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ESTIMATION AND CORRELATION OF LOW FLOW HYDROLOGICAL PARAMETERS USING A NOVEL MODIFIED STORAGE-YIELD-RELIABILITY MODEL FOR MALAYSIAN STREAMFLOW STATIONS

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Highlights:

- Low flow estimates are essential for managing river basin water resources.

- Regression equations show fair correlation within a factor of two across hydrological regions.

- The modified storage-yield-reliability model provides reliable low flow estimates with limited data.

Abstract: This study presents a modified methodology to estimate various low flow hydrological parameters of various streamflow stations in Malaysia. This is followed by a subsequent estimation of low flow quantum using a modified storage-yield-reliability (SYR) model. These low flow estimates are crucial in managing the water resources in a river basin. Furthermore, it is also stipulated in the provision of environmental flow (EF) prescription for prior releases in water resources management in Malaysia. The database (90 streamflow stations in Malaysia) adopted in this paper is abstracted from the National Water Resource Study review. This paper presents a novel methodology for low flow yield estimation using Vogel and Kuria's modified version of the SYR model. The modified version adopts the same formulation and structure as the original multiple regression equation, but with an additional calibration step for deriving the calibrated parameters. The correlation between average annual flow and low flow quotient shows a moderately higher coefficient of determination (r2), varying from 0.724 to 0.850 for various hydrological regions in Malaysia. In addition, fair and consistent correlation is demonstrated, falling within a factor of two line visually using the respective coefficient of determination of the regression equations for various hydrological regions in Malaysia. However, minor noises and fluctuations are observed between the estimated results and the observed dataset and records. This novel modified SYR model's significant practicality and utility are vividly shown, and it can be readily used in the pre-feasibility water resources study.

Keywords: low flow; hydrological parameters; mean annual flow; environmental flow; storage-yield-reliability model

1. Introduction

The purpose of this study is to present the correlation between various hydrological parameters, such as mean annual flow (MAF) or annual average flow (AAF), and the low flow yield or quotient of various return periods, such as a 50-year or probability of non-exceedance in the river basin. These design parameters and information on low flow yield are important in setting the nominal capacity of the water treatment facilities that abstract their raw water sources from the river. In addition, the low flow analysis (LFA) study is also being used to estimate the environmental flow (EF) for the river basin. Once the low flow quantum has been firmly estimated, it is equally vital to establish a minimum reservation or allocation for EF. This is to maintain a conducive environment for the fauna and flora communities in the river reach.

To illustrate the utility of EF in routine reservoir operation, it is necessary and mandatory by law and regulation to allocate a minimum amount of reservoir storage for daily releases as part of the prescribed downstream flow. This is commonly known as either maintenance flow or EF for sustaining and preserving the ecologic integrity and well beings of the riverine ecosystem in India, China and Mediterranean Seas region (Baeza Sanz & Matías, 2023; Liu *et al.*, 2024; Mohamad Arbai & Irie, 2025; Pal & Saha, 2022; Rossel & De la Fuente, 2015; Yin *et al.*, 2015). Furthermore, Katz summarised the EF requirement and provided an overview of several countries' quest to provide sustainability in river basin water management undertakings (Katz, 2006).

In addition, Hirji and Davis (2009) emphasised the importance of EF in water resources planning and equitable distribution of and access to water and services provided by the natural aquatic ecosystem. However, during the interim measure and also recommended by various earlier water resources studies, a hydrological indexing and analysis based on historical hydrometric records can be used as a basis for establishing the quantitative amount of flow needed (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011). These hydrological-based techniques were easily available from the results of the analysis of low flow scenarios, such as LFA, drought sequence analysis (DSA), and flow duration (LFD) curves of various streamflow stations in the river basin.

Heng and Hii (2011) and Toriman (2010) reviewed various techniques of commonly used EF estimation for river basins in Malaysia. Almost all techniques are based on observed or measured historical flow records. By its general definition, EF can be considered the master variable because it greatly impacts aquatic habitat, river morphology, biotic life, river connectivity and water quality (Jain, 2012). Sidek et al. (2013) presented a design case study of a mini hydropower development scheme along the main stem of the Pahang River near Temerloh, in the interior region of east coastal Peninsular Malaysia.

Nationwide LFA of available streamflow stations has been part of the routine repertoire in conventional hydrological studies. It has been carried out in various past water resources studies. The results of these individual case studies were appropriately reviewed, updated, and readily incorporated in the national scale water resources study in the National Water Resources Study (NWRS) Review (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011). However, the results and output of the LFA in the national scale water resources study are not readily available because there is a lack of correlation amongst various estimated parameters and stream flow stations of varying degrees of spatiality and temporalities. Therefore, the objectives of this study are to (1) correlate the quantitative flow assessment of mean annual flow and quantum of the low flow regime, and (2) estimate the quantitative low flow magnitude of various stream flow stations using a modified storage-yield-reliability (SYR) model of Kuria and Vogel (2014).

2. Data Acquisition and Methodology

The first state-wide water resources assessment in Malaysia was carried out under the Japan International Cooperation Agency, JICA (1982). Subsequent nationwide studies were also carried out in NWRS Review in 2011, which only covered Peninsular Malaysia regarding references, scope and extent of works. Other state-wide studies have been carried out in individual states, such as Sarawak Integrated Water Resources Management Master Plan (Jurutera Jasa, 2009) in Sarawak and its earlier Sabah Water Resources Master Plan (Water Resources Consulting Services, 1994).

