APPENDIX TWO

Water Quality Assessment by the Citizen Science Approach

Methods and Results

Forever Sabah
November 2020

EXECUTIVE SUMMARY

Three months of laboratory water testing on the Segama River in collaboration with trained community citizen scientists reveal that there are no water quality issues on the mid-Segama that can be shown to be caused by clearance of primary forest and its replacement by industrial agriculture and mining, and no evidence for pollution by the use of chemicals in agricultural and mining activities.

INTRODUCTION

The majority of river segments, watersheds and associated biodiversity are found outside the protected areas. Therefore, clear strategies and plans are required to conserve riverine biodiversity in a practical manner and must consider riverine communities participation. Under the project titled "Mainstreaming of Biodiversity Conservation into River Management", United Nations Development Programme (UNDP) in partnership with the Department of Irrigation and Drainage (DID) has identified the Segama River in Sabah as one of the focus sites. The project aims to value natural capital, reduce environmental impacts and improve access to quality ecosystem services for low income households. In the project document, the followings are highlighted as key threats, namely 1) habitat modification and clearance of riparian corridors, 2) water pollution, 3) alien invasive species (AIS), 4) overexploitation and deleterious fishing practices, and 5) climate change.

Forever Sabah was appointed as the project proponent on 16 March 2020 by UNDP-DID to carry out the aspirations of the project. In relevance to the issue of water pollution, a water quality assessment was carried out from July to September 2020 as a part of the baseline establishment process. The process was crucial to unveil the nuances and possible contexts for driving subsequent actions to mitigate or enhance aquatic biodiversity in the Segama River. In this assessment, "pollutant" refers to organic and inorganic substances that are hazardous, potentially hazardous or prejudicial to public health and safety, or to terrestrial or aquatic wildlife.

FOCUS SITE

Danum Valley Conservation Area (43,800 ha; IUCN Category II) and Tabin Wildlife Reserve are (111,971 ha; IUCN Category IV) are the largest protected areas in project site (BBEC ND). Upriver of Sg Segama has an average rainfall of 2,669 mm (1985–1998), ranging from 1,918 mm (1997) to 3,294 mm (1995). Convective induced rainfall of 30 minutes or less usually occur in the late afternoons (4–6 pm) account for a large percentage of the total annual rainfall. The recurrence of heavy storm events (>170 mm) can be expected in every 10 to 20 years (Douglas et al. 1999). In 1992, the gauging station of a 1.5 km river stretch in an undisturbed controlled forest catchment in Danum Valley Field Centre recorded a complete dry-out event (Douglas et al. 1999). This is a notable reminder that the possibility and impact of intense drought cannot be taken lightly in the Segama River watershed. The upriver of the Segama River comprise undulating terrain of siltstones, sandstones, cherts, spillites and tuffs, many of which are susceptible to erosion (Douglas et al. 1999).

AQUATIC BIODIVERSITY

The Sabah Biodiversity Enactment (2000) defines "biodiversity" as "biological diversity, being the variability among living organisms from all sources, including plant materials, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part of, and the diversity within species, between species and ecosystems, and includes biological resources". There are 150 native fish species from 27 families in Sabah (Ng et al. 2017). A total of 47 fish species from 12 families inhabit the upper Segama River (Martin-Smith and Tan 1998). Correspondingly there are 25 fish species in the SAFE Project area (16 stream catchments, 8,000 ha) comprising compartments of logged forest, old growth forest and oil palm plantation.

Species most commonly captured, in terms of abundance and presence across all land uses, were *Barbodes sealei*, *Nematabramis everetti*, *Rasbora* cf. *sumatrana*, and *T. tambra*, which collectively accounted for 78% of all captures (Wilkinson et al. 2018). These may be assigned as keystone or bio-indicator species of natural water quality in the river. There are 7 species of freshwater crabs from 3 families are recorded in the Danum Valley Conservation Area (Ng and Ng 2018). From Google Earth observation, the following aquatic habitat typologies are present in the Segama watershed, namely 1) hillside torrent streams and falls, 2) floodplain with main channel river, 3) oxbow lake, 4) peatswamp, 5) nipah brackish swamp, and 6) mangrove marine coast.

ASSESSMENT CONTEXT

The Segama River was found to be "significantly polluted" by the Environment Protection Department (EPD 2011a) primarily by the oil palm sector with minor contributions from human settlements and mining activities (UNDP ND, p.162). So far the literature of systematic water quality assessment of the entire length of Segama River is absent. The range of organic and inorganic pollutants in various segments of Segama River is not fully known although the water safety and security aspects to support 206,861 populations in Lahad Datu are fully dependent on the river. The immediate issue at stake is – until the existing water quality characteristics in various natural and anthropogenic river segments are clarified, any river conservation actions to support human well-being and aquatic biodiversity cannot be pursued with rigor and depth.

OBJECTIVE

Underpinned by the context aforementioned, a water physico-chemistry assessment was carried out by the citizen science approach along the Segama River. Since the palm oil industry is the most prevalent socio-economic activity in the watershed, the parameters were analysed in the context of pollutants generated by the industry. Additionally, pollutants from riverine human settlements, sand mining and possible artisanal gold mining were also examined to understand their implications to humans and aquatic biodiversity.

