UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF SEDIMENT TRANSPORT ESTIMATION METHODS IN SELECTED CHANNELS

HYDAR LAFTA ALI

ASSESSMENT OF SEDIMENT TRANSPORT ESTIMATION METHODS IN SELECTED CHANNELS

By

HYDAR LAFTA ALI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

April 2015

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

ASSESSMENT OF SEDIMENT TRANSPORT ESTIMATION METHODS IN SELECTED CHANNELS

By

HYDAR LAFTA ALI

April 2015

Chairman: Prof. Thamer Mohammed Ahmed, PhD
Faculty: Engineering

In this study, equations for estimating sediment transport in channels are assessed using field data of 15 rivers located at different part around the world, in which 14 are existing data and 1 is a new measured data. The new field data is for Al-Garraf river, Iraq measured using devices Son Tek River Surveyor (to measure hydraulic and geometric parameters), Van veen grab sampler (to collect bed materials), and Van Dron horizontal water bottle (to obtain suspended sediment load). Data sets related to other rivers is acquired from Brownlie (1981). The acquired data is widely used worldwide and known with its reliability. Several sediment transport equations have been computed and tested in order to recommend their accuracy. The tested equations include most river hydraulic and morphological characteristics.

For bed load estimation in rivers, the results of computations show that there are variations of computed values with significant difference associated with applying Shield equation compare with other computed equations. The differences of computed values are referring to the concepts and methods of each equation.

For estimation of suspended load, the results of comparisons show that Bagnold, Einstein and Van Rijin gave the least error in estimating the suspended load among the other tested equations. The least values of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are equal 0.012 and 0.015 (kg/s/m) respectively. It is found that this least error was associated with applying Bagnold equation.

Moreover, an equation was proposed for computing suspended load in rivers based on the Einstein, Ackers and White, Shield parameters and Regression analysis. The coefficient of determination (R^2) for proposed equation is found to be 0.80. The results obtained from applying the proposed equation show a reasonable performance when compared with other tested equations using field data for rivers Atchafalaya, Red, South American, Rio Grande, and Al-Garraf. The ranges of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are 0.005 to 0.007 and 0.09 to 0.289 (kg/s/m) respectively. The proposed equation is easy to apply compared with Einstein equation that requires complex procedure and longer time. The proposed

equation will assist engineers to estimate suspended sediment load in natural rivers because it require short procedure and give a reasonable accuracy.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN KAEDAH ANGGARAN PENGANGKUTAN SEDIMEN DI DALAM SALURAN TERPILIH

Oleh

HYDAR LAFTA ALI

April 2015

Pengerusi: Profesor Thamer Mohammed Ahmed, PhD
Fakulti: Kejuruteraan

Dalam kajian ini, persamaan untuk menganggar pengangkutan sedimen di saluran dinilai menggunakan data lapangan dari 15 sungai yang terletak di serata dunia, yang mana 14 daripadanya adalah data sedia ada dan satu adalah data lapangan yang baru diukur. Data lapangan yang baru ialah bagi Sungai Al-Garraf, Iraq yang telah diukur menggunakan peranti seperti *Son Tek River Surveyor* (untuk mengukur parameter hidraulik dan geometri), *Van Veen Grab Sampler* (untuk mengumpul bahan-bahan dasar sungai) dan *Van Dron Horizotal Bottle* (untuk mencerap beban sedimen terampai). Set data yang berkaitan dengan sungai-sungai lain diperolehi daripada Brownlie (1981). Data yang diperolehi ini digunakan secara meluas di seluruh dunia dan diiktiraf kebolehpercayaannya. Beberapa persamaan pengangkutan sedimen telah digunakan untuk mengira beban dasar dan beban terampai. Persamaan yang diuji termasuk ciri-ciri hidraulik dan morpologi sungai.

Untuk anggaran beban katil di sungai, keputusan pengiraan menunjukkan bahawa terdapat variasi nilai yang dihitung dengan perbezaan penting yang berkaitan dengan menggunakan persamaan Shield membandingkan dengan persamaan yang dihitung lain. Perbezaan nilai yang dihitung merujuk kepada konsep dan kaedah bagi setiap persamaan.

