found that turbidity is evident at dredging sites or wash-water discharge points due to the re-suspension of sediment and sedimentation caused by stockpiling and dumping of excess mining materials. Correlation analysis shows that turbidity has a perfect positive linear relationship with TSS (r=1.000, p<0.01) which indicates that an increase in turbidity will increase the TSS. Moreover, high values of BOD, COD, TSS and turbidity are always marked as an indicator of pollution. The current study found that there are significant positive relationships between BOD, COD, TSS and turbidity (r=0.754 to 1.000; p<0.01; Table 4). In addition, these four parameters show similar trends (Figure 3) among the stations as each parameter increase with each other.

The EC values ranged between 0.14 and 1.08 mS/cm, the salinity values ranged between 0.07 and 0.51 o/oo while the TDS values ranged between 0.10 and 0.65

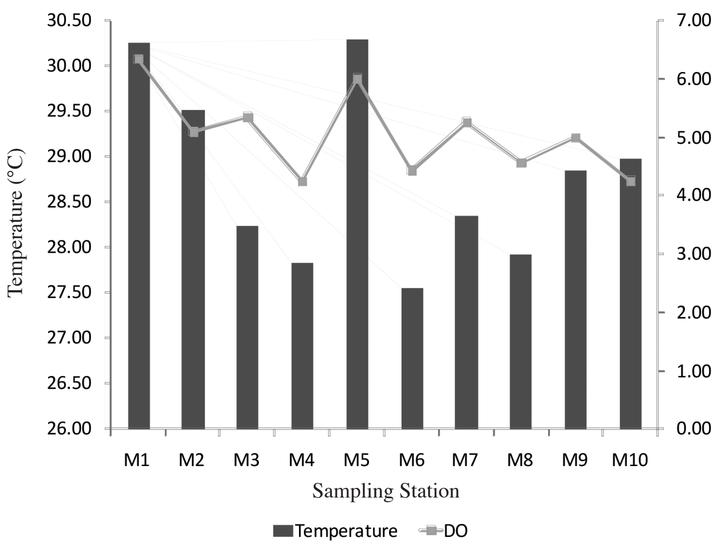

FIGURE 2. Temperature (°C) and DO (mg/L) of rivers at Kota Marudu accordingly to each sampling station

mg/L. Electrical conductivity (EC) measures the ability of water to allow electric current to flow and total dissolved solids (TDS) is a good indicator of dissolved ions in water (Reza & Singh 2010). The relative difference in the water ion constituent was represented by the different values of EC from each station. Subsequently, the higher the dissolved salt content present in the water, the higher the EC values obtained. Mean variations in EC, salinity and TDS followed a similar trend (Figure 4); which showed that there is a direct relationship between these variables. This was supported by a strong significant relationship between EC and TDS (r=0.915; p< 0.01), TDS and salinity (r=0.996; p< 0.01) and also EC and salinity (r=0.927; p< 0.01). These three variables show significant differences in their concentrations among the stations (p<0.05). The low EC value might be due to the natural characteristics of