MATERIAL AND METHODS

Prior to the water sampling exercise, a desktop literature review and remote GIS investigation was carried out to identify suitable sampling locations that are representative of the natural and anthropogenic water quality characteristics of the Segama River. It was hypothesized that pristine water untainted by pollutants can be found in the uppermost parts of the river that is still surrounded by intact forest of the Danum Valley. Thus point A and B were selected at the "reference site". Additionally, point J was also selected as the "reference site" since the tributary originated from the intact Tabin Forest Reserve. The locations of point D, E and F were explicitly selected to detect pollutants in waters near the intake of the Lahad Datu water treatment plant. Other points C, G, H and I were located along the river for registering possible pollutants originating from the oil palm plantations. The locations of all sampling points are illustrated in Figure 1.

In total 47 participants from the following villages were engaged and trained for the citizen science assessment exercise, namely Kg. Upak, Kg. Lituk Pulau, Kg. Pendising, Kg. Tawaiyari, Kg. Sapadulang, Kg. Batu 8, Kg. Bukit Balacon, Kg. Litang and Kg. Dagat. They live near the sampling points and were the best local stewards to work with for the assessment. The list of participants is presented in Appendix 1 of the Forever Sabah Sungai Segama Second Deliverables Report furnished to UNDP-DID in September 2020.

Water sampling exercises were deployed in July, August and September (i.e. 3 months; 1 sample per point per month; total 3 samples per point) by members of the communities. In each sampling point, approximately 2000 mL water sample was collected and stored in special bottles in accordance to parameters to be tested (Figure 7). This was necessary as certain bottles were tinted or contain preservatives for maintaining the physico-chemistry conditions of water samples. Collected water samples were stored in cooler box to ensure they were not exposed to sunlight and heat that could compromise the test results.

Since no water testing laboratory was available in the nearest town Lahad Datu, all samples were transported to ALS Technichem (M) Sdn Bhd, a laboratory certified to MS ISO/IEC17025 in Kota Kinabalu, for testing processes. Water chemistry testing protocols and processes were carried out following American Public Health Association (APHA) standards practised by ALS Technichem. Metallic and glyphosate content of water samples were tested using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Liquid Chromatography Tandem Mass Spectrometry (LCMS) methods, respectively. The Class IIB thresholds were taken as the benchmark for interpretation (DOE 2018, p.169). The class is typically applied for water appropriate for body contact and consumption (with treatment).

RESULTS & DISCUSSION

The itemized result of key pollutants that may originate from the palm oil industry, human settlements, sand mining and possible artisanal gold mining are described in Table 1.

In the context of water for human consumption, it was found that aluminium and coliform values exceeded the Class IIB thresholds in point D and F which are nearest to the water treatment plant of Lahad Datu. However, the non-compliances may not be construed as "pollution" per se because the parameters were also naturally high in point A and B (reference sites). Geologically, the greatest expanses of mineral-rich ultramafic bedrock occur in northern Borneo and southern Philippines (van der Ent et a. 2015). An arc stretching from the Labuk Highlands to the Segama Highlands in eastern Sabah has been reported to be favourable for economic mineral mining (Thomas et al. 1976). One of the key minerals identified is aluminium thus natural bauxite leaching into the watershed is to be expected and naturally occurring. In an EIA carried out in Mount Wullersdorf, Tawau, similar condition was recorded as the aluminium levels ranging 0.17–1.3 mg/L were also reported (Class III threshold < 0.06 mg/L) (Southsea 2015). Chromite, monazite and gold were panned from the Segama River by locals in the past (Kiew 1976). Consequently, various minerals may also be present in the waters of the Segama River at noticeable levels.

Surprisingly, high levels of coliform were detected in reference site A and B. Literature show this is possible as high levels of coliform were also reported to occur naturally in tropical forest drainages elsewhere (e.g. Carrillo et al. 1985; Hazen 1988; Rivera et al. 1988). The term “coliforms” refers to a large group of rod-shaped bacteria that includes thermo-tolerant coliforms and bacteria of faecal origin, as well as bacteria from the natural environment (UNEP-WHO 1996). Little is known of the distribution and composition patterns of coliform bacteria in the natural and anthropogenic rivers of Sabah as no literature could be found. From casual conversations with the locals, diarrhoea is not a common health issue thus it is expected that chlorine dosages applied by the local water treatment plant and household practice of boiling water prior to consumption had suppressed the concern.

Currently, total coliform and faecal coliform are official indicators for microbial contamination of water in Malaysia (DOE 2018, p. 169). Testing for the presence of faecal streptococci is however regarded as more plausible as evidence of faecal contamination by the latest school of thought (Sinton et al. 1993; WHO 2001). However, so far, no report adopting the microbial test in Sabah could be found based on literature search. Also, the distinction between human versus animal streptococci has not been established in Sabah and elsewhere in Borneo. Since the Danum Valley located in the upriver of Segama is expected to host a high density of wildlife as evidenced by the high Ammoniacal Nitrogen level detected in reference site point B in September, it would be interesting and valuable to begin building scientific and testing capacity towards understanding the sources, ecology and distribution pattern of riverine faecal streptococci. The findings will become useful building blocks for furthering our understanding of water safety and watershed conservation in Sabah, Malaysia, and elsewhere in tropical Southeast Asia. The work may make a strong case for shifting the testing norm from faecal coliform to faecal streptococci to indicate microbial pollutant.