The common denominators of these nation-wide or state-wide water resources encompass inter-disciplinary fields such as the projection of primarily domestic and irrigation water demand based on methodological statistical forecasting and analysis of human population in the future horizon. In addition, future industrial and institutional demand will also be included. The water resources studies also address the status of water quality and EF requirements in the river basin.

To carry out the objective of correlation in this study, the results of the LFA of the point streamflow station in the NWRS Review (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011) are entirely adopted. The database of 90 streamflow stations was adopted for this study. They were categorized into four (4) geographical regions and summarized respectively in **Table 1**, **Table 2**, **Table 3**, and **Table 4**.

Table 1. AAF and low flow for west coast region of Peninsular Malaysia (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011)

STREAMFLOW RECORDS: AAF and 1Q50 and 7Q50 Correlation									
River Basin	**Streamflow Station**	**Catchment Area**	**AAF**	**AAF**	**AAF**	**1Q50**	**7Q50**	**1Q50**	**7Q50**
WEST COAST		**km2**	**MCM/year**	**mm/year**	**m3/s**	**m3/s**	**m3/s**	**%AAF**	**%AAF**
Sg Arau	Ladang Tebu	21	24	1166	1	0.01	0.04	1.3	5.2
Sg Jerneh	Titi Tampang	24	10	429	0.3	0.01	0.01	3.1	3.1
Sg. Ketil	K Pagang	704	631	896	20	2.17	2.73	10.8	13.6
Sg Muda	Ldg Victoria	4010	3312	826	105	8.7	10.1	8.3	9.6
Sg Muda	Jeniang	1710	1411	825	45	0.5	0.1	1.1	0.2
Sg Kulim	Ara Kuda	129	172	1332	5	0.58	0.65	10.6	11.9
Sg Trolak	Trolak	66	87	1316					
Sg Bidor	Malayan Tin Bhd	210	400	1906					
Sg. Chenderiang	Bt 32 Jln Tapah	119	211	1774					
Sg. Kinta	Weir G Tualang	1700	2553	1502	81	6.58	7.07	8.1	8.7
Sg Pari	Jln Selibin	245	282	1152	9	0.22	0.27	2.5	3.0
Sg. Kinta	Tg Rambutan	246	241	981	8	0.25	0.42	3.3	5.5
Sg. Perak	J Iskandar	7770	7964	1025					
Sg. Plus	Kg Lintang	1090	1014	930	32	4.2	5.6	13.1	17.4
Sg Ijok	Titi Ijok	216	387	1790	12	0.29	0.48	2.4	3.9
Sg Kerian	Selama	629	917	1458					
Sg. Batang Padang	Tg Keramat	445	1104	2481					
Sg Kampar	Kg Lanjut	432	519	1201					
Sg Langat	Kajang	380	242	637					
Sg Selangor	Rasa	321	401	1250	13	2.6	2.6	20.4	20.4
Sg Selangor	Rantau Panjang	1450	1788	1233	57	8.58	9.85	15.1	17.4
Sg Bernam	J SKC	1090	1614	1481	51	8.34	8.86	16.3	17.3
Sg Batu	Sentul	145	205	1417					
Sg Gombak	Jln Tun Razak	122	163	1335					
Sg Linggi	Sua Bentong	523	514	982	16	0.65	0.88	4.0	5.4
Sg Pedas	Kg Pilin	111	144	1294	5	0.04	0.06	0.9	1.3
Sg Gemencheh	Gedok	114	44	382	1	0.004	0.005	0.3	0.4
Sg Gemencheh	Jln Gemas Segamat	453	202	446					
Sg Linggi	J Jln Persekutuan	230	150	653	5	0.67	0.99	14.1	20.8
Sg Muar	Bt 57 Jln Gemas Rompin	1210	581	480	18	0.7	0.85	3.8	4.6
Sg Linggi	Rahang	189	177	939					
Sg Kepis	J Kayu Lama	21	14	664	0	0.01	0.02	2.3	4.5
Sg Triang	Chenor	228	170	744	5	0.37	0.5	6.9	9.3
Sg Kesang	Chin Chin	161	74	461	2	0.04	0.06	1.7	2.5
Sg Melaka	Pantai Belimbing	350	186	530					
Sg Durian Tunggal	Bt 11 Air Rasam	73	29	400					
Sg Johor	Rantau Panjang	1130	1092	966	35	1.23	1.76	3.6	5.1
Sg Linggiu	Rachangan Tanah	209	228	1090	7	0.4	0.9	5.5	12.5
Sg Sayong	J Johor Tenggara	624	573	918	18	1.03	1.49	5.7	8.2
Sg Bekok	Bt 77 Jln Yong Peng dam	350	256	732	8	0.95	0.98	11.7	12.1
Sg Pengali	Felda Inas	143	169	1182	5	0.26	0.38	4.9	7.1
Sg Kahang	Bt 26 Jln Kluang	687	1014	1476	32	1.25	1.42	3.9	4.4
Sg Muar	Buluh Kasap	3130	1302	416	41	0.85	1.16	2.1	2.8
Sg Segamat	Segamat	658	592	899	19	0.62	0.66	3.3	3.5
Sg Lenggor	Bt 42 Jln Kluang Mersing	207	358	1729	11	0.42	0.58	3.7	5.1