TABLE 4. Pearson correlation coefficient (r) between water quality parameters

	Temp	EC	TDS	Sal	DO	pH	Tur	NH_3-N	BOD	COD	TSS	Na	Ca	Mg
Temp	1	0.949	0.948	0.892	0.008**	0.098	0.696	0.135	0.674	0.354	0.669	0.966	0.316	0.810
EC	0.023	1	0.000**	0.000**	0.193	0.410	0.011*	0. 565	0.000**	0.045*	0.012*	0.000**	0.932	0.000**
TDS	0.024	**0.915**	1	0.000**	0.149	0.600	0.001**	0.525	0.002**	0.031*	0.001**	0.000**	0.653	0.000**
Sal	0.050	**0.927**	**0.996**	1	0.191	0.583	0.001**	0.659	0.002**	0.033*	0.001**	0.000**	0.666	0.000**
DO	0.776	-0.449	-0.491	-0.451	1	0.069	0.161	0.019*	0.122	0.045*	0.148	0.174	0.630	0.123
pH	0.552	-0.294	-0.190	-0.198	0.596	1	0.286	0.333	0.493	0.037*	0.265	0.261	0.347	0.447
Tur	-0.142	**0.756**	**0.873**	**0.877**	-0.479	-0.374	1	0.709	0.004**	0.0 04**	0.000**	0.006**	0.191	0.001**
NH_3-N	-0.507	0.207	0.229	0.160	-0.719	-0.342	0.136	1	0.357	0.298	0.699	0.469	0.578	0.775
BOD	-0.153	**0.860**	**0.846**	**0.838**	-0.521	-0.246	**0.815**	0.327	1	0.012*	0.004**	0.001**	0.340	0.003**
COD	-0.329	**0.643**	**0.677**	**0.673**	**-0.643**	**-0.663**	**0.818**	0.366	**0.754**	1	0.003**	0.021*	0.151	0.011*
TSS	-0.155	**0.753**	**0.871**	**0.874**	-0.493	-0.39	**1.000**	0.140	**0.813**	**0.823**	1	0.006**	0.194	0.001**
Na	-0.016	**0.982**	**0.914**	**0.926**	-0.466	-0.393	**0.799**	0.260	**0.866**	**0.713**	**0.797**	1	0.60 8	0.001**
Ca	0.354	-0.031	-0.163	-0.156	0.174	0.333	-0.451	-0.201	-0.338	-0.490	-0.448	-0.185	1	0.715
Mg	-0.088	**0.899**	**0.930**	**0.943**	-0.520	-0.272	**0.874**	0.104	**0.825**	**0.759**	**0.872**	**0.880**	-0.133	1
K	0.328	0.262	0.164	0.168	-0.029	0.116	-0.107	-0.047	-0.113	-0.219	-0.104	0.135	**0.904**	0.150

(Temp, temperature; EC, electrical conductivity; TDS, total dissolved solid; sal, salinity; DO, dissolved oxygen; tur, turbidity; NH3-N, ammoniacal-nitrogen; BOD, biological oxygen demand; COD, chemical oxygen demand; TSS, total suspended solid)

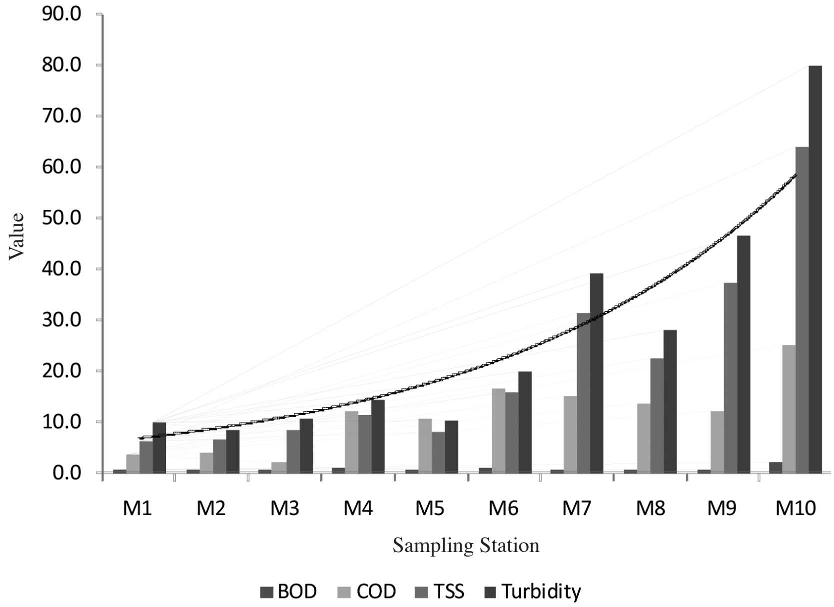

FIGURE 3. BOD (mg/L), COD (mg/L), TSS (mg/L) and turbidity (NTU) of rivers at Kota Marudu accordingly to each sampling station