Untuk anggaran beban terampai, keputusan perbandingan menunjukkan antara persamaan yang diuji, persamaan Bagnold, Einstein dan Van Rijin memberikan ralat terendah dalam menganggarkan beban terampai. Nilai-nilai *Mean Absolute Error (MAE)* dan *Root Mean Square Error (RMSE)* masing-masing adalah sama dengan 0.012 dan 0.015 (kg/s/m). Didapati ralat terkecil ini terhasil daripada pengunaan persamaan Bagnold.

Selain itu, satu persamaan telah dicadangkan untuk pengiraan beban terampai di sungai berdasarkan analisis parameter Einstein, Ackers and White, Shield dan analisa regresi. Pekali penentuan (R^2) bagi persamaan yang dicadangkan ialah 0.80. Keputusan yang diperolehi dari penggunaan persamaan tersebut menunjukkan prestasi yang manasabah jika dibandingkan dengan lain-lain persamaan yang diuji

menggunakan data sungai Atchafalaya, Red, Amerika Selatan, Rio Grande dan Al-Garraf. Julat ralat *Mean Absolute Error (MAE)* dan *Root Mean Square Error (RMSE)* adalah masing-masing 0.005 hingga 0.007 dan 0.09 hingga 0.289 (kg/s/m). Persamaan yang dicadangkan lebih mudah untuk digunakan berbanding dengan persamaan Einstein yang memerlukan prosedur yang kompleks dan masa yang lebih lama. Persamaan yang dicadangkan akan membantu Jurutera untuk menganggarkan beban sedimen terampai di sungai-sungai kerana ia memerlukan prosedur yang ringkas dan memberikan tahap ketepatan yang munasabah.

ACKNOWLEDGEMENTS

First I sincerely thank my supervisor Professor Thamer Mohammed Ahmed for providing a friendly research environment, encouragement and valuable suggestions. I would like to thank my committee members Dr. Badronnisa Yusuf and Dr. Azlan A. Aziz for their valuable guidance and earnest suggestions.

I would like to express my sincere appreciation and deepest gratitude to the Ministry of Water Resources / Center for the Restoration of the Iraqi Marshlands (CRIM) for providing me scholarship. I would feel remiss if I did not express my gratitude for the support and assistance demonstrated by my General Director Hani Fakhri Najee. I also would extend my thanks to all my colleagues in Center for the Restoration of the Iraqi Marshlands who are always willing to help me.

Finally I appreciate the support and understanding of my good wife Basma, and my children Asma and Hussein. I am sincerely thankful to my mother, Father and other family members for their patience and prayers while I was away during the period of this study.

I certify that a Thesis Examination Committee has met on 28 April 2015 to conduct the final examination of Hydar Lafta Ali on his thesis entitled "Assessment of Sediment Transport Estimation Methods in Selected Channels" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Farah Nora Aznieta binti Abdul Aziz, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdul Halim bin Ghazali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zainuddin bin Md Yusoff, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Aminuddin Ab. Ghani, PhD
Professor
Universiti Sains Malaysia
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 June 2015

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Thamer Mohammed Ahmed, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Badronnisa Yusuf, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Azlan A. Aziz, Ir
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

BUJANG BIN KIM HUAT, PHD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _______________________ Date: __________________

Name and Matric No.: Hydar Lafta Ali GS37268

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________
Name of Chairman of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

TABLE OF CONTANTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 General

Sediment is defined as the grainy material that transport particles within the range of size that is originally from physical or chemical degradation of rocks by flow from the basin (Van Rijin, 1993; Yang, 2010). Sedimentation involves the processes of erosion, entrainment, transportation, deposition and compaction (Graf, 1971). Sediment transport has great concern for Engineers, Geologists, and Environmental researchers due its importance. The mechanism of sediment transport has been a subject of study for many years as it enables scholars to understand the movement of sediment particles. To date, there are many equations for the computing sediment discharge in natural rivers. Basically there are three types of sediment equations bed load, suspended load, and total load. Total load can be obtain directly by empirical equations or indirectly as the summation of the bed load and suspended load equations. The categories of bed load and suspended load are not rigid because they depend on the velocity of the flow. For instance, in high velocity or very turbulent water, gravels and large size of sediment can travel most of them in suspension. On the other hand, in very low velocity or very low turbulent, the small size of sediment particles such as silt and clay move totally in bed load (Chien and Wan 1999). The importance of sediment transport referring to the positive and negative aspects arising from this phenomenon which is considering in may locations as a harmful due to movement of soil erosion imperceptible.