Other toxic substances that may originate from the agriculture and mining activities, namely mercury, arsenic and glyphosate, were below the thresholds.

The consolidated monthly data is presented in Table 2 and 3. The bar-chart comparison of parameter values between sampling points is illustrated in Figure 2, 3 and 4 and visuals of the sampling sites are presented in Figure 5, 6 and 7. The laboratory test reports from ALS Technichem (M) Sdn Bhd are attached herein.

CONCLUSION

The findings of this rapid assessment represent the baseline of water quality characteristics in the Segama River. Although the values of parameter may deviate according to climatic, fluvial geomorphologic and anthropogenic forcing in the future, they provide the necessary foundation to drive further actions for the project.

In relevance to human health and aquatic biodiversity, the water quality results do not imply any detrimental pollutants were present in the river during the baseline assessment exercise. From academic and grey literature searches, no fish kill was reported in the sampling points so far. However, evidence of non-native species presence has been reported and this would be addressed by a separate assessment.

Notably, physical riparian erosions and sand mining activities were reported in Appendix 5 Report on Ground-Truthing of Riparian Zones on Sites 2, 3, 5 & 8 Sungai Segama, Sabah, submitted to UNDP-DID in September 2020. The activities are currently causing high levels of suspended solids in certain segments of the river. According to the report there are 11 sand mining operations, namely four in the upriver of the Lahad Datu water intake point and seven in Kg Sapadulang and Kg Batu Lapan areas. The report noted that the operations behaved very differently from each other; some were adhering to the Guidelines for Minimising Impacts of Sand Mining on Quality of Specific Rivers in Sabah (EPD 2011b) while others were destructive (view p.8 of the report).

As a precaution, it is recommended that all sand mining activities in the upriver of Lahad Datu water intake should cease. This is to ensure water safety and security are enhanced and conserved for the large population of Lahad Datu. If a total cessation cannot be implemented, monitoring and enforcement activities should be increased. Ground truthing report mentioned earlier suggests it is possible for mining operations to be carried out in a proper manner as some operators were already practising protocols of the Guidelines for Minimising Impacts of Sand Mining on Quality of Specific Rivers in Sabah (EPD 2011b); this guideline was prepared exclusively for the Segama River. Additionally, riparian reforestation should be deployed rapidly to reduce sedimentation and siltation from eroded riverbanks. To support aquatic biodiversity, flowering and fruiting tree and plant species should be selected for the reforestation process. Fruit and flower litters in the river will provide diverse and more feeding opportunity for aquatic, as well as terrestrial, wildlife of the Segama River.

Whilst pollutants and toxic substances that may originate from the agriculture and mining activities, namely mercury, arsenic and glyphosate, were below the thresholds in this assessment, they should be continuously monitored in particular during dry weather when the volumetric flow of the river is low. Under such condition, the concentration of pollutants and toxic substances would be higher and easier to detect. As a guide, the monthly rainfall trend and intensity range can be viewed in Figure 8.

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Table 1. Highlights of key water physico-chemistry baseline assessment affecting human and aquatic biodiversity well-being

No.	Parameter	Threshold Class IIB	Result range	Comments
1	Coliforms	< 5000 cfu/100mL	3-29000 cfu/mL	Samples of point F (7000 cfu/mL) and D (7800 cfu/mL) failed in July and Sept, respectively; this was a sampling point near the water intake of treatment plant. However the high levels of coliforms were also detected in reference site point A and B which registered 200–29,000 and 3–8000 cfu/100mL, respectively. This implies coliform is naturally occurring in the upper Segama River. Similar conditions were reported elsewhere a few decades ago (e.g. Carrillo et al. 1985; Hazen 1988; Rivera et al. 1988). Since literature of the topic is absent in Sabah, a detail study on coliform ecology and population dynamism is necessary to expand the understanding of natural riverine coliform prevalence in Sabah. Other tests should also be explored as coliform has shown to be unreliable in the Segama River to indicate faecal contamination.
2	Ammoniacal Nitrogen	< 0.3 mg/L	0.01–0.82 mg/L	Samples from reference site point B (0.82 mg/L) failed in Sept. This parameter is a measure of ammonia, a pollutant often found in landfill leachate, municipal effluent discharges, agriculture and livestock farming runoffs. This is surprising as reference site point B is located in the pristine part of the Segama River. The sample of Sept may be tainted by faeces or urine residues of wildlife population inhabiting the upstream region and may reflect wildlife abundance.
3	pH	6–9	7–8	No anomaly detected.