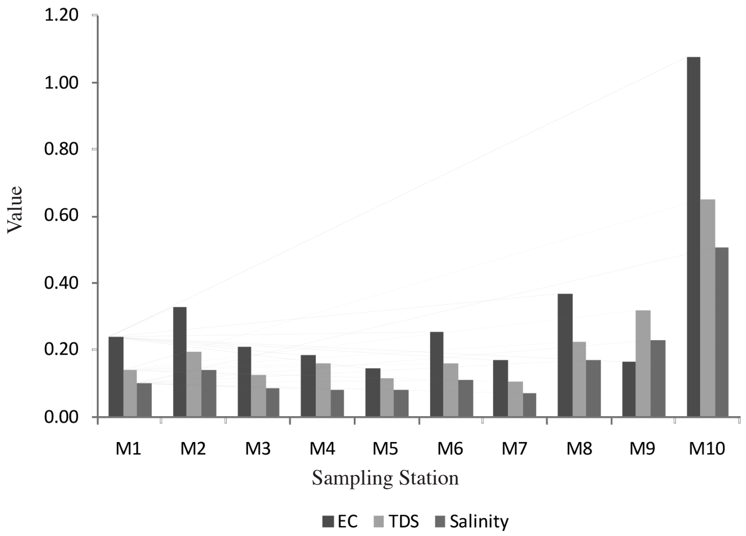

FIGURE 4. Electrical conductivity (mS/c), total dissolved solid (mg/L) and salinity (o/oo) of rivers at Kota Marudu accordingly to each sampling station

the river itself. The strong relationship between EC with Na (r=0.982; p< 0.01) and Mg (r=0.899; p<0.01) proved that Na and Mg have contributed to high value of EC. In addition, the high value of turbidity, BOD, COD and TSS are also responsible for the high value of EC. These were indicated by significant relationships between EC and turbidity (r= 0.765; p< 0.05), BOD (r=0.860; p< 0.01), COD (r=0.643; p<0.05) and TSS (r=0.753; p<0.05) (Table 4). This means that certain station might be exposed to human-induced activities, which produce domestic waste and agricultural run-offs into the river. Therefore, the continuous monitoring of the river water in their vicinity is recommended.

ION CONCENTRATION AND DISTRIBUTION

In respect of the physical characteristics of rivers, the chemical analysis of water is essential for the interpretations of the status of river water quality. The characterization of the hydrochemistry and interpretation of hydrological process taking place within the watershed are important. The major ion chemistry of the rivers at Kota Marudu were dominated by Na>Mg>Ca>K as shown in the ternary diagram (Figure 5).

The abundance of the common rock-forming minerals controlled the background levels of trace metal in rocks (Garrett 2000). Ca, Mg, Na and K are known as major cations and they constitute more than 30% of the total content of elements in the earth's crust (Alloway 1995). As a part of the natural biogeochemical cycle, metals are released from rocks by weathering processes or cycled through various environmental compartments by biotic and abiotic processes. These four elements are considered as relatively soluble cations, which are easily leached through the rock weathering process. Hence, they were found to be significantly higher in the river water at Kota Marudu. The cations concentrations shows no significant

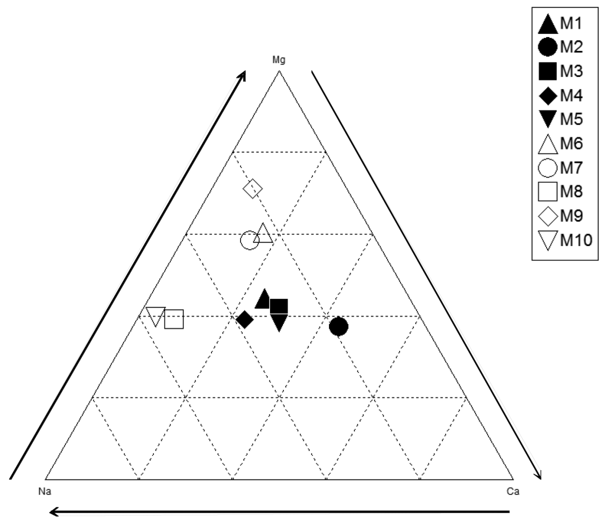

FIGURE 5. Ternary diagram of the water samples from rivers at Kota Marudu

difference (p>0.05) between stations with the exception of Ca. Generally, their concentration were found to be within the natural levels and suggesting that the Na, Mg and K constituents mostly originated from natural inputs. During rainwater or river water flows through the continental bedrock and soil, the hydrogen ions in water will react with carbonate rock and release dissolved ions into the river water. The Ca concentrations are higher than the baseline data observed from Maliau basin, which is a pristine area in Sabah (Mokhtar et al. 2009). The results suggest that the Ca content may not only origin from natural processes but also from anthropogenic input such as fertilizer. Garret (2000) stated that particularly calcium ions may derived from the production of agricultural fertilizers such as monocalcium phosphate ($Ca(H_2PO_4)_2$), calcium cyanamide ($CaCN_2$), calcium nitrate ($Ca(NO_3)_2$). Kota Marudu is intense with agricultural activities, therefore, the usage of fertilizer, especially on the palm oil and fruit plantation are commonly found in the study area. However, the average concentrations of cations are still under the permissible level recommended from WHO (2004) and MOH (2004). Hence, cations (Ca, Mg, Na and K) in the study area are not considered as a hazard to human for consumption.