1.2 Problem Statement

Sediment causes many problems such as reducing capacity of rivers, canals and reservoirs and this lead to significant impacts on water resources planning, development, utilization, and sustainability. As mentioned above, effect on water quality by sediment is originally from physical or chemical degradation. Therefore, there are some problems that caused by sediment transport and one of the important impacts is on the water quality and suitability of water consumption for human, and industry. There is a vital connection between sediment transport and water quality (Chao et al., 2010; Hantush et al., 2013). Moreover, operational problems of turbine, pumping stations, and erosions at other hydraulic structures such as scour at bridge pier. Sediment has also many positive aspects, like the delivery of nutrients for aquatic ecosystems, as well as for agricultural purposes, the formation and preservation of river deltas, the provision of sand as a building material and so on. Therefore, it is important to study sediment transport in natural rivers. On the other hand, calculating sediment loads in river section is not easy to obtain (Ab. Ghani et al., 2010). The applications of sediment transport equations for estimating sediment load require tedious and long procedure. The estimation of sediment load is essential to protect rivers and structures. Thus, finding accurate methods for estimation sediment load will help to control sedimentation at critical locations and those having direct effect on the economy. In this study, assessment of existing sediment transport equations new and old equations are assessed, also an equation which is easy to apply is proposed to determine suspended sediment load in rivers. The field data of rivers used in this study is located at different part around the world, one of these field data of sediment transport measurement is conducted at the tail of Al-Garraf river, Iraq in order to determine the suspended sediment load in the river beside using the data for validation of the sediment transport equations. There are no studies and field works related to the sediment transport at Al-Garraf river, Iraq although such studies are essential to understand suspended sediment load, sediment distribution, and hydraulic characteristics of the river.

1.3 Objectives

The main objective of this study is to assess sediment transport methods using field data while the specific objectives are as stated below:

1. To compute bed load based on the characteristics of field data
2. To assess the performance of suspended load sediment transport equations using field data
3. To propose an equation to estimate the suspended sediment load in channels

1.4 Scope and Limitation of the Study

The scope and limitation of this study are listed below:

1. The field data of 15 rivers located at different parts around the world have been used in this study. One of these rivers data is Al-Garraf river that was measured using available equipment such as Son Tek River Surveyor, Van Dron horizontal water battle, and Van Veen grab sampler to collect sediment and hydraulic parameters. Other field data of 14 rivers are acquired from Brownlie (1981) and these rivers are Indian canal, Colorado, Middle Loup, Mississippi, Niobrara, Oak Creek, Portugal River, Rio Grande Conveyance Channel, Snake and Clearwater, Trinity, Red, Rio Grande, Atchafalaya, and South American
2. The computed bed load equations are limited to selected equations of Einstein, Bagnold, Du Boys, Shield, Meyer-Peter, Kalinskie, Meyer-Peter Muller, Schoklitsch, Van Rijin, and Cheng
3. The tested suspended load equations are limited to selected equations of Einstein, Bagnold, Lane and Kalinske, Brook, Chang, Simons and Richardson
4. The Proposed equation for computing suspended load is limited to the median diameter D_{50} less than 0.4 mm.

REFERENCES

Ab. Ghani, A., Azamathulla, H. Md., Chang, C. K., Zakaria, N. A., Abu Hasan, Z. (2010). “Prediction of total bed material load for rivers in Malaysia: A case study of Langat, Muda and Kurau Rivers,” Environ Fluid Mech (2011) 11:307–318.

Ackers, P., and W.R. White (1973). "Sediment Transport: New Approach and Analysis," Journal of the Hydmulics Division, ASCE, vol. 99, no. HY11, pp. 2041-2060.

Ariffin, J., Ab. Ghani, A., Zakaria, N. A., Yahya, A. S., (2002). “Evaluation of equations on total bed material load.” International Conference on urban Hydrology for the21st Century, 14-16 October 2002, Kuala Lumpur.

Bagnold, R. A. (1966). “An Approach to the Sediment Transport Problem from General Physics,” U.S. Geological Survey Professional Paper 422-J.

Brooks, N. H. (1963). “Calculation of suspended load discharge from velocity and concentration parameters,” Proceedings of Federal Interagency Sedimentation Conference, U.S. Department of Agriculture, Miscellaneous Publication no. 970.