4	Biochemical Oxygen Demand (BOD)	< 3 mg/L	0–5 mg/L	Samples of point G (5 mg/L) failed in August. This parameter represents the amount of dissolved oxygen needed by microorganisms to break down organic material present in given water sample. Point G is located in a tributary that originated from an oil palm plantation landscape but no mill was observed within the vicinity. The non-conformance detected indicates Palm Oil Mill Effluent (POME) may have been discharged at some point of time along the river during the August sampling exercise.
5	Chemical Oxygen Demand (COD)	< 25 mg/L	0–12 mg/L	No anomaly detected and all values were within threshold. This parameter measures the oxygen-depletion capacity of a water sample contaminated with organic and inorganic pollutants.
6	Dissolved Oxygen (DO)	5–7 mg/L	7.0–9.3 mg/L	No anomaly detected and most values exceeded the upper limit. This is a favourable condition because high dissolved oxygen is critically required to support aquatic wildlife and for neutralizing pollutants.

7	Total Suspended Solids (TSS)	< 50 mg/L	0.0–227.0 mg/L	TSS in the Segama River can be categorized under two states, namely normal and erratic. In river segments where riparian erosions and sand mining operations were prevalent, fairly high TSS normally occurred. In river segments where the riparian was stable and there was no anthropogenic activity, high level of TSS could still occur–but erratically during stormy weather. The normal values of TSS in critical sampling points near the Lahad Datu water intake, namely point D, E and F, were ranging from 7 to 66 mg/L. Riparian erosion and sand mining activities were observed in the upriver near the points. The 66 mg/L value detected in Sept may be slightly over the upper limit but the water treatment plant is usually capable of filtering such marginally higher level of suspended solids. Point A chosen as Reference Site 1 exhibited high level of TSS in July (154 mg/L). This should not be misconstrued as a non-conformance as the condition was erratic. In nature, an alluvial river flowing through the intact forest will experience high sedimentation and siltation loading after a heavy storm (Douglas et al. 1999). Coincidentally, water sample was extracted under such scenario in July. This is not entirely unfavourable or a flaw in the sampling exercises because the high TSS detected offer an insight of how murky the river can naturally be–spatially and temporally–after a heavy rainfall in the upriver although the downriver is sunny.
8	Salinity	seawater > 20,000 mg/L	5.00–28.59 mg/L	No anomaly detected and all values were within threshold. The values of point I and J nearest to the coast ranged 8.6–16.37 mg/L showing seawater intrusion in the Segama River is not evident at the time of assessment.

9	Glyphosate	< 10 ug/L	< 10 ug/L	No anomaly detected and all values were below threshold. This parameter was assessed to detect the presence of water-soluble herbicide leaching into the Segama River by surrounding oil palm plantations.
10	Mercury	< 0.001 mg/L	< 0.001 mg/L	No anomaly detected and all values were below threshold. This parameter was assessed to detect any presence of artisanal gold mining activity in Segama watershed.
11	Arsenic	< 0.05 mg/L	0–0.005 mg/L	No anomaly detected and all values were below threshold. Arsenic is a naturally occurring metalloid component of the Earth's crust. Levels above the threshold usually occur in industrialized areas.
12	Aluminium	0.06 mg/L (class III)	0.020–10.100 mg/L	This parameter was assessed to detect aluminum sulphate (alum), sodium aluminate and polyaluminum chloride (PAC) residues originating from the oil palm mills as the chemicals are used as coagulants in boiler water treatment to reduce the turbidity, organic substances, and colour of raw water (Osman et al. 2020). High levels of aluminium were detected in all samples but the cause may not be oil palm mills. If reference site points are taken as the baselines, results show aluminium is naturally occurring in Segama watershed, even in pristine forested area. Levels higher than the Class III threshold were detected in reference site point A (1.710–9.07 mg/L), B (0.02–0.682 mg/L) and J (0.283–4.280 mg/L).

Table 2. Consolidated test results of water sample batches collected in July, August and September 2020

values of Reference Site*
values near the water intake point

Parameter per NWQS**	Coliform (cfu/100mL)			Ammoniacal Nitrogen (mg/L)			pH			Biochemical Oxygen Demand (mg/L)			(Intentionally blank)
Threshold Class IIB	< 5000			< 0.3			6–9			< 3			
Sampling point	July	Aug	Sep	July	Aug	Sep	July	Aug	Sep	July	Aug	Sep	
A (ref site)	14000	200	29000	0.02	0.02	0.01	7.9	8	7.4	0	1	0	
B (ref site)	1200	3	8000	0.08	0.01	0.82	7.8	8	7.4	0	0	0	
C	11000	5800	14000	0.04	0.01	0.01	7.5	8	7.3	0	0	0	
D	3800	400	7800	0.09	0.01	0.01	7.5	7.7	7.3	0	2	0	
E	2300	3	4700	0.19	0.01	0.04	7.5	7.6	7.3	0	2	0	
F	7000	19	1700	0.11	0.02	0.01	7.5	7.7	7.3	0	0	0	
G	1000	3100	8100	0.24	0.10	0.01	7.1	7.1	7.0	0	5	0	
H	2700	5500	15000	0.16	0.05	0.01	7.3	7.5	7.2	0	0	0	
I	1000	3300	2000	0.14	0.01	0.01	7.2	7.5	7.1	0	0	0	
J (ref site)	3200	3200	800	0.09	0.05	0.01	7.3	7.3	7.1	0	0	0	