Table 2. AAF and low flow for east coast region of Peninsular Malaysia (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011)

STREAMFLOW RECORDS: AAF and 1Q50 and 7Q50 Correlation									
River Basin	**Streamflow Station**	**Catchment Area**	**AAF**	**AAF**		**1Q50**		**1Q50**	**7Q50**
EAST COAST		**km2**	**MCM/year**	**mm/year**		**m3/s**		**%AAF**	**%AAF**
Sg Triang	Juntai	904	363	401	11	0.96	1.02	8.4	8.9
Sg Bentong	Kuala Marong	241	270	1121	9	0.79	1.02	9.2	11.9
Sg Lepar	J Gelugor	560	538	960	17	2.1	2.2	12.3	12.9
Sg Lipis	Benta	1670	1348	807	43	2.84	3.41	6.6	8.0
Sg Telom	mile 49	88	129	1470					
Sg Liang	Taat Sing	200	224	1122					
Sg Pahang	Temerloh	19000	17575	925	557	74.1	86.6	13.3	15.5
Sg. Pahang	Yap	13200	12448	943	395	21.6	32.4	5.5	8.2
Sg Kemaman	Tayor	650	1170	1800	37	3	6.41	8.1	17.3
Sg Kemaman	Rantau Panjang	625	1183	1892	37	2.09	2.36	5.6	6.3
Sg Besut	Kg Rantau	712	1376	1933	44	0.2	0.34	0.5	0.8
Sg Dungun	J Jerangau	1480	3736	2524	118	5.28	7.73	4.5	6.5
Sg Telemong	Paya Rapat	160	416	2597	13	1.99	2.06	15.1	15.6
Sg Terengganu	Kg Tanggol	3340	6777	2029	215	15.2	17.56	7.1	8.2
Sg Chalok	J Chalok	21	48	2279	2	0.11	0.12	7.2	7.9
Sg Nerus	Kg Bukit	393	1070	2722	34	1.89	2.24	5.6	6.6
Sg Lebir	Kg Tualang	2430	3409	1403	108	5.71	6.33	5.3	5.9
Sg Kelantan	J Guillemard	11900	15910	1337	505	58.69	68.28	11.6	13.5
Sg Golok	Rantau Panjang	761	1723	2264	55	1.11	1.79	2.0	3.3
Sg Kemasin	Peringat	48	116	2419	4	0.09	0.11	2.4	3.0
				1241	**Average**	**5.1**	**6.2**	**6.6**	**8.3**

Table 3. AAF and low flow for Sabah (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011)

River Basin	Streamflow Station	Catchment Area	AAF	AAF	AAF	1Q50	7Q50	1Q50	7Q50
SABAH		km2	MCM/year	mm/year	m3/s	m3/s	m3/s	%AAF	%AAF
Sg Tawau	Kuhara	104	88	845	3	0.14	0.21	5.0	7.5
Sg Balung	Balung Bridge	137	135	987	4	0.04	0.05	0.9	1.2
Sg Kalabakan	Kalabakan	1150	930	809	30	0.57	0.68	1.9	2.3
Sg Sapulut	Sepulut	2599	2539	977	81	6.29	7.21	7.8	9.0
Sg Mengalong	Sindumin	472	882	1868	28	0.03	0.27	0.1	1.0
Sg Padas	Kemabong	3185	3675	1154	117	3.21	3.68	2.8	3.2
Sg Kuamut	Ulu Kuamut	2950	3891	1319	123	1.81	2.62	1.5	2.1
Sg Padas	Tenom	7815	6721	860	213	1.76	3.14	0.8	1.5
Sf Segama	Limkabong	2450	2813	1148	89	2.37	2.58	2.7	2.9
Sf Pegalan	Ansip	2155	1674	777	53	2.49	2.77	4.7	5.2
Sg Kinabatangan	Pagar	9430	11354	1204	360	8.99	10.5	2.5	2.9
Sg Labau	Sinua	114	174	1522	6	0.38	0.39	6.9	7.1
Sg Kegibangan	Tamplas PH	800	1492	1865	47	2.41	2.95	5.1	6.2
Sg Papar	Kaiduan	365	780	2137	25	1.05	1.27	4.2	5.1
Sg Liwagu	Maringkan	2000	1434	717	45	2.05	2.37	4.5	5.2
Sg Labuk	Porog	3185	5434	1706	172	4.55	7.09	2.6	4.1
Sg Moyog	Penampang	191	473	2476	15	0.39	0.47	2.6	3.1
Sg Liwagu	Kinabalu Park	11	21	1878	1	0.005	0.01	0.8	1.5
Sg Sugut	Bukit Mondou	2101	2534	1206	80	3.05	4.07	3.8	5.1
Sg Kadamaian	Tamu Darat	308	1052	3415	33	0.95	1.11	2.8	3.3
Sg Bogon	Timbang Batu	570	481	844	15	1.05	1.17	6.9	7.7
Sg Bengkoka	Kobon	700	930	1329	29	0.26	0.32	0.9	1.1
				1411	Average	2.0	2.5	3.3	4.0

Table 4. AAF and low flow for Sarawak (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011)

