UNIVERSITI PUTRA MALAYSIA

SAMPLING DESIGNS AND ESTIMATION METHODS FOR SEDIMENT LOAD PREDICTION IN TWO RIVERS IN IRAN AND MALAYSIA

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By

MAHMOOD ARABKHEDRI

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

July 2009

THIS DISSERTATION IS DEDICATED
TO

MY WIFE, MY LOVELY CHILDREN,
MY MOTHER AND THE SOUL OF MY FATHER,

AND
MY FAMILY

Abstract of thesis presented to the Senate of University Putra Malaysia in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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Chairman: Assoc. Prof. Dr. Lai Food See, PhD

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The effect of sampling designs and estimation methods on the accuracy of predicted total suspended sediment load (SSL) were evaluated in Gorgan-Rood and Sg. Pangsun, two rivers in Iran and Malaysia respectively. Concerning the rare clustered nature of high load periods during transport, adaptive cluster sampling (ACS) was conducted. Nevertheless, some adaptations were made because continuous sediment records of study rivers are time-scale populations rather than ordinary spatial-scale in previous studies. This study suggests the use of forward neighborhood relation instead of symmetric and the use of flow duration curve instead of ranking of initial samples.

In order to evaluate the ACS in river sediment estimation, 12000 sample sets were generated in each river which categorized in scenarios differed in terms of neighborhood relation, flow discharge threshold, cluster size and initial sample size. For all sample sets, total SSLs were predicted using the

modified Hansen-Hurwitz (HH) and Horvitz-Thompson (HT) estimators which then were statistically evaluated. The results suggests that ACS can not estimate sediment load properly when sample size is smaller than 15 % of the size of respective population. HT estimator showed a better performance than the HH. Moreover, employing forward neighborhood relation instead of symmetric showed underestimations less than 5%.

In the evaluation of sampling designs and estimation methods on total SSL, 14 estimation approaches were set up. 450 sample sets were generated in accordance to three sampling designs- adaptive (Ada), selection at list time (SALT) and calendar-based (Cal) - under three predetermined sample size categories in each study river. In the next step, 4200 total SSLs were estimated using four types of sediment rating curves (SRCs), four estimators of survey sampling, and artificial neural network (ANN) estimation methods.

The results differed for the two study basins. While, all combinations of SRCs and calendar-based sample sets (SRCs-Cal approaches) poorly estimated the observed SSL in Gorgan-Rood even with 70% error, they produced less than 6% error in Sg. Pangsun. In Gorgan-Rood, the SRCs-Ada approaches increased >10% the total SSLs compared to the SRCs-Cal. The results suggest that the corrected SRC with parametric correction factor and logged mean load within discharge classes in adaptive sample sets gave the most accurate estimates. The estimates obtained from adaptive sample sets showed higher variance, but overall their results were more accurate based on the root mean square error.

ANN-Cal approach produced less than 3.8% error for Gorgan-Rood compared to the other methods, whereas for Sg. Pangsun, the result was poorer than SRCs. ANN-Ada did not improve the obtained SSL estimates.

Among the four survey sampling approaches, SALT produced the best estimates (<0.3% error) for Sg. Pangsun followed by the ACS-HT, ACS-HH and SRS. In Gorgan-Rood, ACS-HT gave most accurate result only for the large sample sets.

Choosing a sampling design and an estimator in a study river are complicated issues that require considering some technical and administrative constraints. Although ACS can provide better sample sets for the adoption of SRCs and ANN even with lower cost, three important limitations were addressed in the conclusion part. This study recommends the use of more elaborate neighborhood patterns for further study instead of the simple neighborhood adopted. Testing ACS in basins with long continuous records and variety of conditions regarding the discharge-sediment concentration relation is suggested.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doctor Philosophy

PENGARUH REKABENTUK DAN KAEDAH PENGANGGARAN PERSAMPELAN TERHADAP KETEPATAN ANGGARAN MUATAN SEDIMEN DI SUNGAI TERPILIH DI IRAN DAN MALAYSIA

Oleh

MAHMOOD ARABKHEDRI

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Objektif utama kajian ini ialah untuk menilai fungsi-fungsi ini terhadap ketepatan penganggaran jumlah muatan sedimen melalui gabungan konsep tinjauan persampelan dan hidrologi. Kajian ini dijalankan menggunakan dua set rekod populasi sedimen selanjar untuk Sungai Gorgan-Rood di Iran dan Sungai Pangsun di Malaysia.