Brownlie, W. R. (1981). “Compilation of alluvial channel data: Laboratory and Field,” Rep. No. KH-R-43B, California Institute of Technology, Calif.

Bombar, G., and Güney, M. S., (2010). “Experimental investigation of sediment transport in steady flows.” Scientific Research and Essays Vol. 5(6), pp. 582-591. ISSN 1992-2248.

Bartram, J., and R. Balance., (1996). Water Quality Monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Published on behalf of the United Nations Environment Programme. E&FN Spon, Chapman & Hall, London.

Chien, N., and Wan, Z. (1999). Mechanics of Sediment Transport, ASCE, Reston, Va.

Chang, F. M., D. B. Simons, and E. V. Richardson (1965). “Total Bed-Material Discharge in Alluvial Channels,” U.S Geological Survey Water-Supply Paper 1498-I.

Cheng, N. S. (2002). “Exponential Formula for Bedload Transport.” Journal of Hydraulic Engineering, vol. 128, no. 10.

DuBoys, M. P. (1879). “Le Rhone et les Rivieres a Lit affouillable,” Annales de Ponts et Chausses, sec. 5, vol. 18, pp. 141-195.

Duan, J. G., (2013). "A Simple Total Sediment Load Formula." World Environmental and Water Resources Congress 2013: pp. 1942-1950.

Dupuit, H. P., (1865): "Traite de la Conduite et de la Distribution Des Eaux", Paris. As reported by Graf, Walter Hans (1971).

Einstein, H. A. (1950). "The Bed Load Function for Sediment Transportation in Open Channel Flows," U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin no. 1026.

Graf, Walter Hans (1971): Hydraulics of sediment transport, McGraw-Hill, Inc.

Hantush, M. M., Kalin, L., Isik, S., Yucekaya, A., (2013). "Nutrient Dynamics in Flooded Wetlands. I: Model Development." Journal of Hydrologic Engineering, vol. 18, no.12.

Hossain, M. M., and Rahman, M. L, (1998). "Sediment transport functions and their evaluation using data from large alluvial rivers of Bangladesh." Proceedings of a Symposium Held at Vienna. IAHS Publ. No. 249.

Hassanzadeh, H., Faiznia, S., Bajestan, M. S., and Motamed, A., (2011). "Estimate of Sediment Transport Rate at Karkheh River in Iran Using Selected Transport Formulas." World Applied Sciences Journal 13 (2):376-384. ISSN 1818-4952.

Interagency committee, (1963). "Determination of fluvial sediment discharge." Report no. 14, subcommittee on sedimentation.

Jamieson, E. C., Rennie, C. D., Jacobson, R. B., Townsend, R. D., (2011). "Evaluation of ADCP Apparent Bed Load Velocity in a Large Sand-Bed River: Moving versus Stationary Boat Conditions." Journal of Hydraulic Engineering, vol. 173, no. 9.

Kiat, C. C., Ab. Ghani, A., Zakaria, N. A., Abu Hasan, Z., Abdullah, R., (2005). "Sediment transport equation assessment for selected rivers in Malaysia." International Journal of River Basin Management, vol. 3, No. 3, pp. 203–208.

Kennedy R. G., (1895). "The prevention of silting in irrigation canals." Min. Proc. Inst. Civil Eng. 119, 281–290.

Lane, E. W., and A. A. Kalinske (1941). "Engineering Calculations of Suspended Sediment." Transactions of the American Geophysical Union, vol. 20, pt. 3, pp. 603-607.

Lane, E.W., 1955. Design of stable channels, Transactions, ASCE, Paper no. 2776, 20, 1234-1279.

Meyer-Peter, E., H. Favre, and Einstein, A. (1934). "Neuere Versuchsresultate über den Geschiebetrieb." Schweiz Bauzeitung, vol. 103, no.13.

Meyer-Peter, E., and R. Müller (1948). “Formulas for bed load transport.” Report on second meeting of international association for Hydraulics Research, Stockholm, Sweden, pp. 39-64.

Owens P N, Batalla R J, Collins A J, Gomez B, Hicks D M, Horowitz A J, Kondolf G M, Marden M, Page M J, Peacock D H, Petticrew E L, Salomons W, & Trustrum N A, (2005). “Fine-grained sediment in river systems: environmental significance and management issues.” River Research and Applications 21:693-717.