River Basin	Streamflow Station	Catchment Area	AAF	AAF	AAF	1Q50	7Q50	1Q50	7Q50
SARAWAK		km2	MCM/year	mm/year	m3/s	m3/s	m3/s	%AAF	%AAF
Sg Sarawak	Kg Git	440	1054	2395	33	1.69	2.43	5.1	7.3
	Buan Bidi	217	512	2359	16	1.41	1.64	8.7	10.1
Btg Samarahan	Maang	138	317	2297	10	0.15	0.21	1.5	2.1
	Batu Gong	53	124	2340	4	0.1	0.13	2.5	3.3
Btg Sadong	Krusen	456	948	2079	30	0.17	0.49	0.6	1.6
	Meringgu	338	657	1944	21	0.26	0.4	1.2	1.9
	Sabal Kruin	127	466	3669	15	0.16	0.2	1.1	1.4
	Serian	951	1785	1877	57	0.79	1.03	1.4	1.8
Btg Lupar	Engeban	715	1873	2620	59	1.86	2.98	3.1	5.0
	Entulang D	44	100	2273	3	0.05	0.1	1.6	3.2
Btg Saribas	N Lubau	321	612	1907	19	0.18	0.33	0.9	1.7
Sg Kerian	Sebatan	34	67	1971	2	0.05	0.1	2.4	4.7
Btg Rajang	N Mukeh	2273	6210	2732	197	6.15	16.51	3.1	8.4
	Telok Buing	9522	16559	1739	525	7.62	13.77	1.5	2.6
Btg Oya	Stapang	864	1952	2259	62	2.2	2.37	3.6	3.8
Btg Kemena	Sibiu ATC	103	214	2078	7	0.1	0.14	1.5	2.1
Btg Baram	L Terawan	3370	7467	2216	237	1.6	7.45	0.7	3.1
	Lambir	66	90	1364	3	0.29	0.32	10.2	11.2
Sg limbang	N Insungai	2413	4241	1758	134	0.38	3.18	0.3	2.4
				2204	Average	1.3	2.8	2.7	4.1

3. Storage-Yield-Reliability (SYR) Screening Model by Kuria and Vogel (2014)

As mentioned earlier, one of the tasks of the water resources assessment is the ability to estimate the low flow quantum with confidence. The conventional technique is LFA of various streamflow stations in the river basin. A further step to derive the low flow quotient is based on regionalization using index LFA techniques. Other emerging techniques that have been carried out are novel genetic algorithms (GAs), stochastic, and geostatistical analogies. These techniques have provided a quick and accurate quantitative assessment for preliminary screening tasks.

There are many water resources screening techniques, including a generic term of SYR model, which are suitable for providing a quick and preliminary assessment of the reservoir system yield. These models provide useful insights on the order of magnitude of yield that a reservoir system could harness. Some screening models include the Gould-Dincer model (McMahon *et al.*, 2007), Kuria and Vogel (2014) and others. The SYR model by Kuria and Vogel (2014) was chosen in this study. The original form of the Kuria and Vogel (2014) model was formulated based on a global data set of 729 unregulated river flows of at least 25 years of record. They were collated to derive a SYR reservoir yield model. This is derived from a statistical linearised multiple-regression model using several essential independent variables, such as reservoir inflow statistics, storage capacity, and probability of flow non-exceedance or representative return period in terms of standardised Normal Z score (Kuria & Vogel, 2014).

In this current study, a modified novelty version of SYR (Kuria & Vogel, 2014) was proposed to estimate the low flow regime in the river basin. Leading to this argument, it was hypothesised that the SYR model, although originally designated for reservoir yield estimation, can also be utilised for low flow estimation. To do so, the original SYR model is proposed to be subjected to additional conventional calibration and validation treatments. Importantly, it is assumed by calibration that the reservoir storage is approaching zero, similar to the case of run-of-river (ROR) yield. Other parameters, however, are kept in status quo, as they are deemed essential hydrological components to the SYR model.

4. Results and Discussion

4.1. Correlation of AAF and Low Flow

Although Malaysia is a relatively smaller country by land mass, comprising a peninsula and islands that share a boundary with Indonesia, slight microclimate differences in rainfall and runoff exist in the context of hydrometric variability. The central and eastern coastal regions of Peninsular Malaysia receive higher-than-average rainfall annually than the western coastal region. Both regions are exposed to the southwest and northeast monsoons during April-June and November-December. However, the south western region of Peninsular Malaysia, such as

Melaka and Negeri Sembilan, and most of the coastal region of Batu Pahat are rainfall deficit states with average annual rainfall of about 350 to 500 mm/year.

On the other hand, both states of Sabah and Sarawak's rainfall regimes are generally higher than the national average of about 2400 mm/year (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011). For convenience and also out of consideration of these climatic variations in the hydrometric (streamflow) database, they are conveniently subdivided into four (4) zones, namely, (1) east and (2) west coastal region of Peninsular Malaysia, (3) Sabah and (4) Sarawak. There are 106 streamflow stations in total with more than 30 years of record (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011) available in the database, but out of these, only ninety (90) streamflow stations were paired records with concurrent AAF and low flow quotients of 1Q50 and 7Q50.