Kajian lepas telah menunjukkan ketidakberkesanan rekabentuk persampelan berasaskan kalendar untuk memberikan set sampel yang baik. Oleh itu, teknik Persampelan Kelompok Adaptif (PKA) telah digunakan di kawasan persampelan berkaitan dengan tempoh kecenderungan pelonggokan muatan tinggi semasa pengaliran sungai. Dalam rekabentuk ini, sampel tambahan di kawasan persekitaran unit-unit penting (mengandungi muatan sedimen tinggi) turut diambil dan dimasukkan ke dalam set sampel). PKA boleh digunakan untuk penganggaran JHS menggunakan pekali Hansen-Hurwitz (HH) dan Horvitz-Thompson (HT) yang telah diperbaiki.

Memandangkan PKA telah diaplikasikan secara eksklusif dalam kajian permasalahan skala-sekitaran sehingga sekarang, beberapa adaptasi telah dibuat untuk menggunakan rekabentuk ini bagi menangani permasalahan skala-selang masa seperti dalam kajian ini iaitu pengangkutan sedimen dalam sungai. Sebagai contoh, kajian ini mencadangkan penggunaan hubungan kejiranan ke depan berbanding simetri dan juga penggunaan lengkuk selang aliran berbanding pentertiban sampel.

Untuk menilai keberkesanan PKA dalam penganggaran sedimen, 12 senario yang berbeza dari segi nilai asas aliran luahan dan saiz kelompok telah ditakrifkan mengikut hubungan simetri dan kejiranan ke depan bagi setiap populasi kajian. Setiap senario melibatkan 500 set sampel yang dipecahkan kepada sepuluh rawatan (berbeza mengikut sampel saiz) setiap satu dengan 50 replika. Ketidaksaksamaan, kejituan dan ketepatan setiap senario dan rawatan dinilai secara statistik. Keputusan menunjukkan HT adalah lebih baik berbanding HH dengan memberikan anggaran yang secara relatifnya lebih saksama dan tepat serta nilai pekali variasi yang kecil. Ini mencadangkan bahawa untuk kajian sedimen sungai, hubungan kejiranan simetri boleh digantikan dengan kejiranan ke depan tanpa menonjolkan ciri ketidaksaksamaan yang ketara. Didapati, senario dengan nilai asas luahan bulanan berserta saiz kelompok tidak terhad untuk Gorgan-Rood dan senario dengan nilai asas luahan tahunan dengan kelompok bersaiz 40 untuk Sg. Pangsun memberikan keputusan yang terbaik.

Dalam penilaian rekabentuk persampelan dan kaedah penganggaran muatan sedimen terampai (MST), 14 pendekatan penganggaran telah

digunakan. 150 sampel set telah dipilih bersepadanan dengan tiga jenis rekabentuk persampelan; adaptif, Pemilihan Pada Masa Tersenarai (PPMT) dan rekabentuk berasaskan kalendar. Set sampel bagi setiap rekabentuk ini dikumpulkan kepada tiga kategori sampel saiz yang telah ditentukan dengan setiapnya mengandungi 50 replika. Pada langkah seterusnya, muatan sedimen dianggarkan menggunakan empat jenis Lengkuk Kadar Sedimen (LKS), empat penganggar persampelan dan juga kaedah anggaran Rangkaian Neural Buatan (RNB). Keputusan menunjukkan dua kesudahan berbeza untuk kedua-dua lembangan. Didapati kesemua LKS-Kalendar memberikan nilai anggaran MST yang jauh menyimpang untuk Gorgan-Rood tetapi memberikan anggaran yang saksama untuk Sungai Pangsun. Pendekatan LKS-adaptif meningkatkan jumlah anggaran MST pada Sungai Gorgan-Rood tetapi tiada perubahan ketara di Sungai Pangsun. Selanjutnya, keputusan ini menunjukkan bahawa aplikasi LKS dalam rekabentuk persampelan adaptif bagi kedua-dua teknik faktor pembetulan parametrik dan log purata muatan dalam selang luahan dalam sampel set adaptif memberikan hasil yang lebih tepat untuk Gorgan-Rood.