Perks, M. T., (2014). “Suspended Sediment Sampling.” British Society for Geomorphology. ISSN 2047-0371.

Peng G., (2011). “An equation for bed load transport capacities in gravel-bed rivers.” Journal of Hydrology, 402 (2011), 297-305.

Rouse, H. (1937). “Modern Conceptions of the Mechanics of Turbulence,” Transactions of the ASCE, vol. 102.

Shields, A., (1936). “Anwendung der Aenlichkeitsmechanik und Turbulenz forschung auf die Geschiebebewegung.” Mitteil. Preuss. Versuchsanst. Wasser, Erd, Schiffsbau, Berlin, Nr. 26.

Schoklitsch, A. (1950) Handbuch des Wasserbaues, [Handbook of Hydraulic Structures] 2nd edn, Vienna, Austria: Springer.

Simons, D. B., and Sentürk, F., (1976). Sediment Transport Technology, Water Resources Publications, Fort Collins, Colorado, chap. 6.

Sinnakaudan, S. K., Ab Ghani, A., Ahmad, M. S. S., Zakaria, N. A., (2006). “Multiple linear regression model for total bed material load prediction.” Journal of Hydraulic Engineering, 132 (5), 521-528.

Shah-Fairbank, S. C., Julien, P. Y., Baird, D. C., (2011). “Total Sediment Load from SEMEP Using Depth-integrated Concentration Measurements.” Journal of Hydraulic Engineering, vol. 173, no.12.

Sirdari, Z. Z., Ab Ghani, A., and Abu Hassan, Z., (2014). “Bedload transport of small rivers in Malaysia.” International Journal of Sediment Research, vol. 29, no. 4.

Straub, L. G., (1935). “Missouri River Report.” In-House Document 238, 73rd Congress, 2nd Session, U.S Government Printing Office, Washington, D.C., p. 1135.

Vanoni, V. A., and Brooks, N. H., (1957). “Laboratory Studies of the Roughness and Suspended Load of Alluvial Streams,” Report E-68, California Institute of Technology, Pasadena.

Van Rijn, L. C. (1984). Sediment Transport, Part I: Bed Load Transport. Journal of Hydraulic Engineering, vol. 110, no. 10.

Van Rijn, L. C. (1987). Mathematical modelling of morphological processes in the case of suspended sediment transport. Doctoral Thesis. Dept. of Fluids Mechanics, Delft Univ. of Technology, Delft, the Netherlands.

Van Rijn, L. C. (1993). Principle of Sediment Transport in Rivers, Estuaries and Coastal Seas. Aqua Publications, Amsterdam multiple pagination.

Van Rijn, L. C. (2007, a). Unified view of sediment transport by currents and waves, I: Initiation of motion, bed roughness, and bed-load transport. Journal of Hydraulic Engineering, 133(6), p 649-667.

Van Rijn, L. C. (2007, b). Unified view of sediment transport by currents and waves, II: Suspended transport. Journal of Hydraulic Engineering, 133(6), p 668-389.

Wu B., Van Maren D. S., and Li L. (2008). "Predictability of sediment transport in the Yellow River using selected transport formulas," International Journal of Sediment Research 23 (2008) 283-298.

Wren, D. G., Barkdoll, B. D., Kuhnle, R. A., and Derrow, R. W., (2000). "FIELD TECHNIQUES FOR SUSPENDED-SEDIMENT MEASUREMENT." Journal of Hydraulic Engineering, vol. 126, no. 2.

Yang, C.T. (1973). "Incipient Motion and Sediment Transport," Journal of the Hydraulic Division, ASCE, vol. 99, no. HY 10, pp. 1679-1704

Yang, S. Q. (2010). "Sediment Transport Capacity in Rivers." Journal of Hydraulic Research, vol. 42, no. 3(2005), pp. 131-138.

Yang, C.T. (1996). Sediment Transport Theory and Practice, the McGraw-Hill Companies, Inc., New York.

Yang, C. P., Kuo, J. T., Lung, W. S., Lai, J. S., and Wu, J. T., (2007). "Water Quality and Ecosystem Modelling of Tidal Wetlands." Journal of Environmental Engineering, vol. 133, no.7.

Yang, S. Q., and Lim, S. Y., (2003). "Total Load Transport Formula for Flow in Alluvial Channels." Journal of Hydraulic Engineering, vol. 129, no. 1.