Due to mostly differential features of the underlying geological formation, notably in northern and some parts of the central regions of peninsular Malaysia, the base flow contribution for some known limestone formations could be significant in sustaining a higher groundwater flow, especially during dry weather, the Selangor river basin in the state of Selangor. This resulted in a higher sustained dry flow regime in the river basin. Long-term streamflow records and databases, as well as subsequent analyses, have shown higher-than-average unregulated low flow by comparison to other streamflow stations in different hydrological regions. These were vividly shown in some streamflow stations in the states of Perlis, Perak, and Selangor and in the North-western and central west coastal regions of Peninsular Malaysia.

The AAFs of these streamflow stations vary from as low as a percentage distribution with AAF as a common denominator, the 7Q50 ranges from a meagre 2% to some 20% of the AAF of the peninsular Malaysia streamflow stations. On average, the percentage of AAF is 8.3%, 4.0%, and 4.1% for Peninsular Malaysia, Sabah, and Sarawak regions, respectively.

Grouped regression equations were selected to correlate the low flow regime of the selected 7Q50 to the AAF of the corresponding long-term streamflow station records for each hydrological region. These paired 7Q50 and AAF variables generally fall within the order factor of two, albeit with some scattering of the data set. A factor of two means the upper and lower bounds of two times in quantitative values from the regressed equations. In addition, a common yardstick of the coefficient of determination (r2) was adopted for comparison of the goodness of fit of the regression equation. Overall, the results of the regression approach showed reasonable acceptability and satisfactory, with r2 that varied from as low as 0.724 to as high as 0.850 (**Table 5**).

Table 5. Power-based regression equations and r2

Hydrological Region	Streamflow station No.	Regression Equation	r2 coefficient of determination
West Coast	18	$Q_{7Q50} = 0.0484\, AAF^{1.1206}$	0.724
East Coast	31	$Q_{7Q50} = 0.0621\, AAF^{1.0295}$	0.830
Sabah	22	$Q_{7Q50} = 0.0306\, AAF^{1.0212}$	0.840
Sarawak	19	$Q_{7Q50} = 0.0367\, AAF^{0.9671}$	0.850

$Q_{7Q50} = \mathrm{m}^3/\mathrm{s}$:$AAF = \mathrm{m}^3/\mathrm{s}$

Figure 1, **Figure 2**, **Figure 3**, and **Figure 4** show the results in terms of AAF and low flow quotient plots for each hydrological region with upper and lower factors of towlines, such as the west and east coastal regions of Peninsular Malaysia, Sabah, and Sarawak.