*Reference site = River segment located in forested region
**NWQS = National Water Quality Standards of Malaysia

Table 3. Consolidated test results of water sample batches collected in July, August and September 2020

values of Reference Site*
values near the water intake point

Parameter per NWQS**	Chemical Oxygen Demand (mg/L)			Dissolved Oxygen (mg/L)			Total Suspended Solids (mg/L)			Salinity (mg/L)			Aluminium (mg/L)		
Threshold Class IIB	< 25			5–7			< 50			(seawater > 25 g/L)			0.06 (Class III)		
Sampling point	July	Aug	Sep	July	Aug	Sep	July	Aug	Sep	July	Aug	Sep	July	Aug	Sep
A (ref site)	0	2	1	7.4	6.6	8.7	154.0	22.0	36.0	21.55	18.26	6.46	9.07	1.710	4.880
B (ref site)	0	6	1	8.7	7.7	9.3	10.0	0.0	0.0	19.09	7.94	12.01	0.682	0.020	0.148
C	0	4	4	7.3	6.7	8.6	144.0	24.0	61.0	8.94	6.8	7.88	9.54	1.340	2.620
D	1	7	2	8.3	6.7	8.4	35.0	32.0	66.0	12.91	8.98	8.29	2.54	0.585	2.550
E	0	5	1	8.7	7.1	8.9	11.0	7.0	12.0	13.77	10.89	8.59	0.906	0.406	2.060
F	0	0	1	8.5	7.1	8.6	27.0	32.0	17.0	28.59	9.2	7.56	2.67	0.110	1.760
G	4	12	1	7.3	4.2	7.0	10.0	49.0	27.0	10.61	19.13	22.7	0.595	0.566	12.200
H	1	5	1	8.5	6.1	8.7	59.0	24.0	227.0	10.78	10.43	7.36	1.98	0.995	7.740
I	0	4	3	8.5	6.4	8.2	22.0	58.0	90.0	11.39	8.87	5.99	2.51	1.420	10.100
J (ref site)	0	2	1	8.8	6	9.0	10.6	0.0	22.0	10.61	16.37	8.6	2.5	0.283	4.280

*Reference site = River segment located in forested region
**NWQS = National Water Quality Standards of Malaysia

Figure 1. Segama River watershed boundary and the location of 10 sampling points. Point A, B and J were taken as reference sites since water samples from the undisturbed region are expected to be the most natural