Didapati juga RNB telah memberikan anggaran yang kukuh untuk Gorgan-Rood berbanding kaedah lain tetapi bagi Sungai Pangsun kaedah ini adalah lebih lemah berbanding LKS. Di samping itu, RNB-Adaptif tidak memperbaiki ketepatan anggaran MST yang diperolehi.

Kesimpulannya, antara ketiga-tiga pendekatan tinjauan persampelan, PPMT menghasilkan keputusan yang kukuh untuk Sungai Pangsun diikuti PKA dan Persampelan Rawak Ringkas. Untuk Gorgan-Rood, PKA-HT memberikan

keputusan yang lebih baik berbanding pendekatan persampelan lain hanya pada set sampel yang besar.

Beberapa implikasi daripada pengukuran beberapa sampel semasa tepoh muatan tinggi dengan menggunakan PKA turut dicadangkan pada bahagian kesimpulan. Sebagai tambahan, beberapa kriteria pemilihan rekabentuk persampelan dan penganggar muatan sedimen bagi sungai yang dikaji turut dinyatakan.

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LIST OF ABBREVIATIONS

Abbreviation	Notation
ACS	Adaptive cluster sampling
Ada-	Adaptive sample set
ANN	Artificial neural network
Cal-	Calendar-based sample set
CS	Cluster size
CSRC	Conventional sediment rating curve
CV	Coefficient of variation
DT	Discharge threshold
FDC	Flow duration curve
For	Forward neighborhood relation
HH	Hansen-Hurwitz estimator
HT	Horvitz-Thompson estimator
ID	Instantaneous discharge
LMLWDC	Logged mean load within discharge classes
MFDC	Monthly flow duration curve
MFDC2.5	Discharges exceed 2.5% of time in corresponding months, for Pangsun
MFDC20	Discharges exceed 20% of time in corresponding months, for Gorgan-Rood
MSD	Mean square deviation
MVUE	Minimum variance unbiased estimate
NPCF	Non-parametric correction factor
NRMSD	Normalized root mean square deviation
PCF	Parametric correction factor
R2V	Raster to vector (a software)
SALT	Selection at list time
Sg.	Sungai, Malay term for River
SN	Sample number
SRC	Sediment rating curve
SSC	Suspended sediment concentration
SSL	Suspended sediment load
SSY	Suspended sediment yield
Sym	Symmetric neighborhood relation
UCS	Unrestricted cluster size
USGS	United states geological survey
YDT	Yearly discharge threshold
YFDC	Yearly flow duration curve
YFDC1.25	A discharge exceeds 1.25% of time, 208.6 L/s for Pangsun
YFDC10	A discharge exceeds 10% of time, 37.6 CMS for Gorgan-Rood
YFDC2.5	A discharge exceeds 2.5% of time, 170.7 L/s for Pangsun
YFDC20	A discharge exceeds 20% of time, 23.6 CMS for Gorgan-Rood
YFDC5	A discharge exceeds 5% of time , 57.3 CMS for Gorgan-Rood and 142.5 L/s for Pangsun

CHAPTER 1

INTRODUCTION

1.1 The Need for Research on Sedimentation

The increasing trend of soil erosion rate and subsequent sediment transport in rivers are serious environmental issues worldwide, which were frequently reported over the years (Evans, 2006). Sedimentation processes (erosion, transportation and deposition) cause various problems in watershed, stream, reservoir, estuary and coasts. One obvious problem with sediment deposition is the reduction of storage capacity of reservoirs. In accordance with the World Bank report in 1987, on average, 1% of the water storing capacity of the globe's reservoirs is being lost annually (Morris and Fan, 1998). Replacing the lost water storage by constructing new reservoirs could cost several billion dollars each year.

The increasing trend of erosion rate and sediment reaching streams in Malaysia and Iran were acknowledged by various researchers (Arabkhedri and Jafariardakani, 2002; Lai et al., 1995). High sedimentation rates are mostly due to substantial land use changes without environmental consideration in these countries. In some large catchments of Malaysia and Iran, suspended sediment yield (SSY) greater than 2000 t/km^2/yr had been reported (JAMAB, 1999; Lai et al., 1996). The high amount of sediment yield at a catchment outlet indicates severe erosion upstream.

The sediment load of streams consists of i) dissolved load, ii) suspended load and iii) bedload. Fine suspended sediments usually constitute a