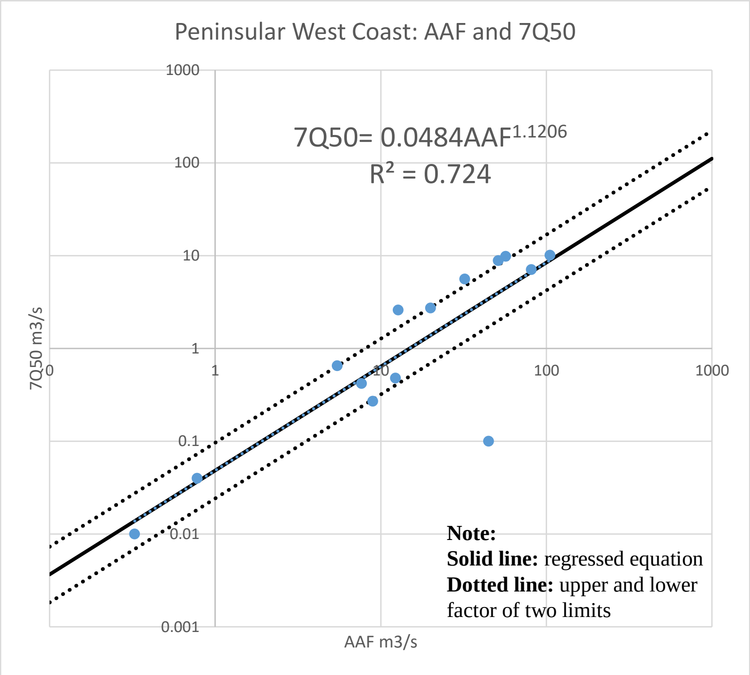

Figure 1. AAF and 7Q50 relationship: West coast of Peninsular Malaysia

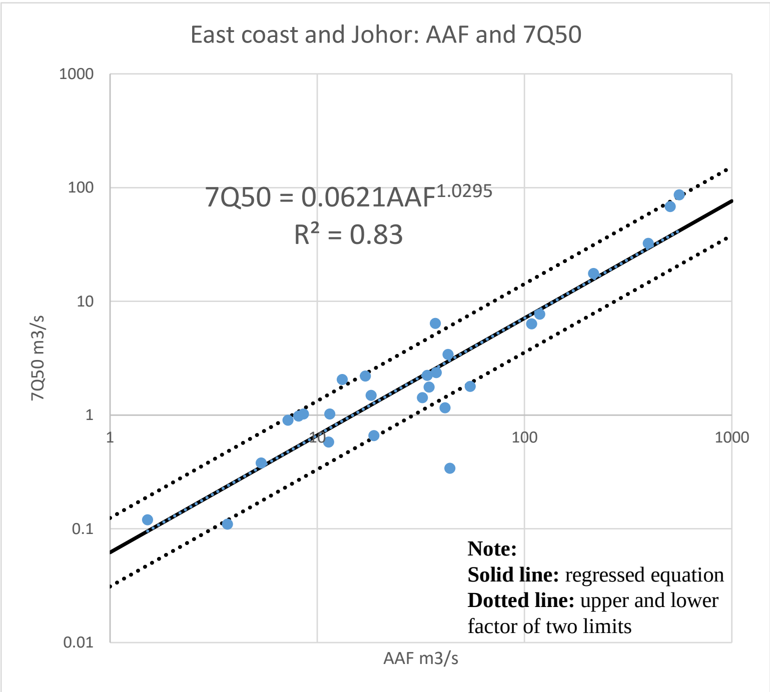

Figure 2. AAF and 7Q50 relationship: East coast of Peninsular Malaysia

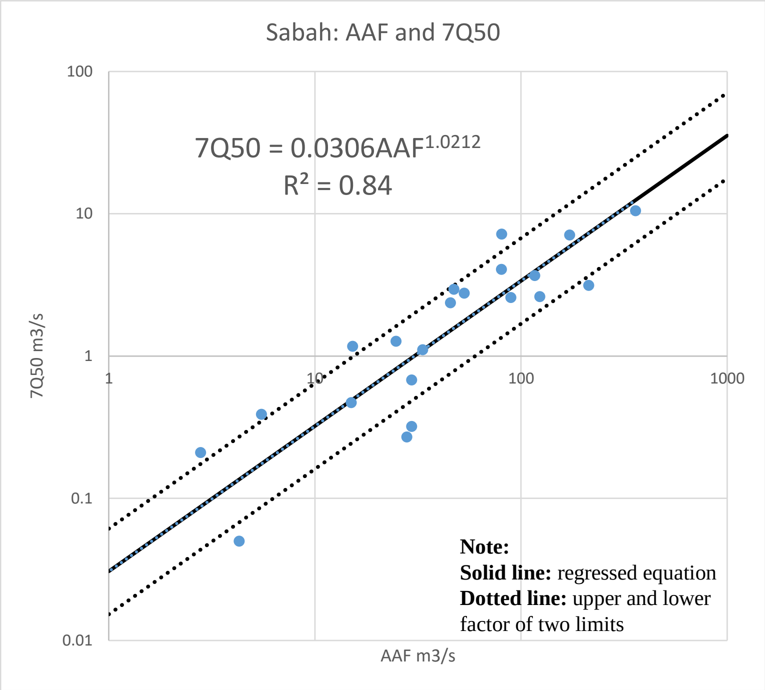

Figure 3. AAF and 7Q50 relationship: Sabah

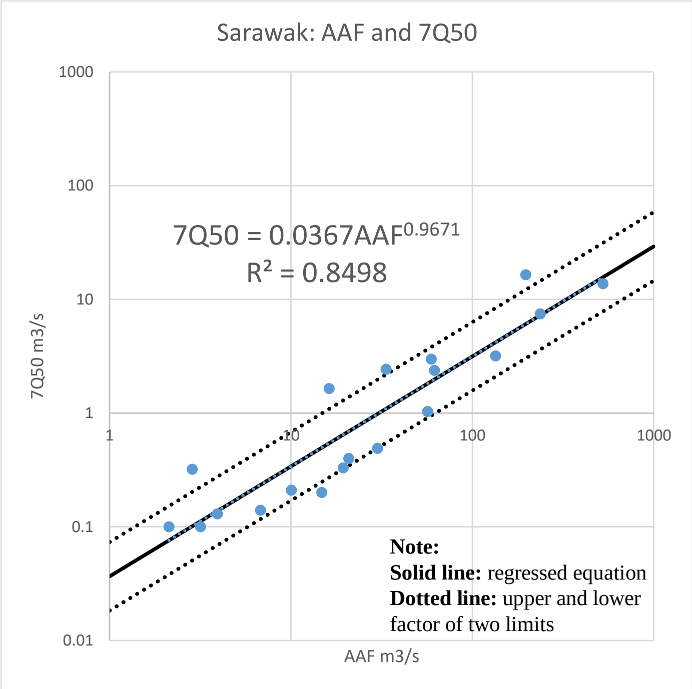

Figure 4. AAF and 7Q50 relationship: Sarawak

4.2. Storage-Yield-Reliability (SYR) Model

Previously, the original version of the SYR model of Kuria and Vogel (2014) was developed to estimate the reservoir yield by a multiple variable regression approach. It was adopted earlier for comparison of the yield reappraisal and reassessment of seven (7) existing water supply reservoir schemes in Selangor, Malaysia (Heng *et al.*, 2017) and also 28 water supply dam schemes in Malaysia (Heng *et al.*, 2018).

This study presents the first attempt to modify the original SYR model (Kuria & Vogel, 2014) for low flow estimation in a river basin. In this modified attempt, the estimated reliable yield, by assuming a run-of-river (ROR) scheme, also known as naturalised flow and uninterrupted flow regime, was then calculated with other variables and input intact by only setting en bloc the storage capacity to a much smaller or negligible value, i.e. 0.001 MCM. By doing so, this SYR output connotes hypothetical scenarios where negligible bank full or instream storage was mostly responsible for artificially altering the natural runoff regime of the river basin.