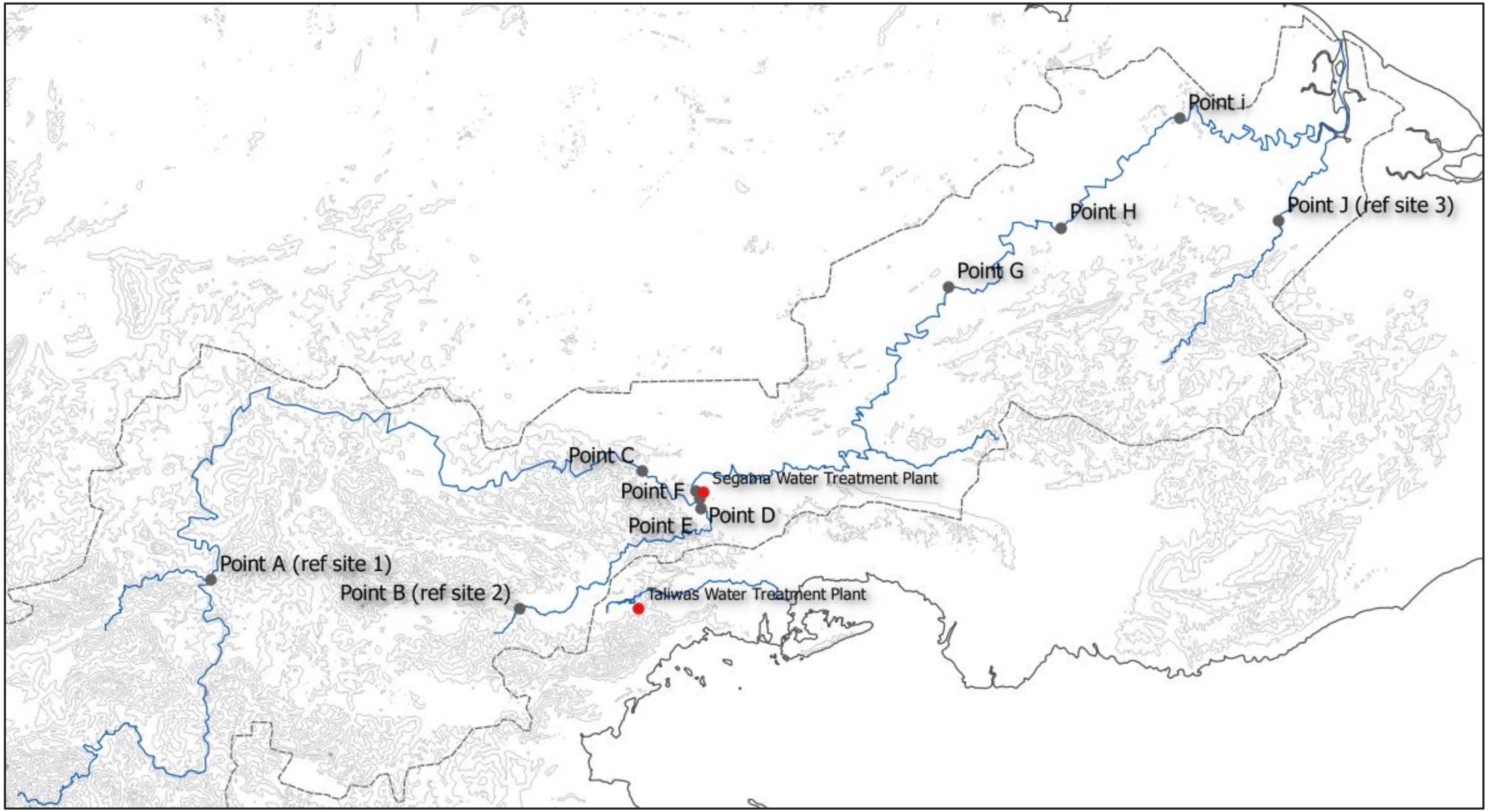


Figure 2. Bar charts for comparing parameter results between the sampling points

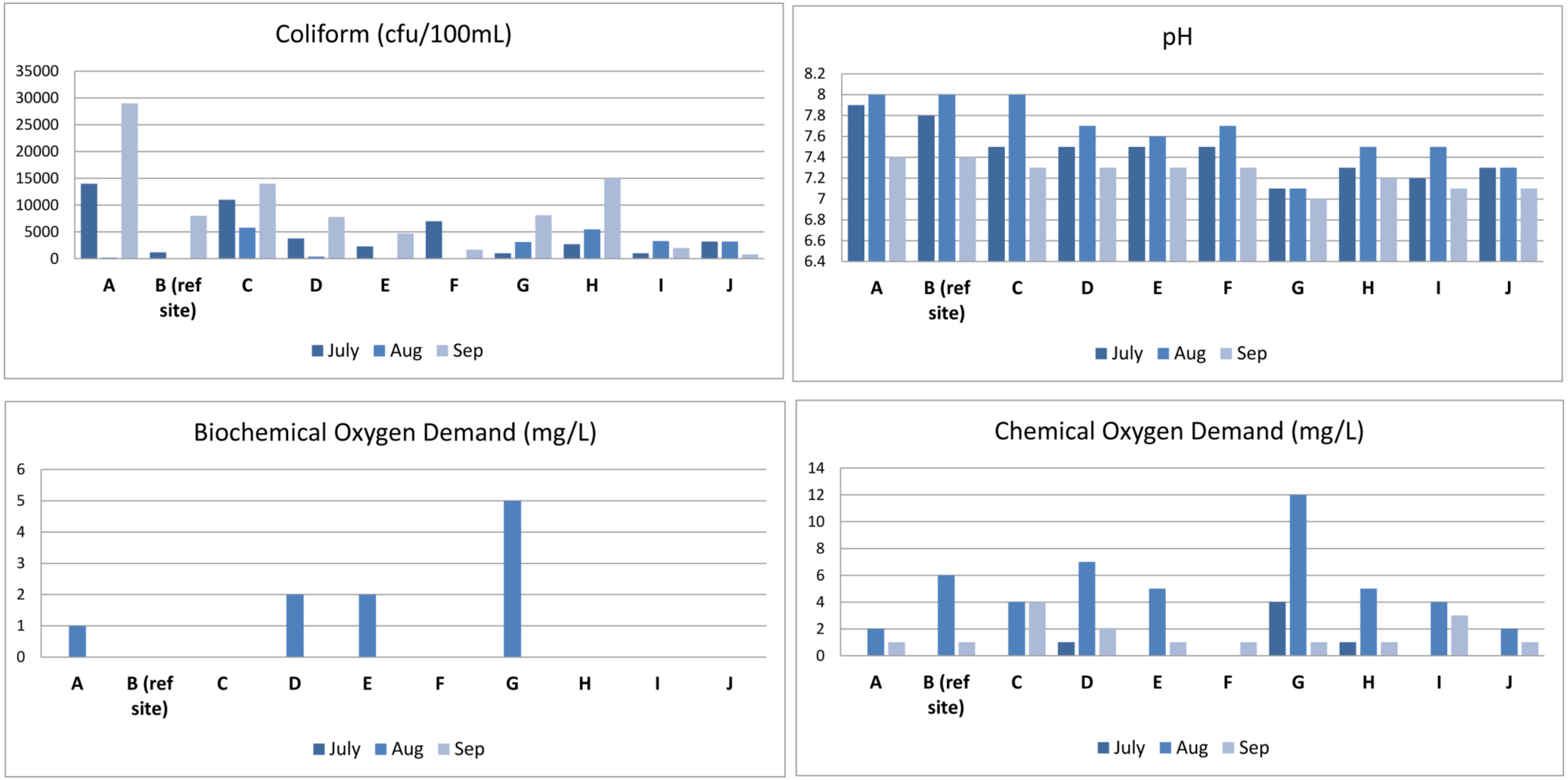


Figure 3. Bar charts for comparing parameter results between sampling points

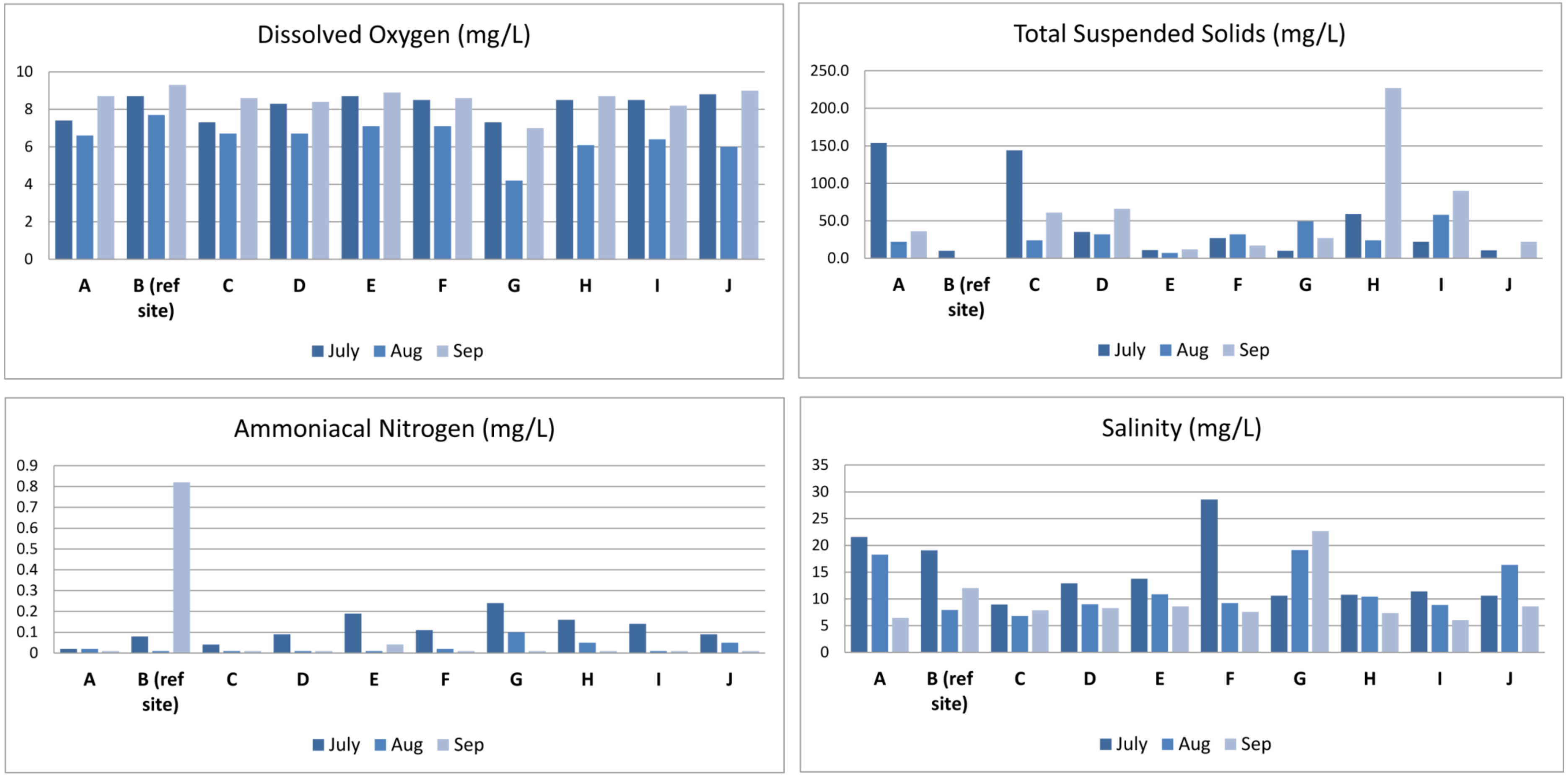