SUITABILITY FOR IRRIGATION

The suitability of water for agricultural irrigation usage was largely depends on the water quantity and quality. For determination of suitability for irrigation purposes, the salinity hazard and sodium absorption ratio (SAR) were considered among the determining factors. Normally, the parameters used to measure water salinity are total dissolved solids (TDS) or electrical conductivity (EC). For salinity hazard, the water is categorized as low-salinity water (<250 μS/cm), medium-salinity water (250-750 μS/cm), high-salinity water (750-2250 μS/cm) and very high-salinity water (>2250 μS/cm) based on the EC values (Mokhtar et al. 2009; Nishanthiny et al. 2010). SAR is a ratio of the sodium (detrimental element) to the combination of calcium and magnesium (beneficial elements) in relation to known effects on soil dispersibility. It is used to characterize the relative sodium status of irrigation water. The SAR value is calculated using (1):

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{1}{2}\left([Ca^{2+}]+[\text{Mg}^{2+}]\right)}}, \qquad (1)$$

where $[Na^+]$, $[Ca^{2+}]$ and $[Mg^{2+}]$ are the respective concentrations in the water in milliequivalents per liter (meq/L) of sodium, calcium and magnesium ions. In general, the SAR of irrigation water is greater if the water has a higher concentration of salt and poses a salinity hazard.

Table 5 lists the general guidelines and explanation for assessment of SAR in irrigation water. It is important to note that the irrigation water hazard levels and soil salinity hazard levels are not equivalent. Based on the EC values observed, 60% of the sampling stations have low salinity of water, 30% of medium and 10% of the sampling stations have high salinity water (Figure 6). The high salinity hazard could reduce the osmotic activity of plants and restricts the plants roots from absorbing water from the soil (Hiscock 2005). Therefore, it is not suitable to be used on soils with restricted drainage. However, the SAR values for all sampling stations were classified as low which means the water is suitable for irrigation. A simple scatter plot, known as Wilcox's diagram, which comprises of SAR and salinity hazard (EC in log scale), was generated based on the analytical results (Figure 6). It showed that the suitability of water for use in agricultural irrigation was divided into two major groups. The diagram shows that only 10% of surface water samples collected was considered as unsatisfactory for irrigation purposes whereas other samples were clustered in the boundary of the good to permissible level.

HIERARCHICAL CLUSTER ANALYSIS (HCA)

All collected data were subjected to a hierarchical cluster analysis (HCA). Hierarchical cluster analysis (HCA) is an exploratory method for recognition of patterns and trends in the data, which assemble objects based on their characteristics (Najar & Khan 2012). The results of HCA will help in interpreting the data and indicating patterns (Singh et al. 2004; Vega et al. 1998). The HCA results in the present study showed different properties of water for each station. Two main clusters (Groups 1 and 2) were identified from ten sampling stations (Figure 7). Group 1 was further divided into two groups – Group 1:i (Manggaris River, Sungoi River, Ragaroh River, Bongan Rakit River, Taritipan River, Rasak River and Rakit River) and Group 1:ii (Langkon River and Tandek River). Both have similar hydrochemistry condition and exhibits lower pollution intensity. Each group corresponds with the natural backgrounds features and the water quality character that is affected by different environmental pollutants. Group 2 only includes Sumbilingan River which poses higher pollution intensity compared to the

TABLE 5. General guideline and explanation for assessment of SAR of irrigation water

Class	SAR	Explanation
Low	<10	Can be used for irrigation on almost all soils with little danger of developing harmful levels of sodium
Medium	10-18	May cause alkalinity problem in fine-textured soils under low-leaching conditions. It can be used on coarse-textured soils with good permeability
High	18-26	May produce alkalinity problem. This water requires special soil management such as good drainage, heavy leaching and possibly the use of chemical amendments such as gypsum.
Very high	>26	Usually unsatisfactory for irrigation purposes

Source: Glover (1996)