However, with some uncertainties and reservations alike, the estimated run-of-river yield by the modified SYR model unfortunately did not specify the duration of the low flow regime; therefore, the result could be interpreted as any duration of a low flow episode, such as either representing a 1Q50 or 7Q50 low flow regime. Bearing this in mind, both of them are plotted against the estimated run-of-river yield (ROR) by the SYR model in terms of a goodness-of-fit plot. The estimated yield by the SYR model was then compared to both 1Q50s and 7Q50s of various streamflow stations (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011). By visual comparison and summary of the coefficient of correlation r^2, it is concluded that a fairly consistent correlation of AAF and low flow regime could be reasonably established for all hydrological regions in Malaysia.

Figure 5, **Figure 6**, **Figure 7**, and **Figure 8** show the goodness of fit plots for both the West and East Coast regions of Peninsular Malaysia, Sarawak and Sabah.

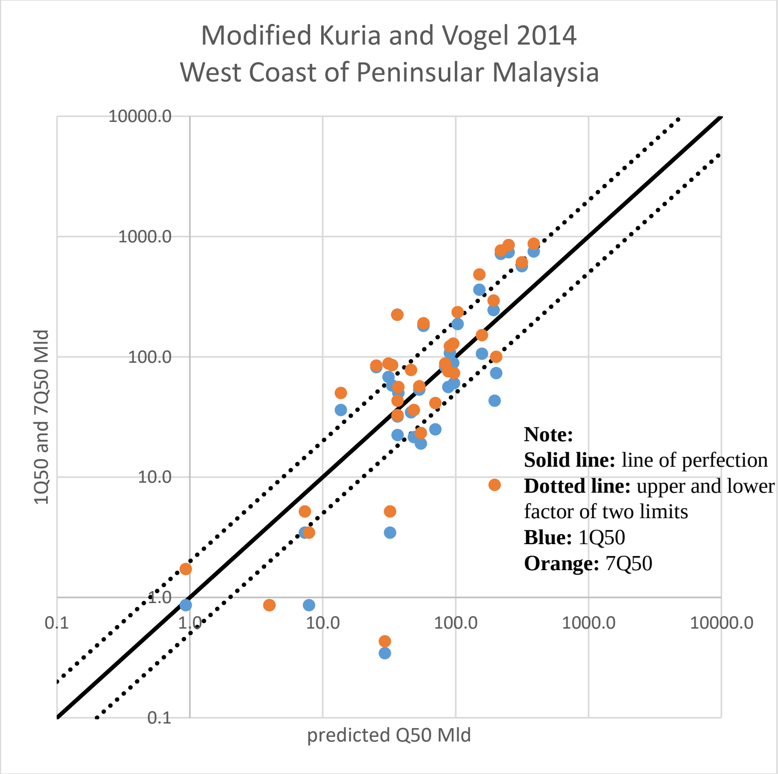

Figure 5. Modified Kuria and Vogel (2014) model: West coast of Peninsular Malaysia

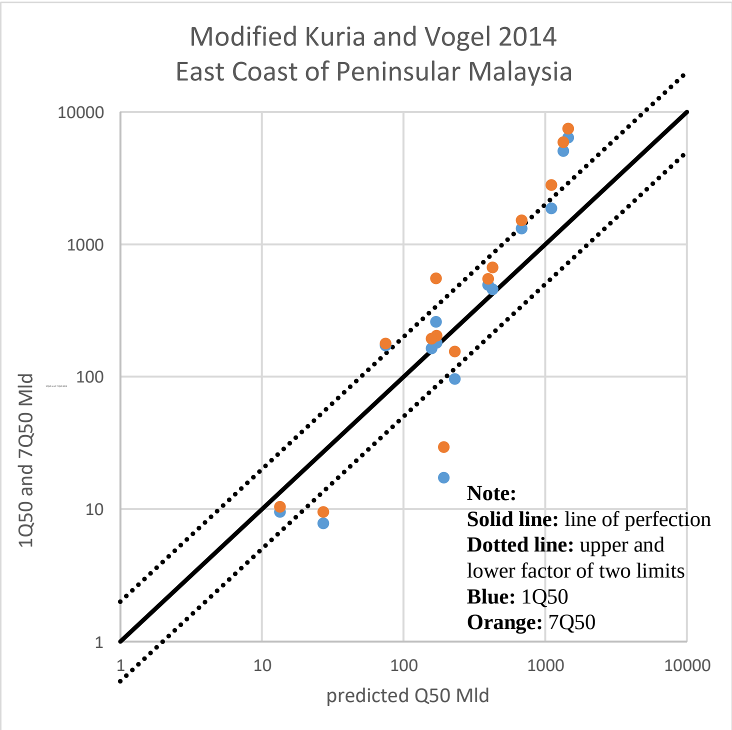

Figure 6. Modified Kuria and Vogel (2014) model: East coast of Peninsular Malaysia