Figure 4. Bar charts for comparing parameter results between sampling points

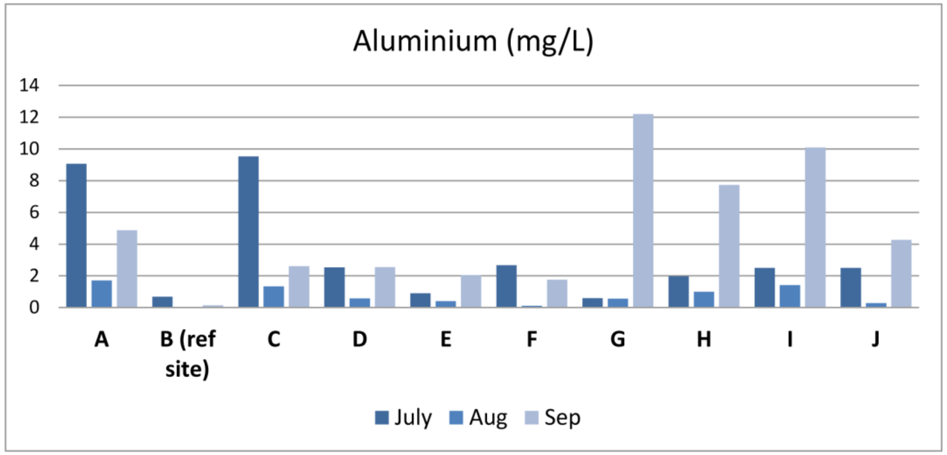
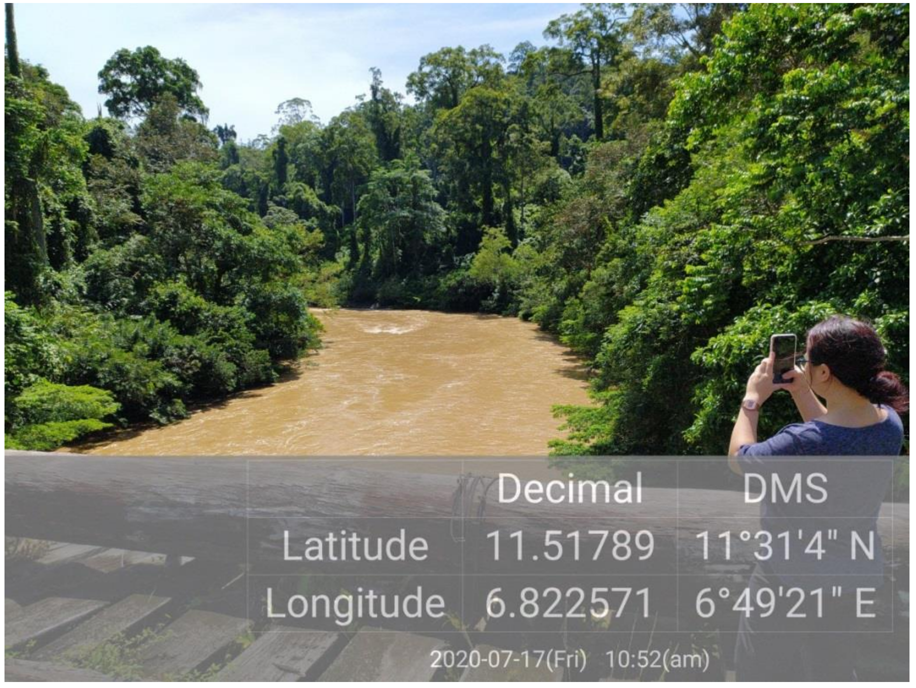
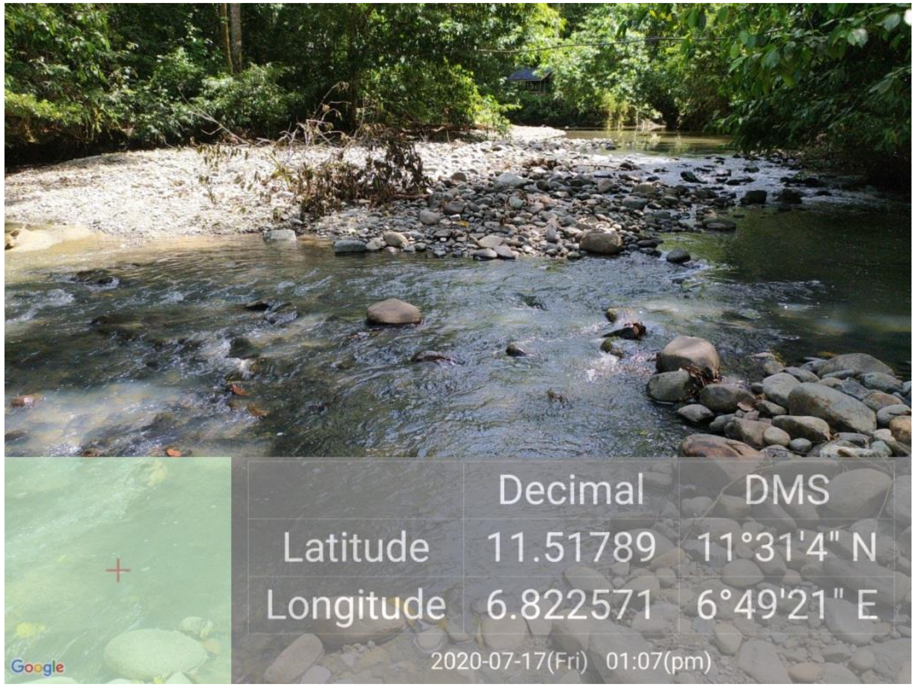


Figure 5. Reference sites selected



Visual of sampling Point A (ref site 1) which is uppermost river



Visual of sampling Point B (ref site 2)

Figure 6. Reference site selected

Visual of sampling Point J (ref site 3) which is near coast

Water sampling technique training held in Kg Dagat which near Point J

Figure 7. Water sample containers used for submission to ALS Technichem (M) Sdn Bhd

Figure 8. Monthly rainfall trend and intensity range of Danum Valley