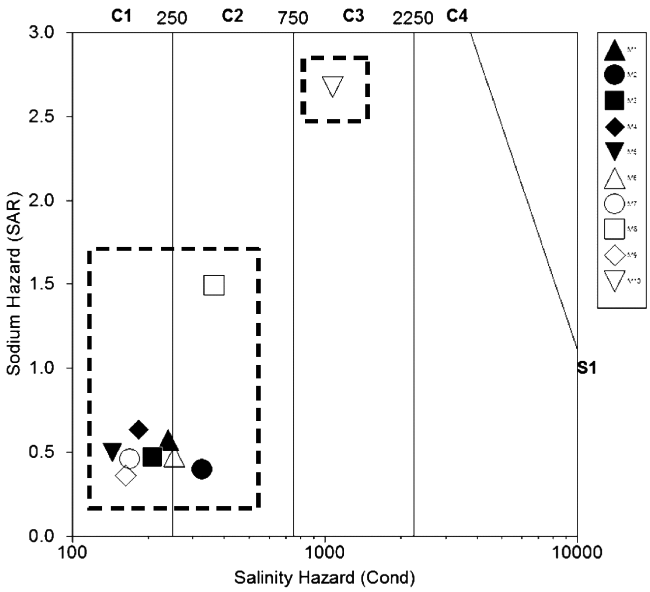

FIGURE 6. Wilcox diagram of irrigation water accordingly to its sampling stations

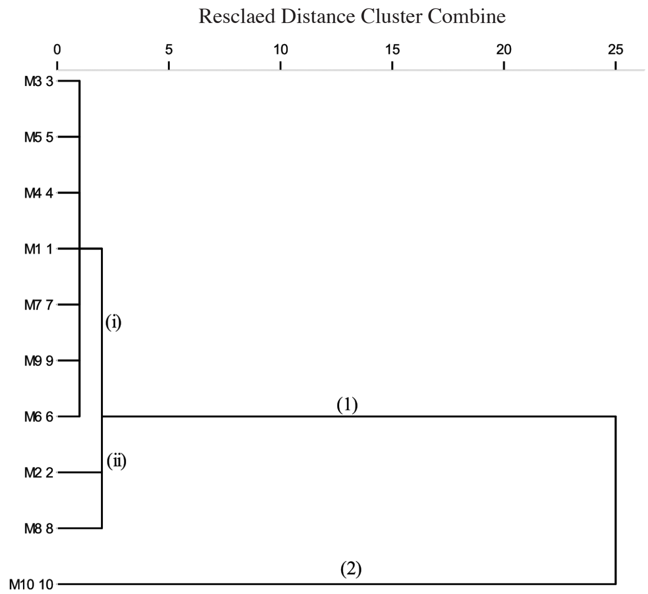

FIGURE 7. Dendrogram generated from hierarchical cluster analysis based using Ward Linkage method

other stations thereby revealing that this river water was affected by pollution loading. HCA provides good results as a first exploratory evaluation of the spatial difference characteristics of the studied systems. This approach provides multivariate statistical grounds for clustering regions of river basins according to similar water chemistry characteristic and pollution intensity. In addition, it can helps the relevant authorities in refining the current monitoring program by reducing the number of monitoring stations to the most representative of the spatial patterns in river water quality.

CONCLUSION

This study highlights potential substantial effects on the drinking and irrigation purposes of the rivers in Kota Marudu. By assessing water quality using physico-chemical parameters, it is clear that most of the stations have a normal range value in their samples and are within the standards (MOH 2004; WHO 2004) except for turbidity. The high turbidity may be caused by the illegal sand dredging in the study area. In general, most of the rivers in Kota Marudu are suitable for drinking, domestic use and also irrigation purpose except for Sumbilingan River.

Based on the Wilcox Diagram, this river is identified as not suitable for irrigation purposes. However, HCA has also distinguished this river from others since its pollution intensity is higher. The variation of studied parameters may be attributed to the hydrogeological factors such as the weathering process and ion exchange process, apart from the anthropogenic sources. The finding from this study will provide useful information concerning the hydrochemical variation and processes in the rivers of Kota Marudu. For future studies, continuous sample collection and re-evaluation of water chemistry data are crucial to create a proper management and better understanding of the hydrology and river water quality at Kota Marudu. It is recommended to further extend the study by including the measurement of microbial pathogens and organic compounds to show the pollution pattern and trend of variation of river chemistry within the basin. This study will also serve as a baseline record for future reference, especially to the governing bodies involved in regulating water policies in such areas.

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Environmental Forensics Research Centre
Faculty of Environmental Studies
Universiti Putra Malaysia
43400 UPM Serdang, Selangor
Malaysia

*Corresponding author; email: zaharin@upm.edu.my

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