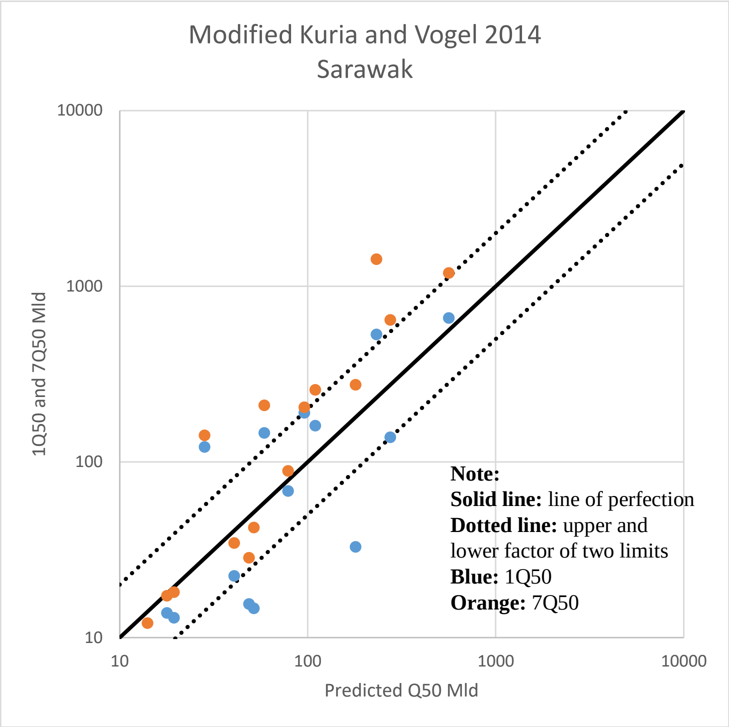

Figure 7. Modified Kuria and Vogel (2014) model: Sarawak

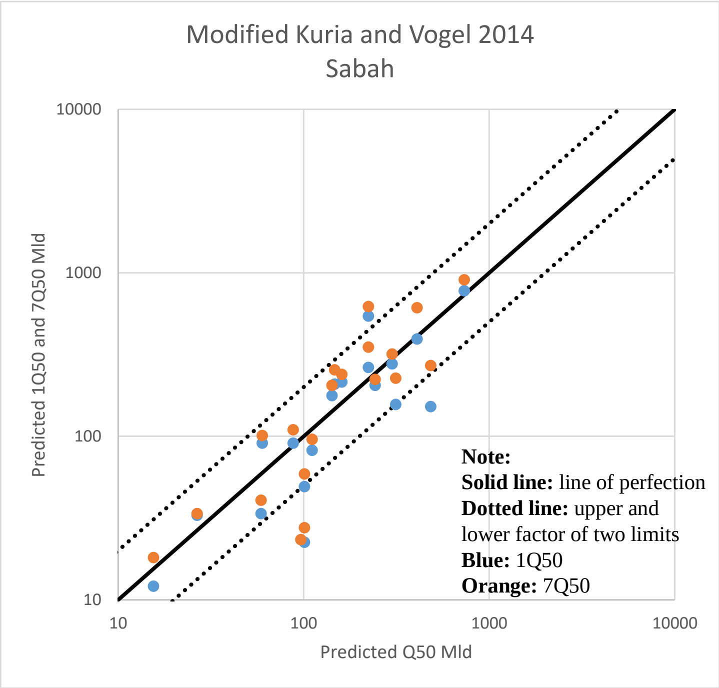

Figure 8. Modified Kuria and Vogel (2014) model: Sabah

5. Conclusion

This study carries out low flow estimation based on the correlation of LFA of NWRS Review (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011), and an LFA estimation exercise using a modified version of the SYR model (Kuria & Vogel, 2014). The technique is termed the “Tenant or Montana” approach in the hydrological lexicon. It is entirely based on hydrological input, such as measured streamflow records, to derive the EF requirement. A simple bivariate regression was selected primarily to correlate the low flow regime of the selected 7Q50 to the AAF of long-term streamflow records for each hydrological region. Generally, the pairs 7Q50 and AAF fall within the order factor of two, with some scatterings of the data set. The regression results showed a reasonably satisfactory coefficient of determination (r2), varying from 0.724 to 0.850. Moderately higher r2 indicates a consistent and wholesome agreement on the correlations between the AAFs and the 7Q50s, albeit with some unexplained noise in the regression exercise. A novelty and modified version of the SYR model of Kuria and Vogel (2014) was then adopted to estimate the low flow quotient by assuming a negligible storage volume in its original equation input. This was accomplished by several trials of calibration undertaken to compare the estimated and observed flows visually. The results also showed a relatively fair comparison between SYR model estimates. They estimated the 1Q50s and 7Q50s reported by NWRS Review (Kementerian Sumber Asli dan Alam Sekitar Malaysia, 2011) by visually comparing the conventional factors of two criteria. Fair and consistent results within a factor of two, line by line, using the respective coefficient of determination of the regression equations, were also observed for various hydrological regions in Malaysia. However, there are also some minor noises and fluctuations amidst the estimated results by comparison to the observed dataset. The limitation of this modified SYR model is the unavailability of extra sets of databases from other regional river basins. Furthermore, the shortcoming of this study is that only the task of the calibration stage was fully carried out. However, this is without the benefit of validation using an independent database, which is the standard repertoire of modelling endeavours by convention. In addition, it would perhaps be worthwhile to compare this with regional and neighbouring records.

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Credit Author Statement

Conceptualization and methodology, Heng, H.H.; review of related literature, Heng, H.H.; validation of solution, Heng, H.H.; writing original draft preparation, Heng, H.H.; writing - review and editing, Pan, W.F., Ong, J. and Chan, J.A.

Conflicts of Interest

The authors declare no conflict of interest.

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