ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

EVALUATION OF ARTIFICIAL NEURAL NETWORK(ANN) AND ADAPTIVE NEURO BASED FUZZY INFERENCE SYSTEM (ANFIS) ON SEDIMENT TRANSPORT

M.Sc. THESIS

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ANFİS VE YAPAY SINIR AĞLARINI KULLANARAK SEDİMENT TAŞIMININ İNCELENMESİ

YÜKSEK LİSANS TEZİ

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**To my parents for their love,
endless support and encouragement.**

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April 2012 Saeed VAZIFEHKHAH

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ABBREVIATIONS

ANN	**:** Artificial Neural Network
TSD	**:** Total Sediment Discharge
ANFIS	**:** Adaptive Neuro Based Fuzzy Inference System
FFBP	**:** Feed Forward Back Propagation
MLP	**:** Multi Layer Perceptron
MLR	**:** Multiple Linear Regression
GRNN	**:**Generalized Regression Neural Networks
ITU	**:** Istanbul Technical University
SSC	**:** Suspended Sediment Concentration
RBF	**:** Radial Basis Function
NF	**:** Neuro Fuzzy
EXCEL	**:**a commercial spreadsheet application written and distributed by Microsoft
MF	**:** Membership Function
SRC	**:** Sediment Rating Curve
RBNN	**:** Radial Basis Neural Networks
LSTR	**:** Long-shore Sediment Transport Rate
ASCE	**:** American Society of Civil Engineering
MNLR	**:** Multiple Non-Linear Regression
ARIMA	**:** Auto Regressive Integrated Moving Average
ST	**:** Sediment Transport
MAPE	**:** Mean Absolute Percent Error
RMSE	**:** Root Mean Square Error
BP	**:** Back Propagation

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EVALUATION OF ARTIFICIAL NEURAL NETWORK (ANN) AND ADAPTIVE NEURO BASED FUZZY INFERENCE SYSTEM (ANFIS) ON SEDIMENT TRANSPORT

SUMMARY

With regard to the importance of sediment transportation in Hydraulic and Water Resources Engineering, it is essential to focus on the topic with details and it is a matter of paramount importance. Recently, sediment and its transportation have become an important issue to experts and scientists. Since 1950s, a wide variety of studies have been conducted in laboratories to evaluate the behavior of sediment transportation. Nowadays, improvement of the computer-aided programs such as MATLAB has paved the way for researchers to explore the generation mechanism easily. In sediment transportation, Artificial Neural Networks (ANN) and ANFIS may be intensely used for evaluation of the laboratory data or a definite river's data. In this study, researches of Yang (1983) have been offered, which are about relationships between water discharge, average velocity, water surface slope, shear stress, stream power and unit stream power with total sediment discharge (TSD). The parameter of unit stream power has been neglected due to the fact that it is very similar to th repetitive manner of other parameters. For getting the input data values, Get Data Graph Digitizer software has been used, where 79 set of data has been considered. For each one, the mean of their output values have been extracted and used as observed output data for evaluation. Feed Forward Back Propagation (FFBP) type of ANN and Hybrid, Back Propagation (BP) types based on Sugeno's approach of ANFIS have been utilized in analyzing the data and giving the results in two classifications as training and testing stages. Subsequently, the relationship between predicted and observed values have been obtained in the forms of scatter diagrams. Correlation (R^2) of higher than 0.99 proves the compatibility and capability of ANN and ANFIS for predicting total sediment discharge.

YANG DENEYSEL VERİLERİNE DAYANIP, ANFİS VE YAPAY SINIR AĞLARINI KULLANARAK SEDİMENT TAŞIMININ İNCELENMESİ

ÖZET

Hidrolik ve Su Kaynakları Mühendisliğinde Sediment Taşınımının Öneminine Ayrıntılı Bir Şekilde Bakmak Zorunludur ve Bu Çok Büyük Öneme Sahiptir. Her Zaman, Bu Alanın Uzmanları ve Bilim İnsanları İçin Sediment ve Taşınımı Önemli Bir Mesele Haline Geldi. Mesela, 1950'lerden Beri Sediment Taşınımın Davranışını Değerledirmek İçin Çok Çeşitli Çalışmalar Laboratuvarlarda Yürütülmekteydi.

Akarsular havzalarından gelen ya da yataklarından söktükleri sediment tanelerini taşırlar. Su ile katı tanelerin birlikte hareket ettikleri iki fazlı akımın hidroliği ve taşınan sediment miktarının belirlenmesi mühendislik açısından büyük önem taşıdığı kadar, incelenmesi çok güç olan problemlerdir. Akarsuların düzenlenmesi, çeşitli maksatlarla kullanılması ve akarsulardan su alma ile ilgili mühendislik problemlerine başarılı çözümler bulabilmek için akarsularda akım ve sediment taşınımı konusunda yeterli bilgilere sahip olmak gerekir.

Yüzeysel erozyon, tortu taşınması ve birikmesi, ekonomik ve kültürel gelişimde önem arz etmesi nedeniyle asırlarca jeoloji mühendislerinin araştırma konusu olmuştur. Eski medeniyetler tarafından su kaynakları ve akarsular tarımda ve ulaşım alanlarında kullanılmıştır.

Bütün akarsular hem su kaynaklarındaki yüzeysel erozyon hem de kitlesel olarak akarsu kenarlarındaki potansiyel erozyon alanları nedeniyle tortu taşınmasını içlerinde barındırmaktadır. Bizim anlayışımıza göre aşınmanın optimum dengesi konusu membadadır; akarsuyun erozyon taşıma kapasitesi tasarım, yararlanma, onarım ve koruma konusunda önem arz etmektedir. Seddeler akarsu kenarlarında taşkın kontrolü için yapılmaktadır. Ayrıca bu seddeler nedeniyle güvenilir bir şekilde su kaynağı oluşturabilmek için depoların yapılması gereklidir.Kanallar su taşıma ve elde etmek için yapılırlar. Kalıcı olarak bu hidrolik yapıların kullanılması bizim anlayışımıza göre erozyon, tortu süreci ve onları hidrolik projelerde nasıl birleştirebileceğimizle alakalıdır.

Artan bulanıklık, su bitkilerin büyümesine sebep olur. Siltin suda olması ışığın girmesine ve sonuç oalrak su bitiklerinin fotosentez ve büyümelerine engel olur. Depolanan sedımentler su altında veya nehir üzerinde olan bitikleri boga bilir. Tarım, bazı sanayi süreçler ve kanalizasyondan gelen sediment ler nitrat ve fosfat oranını arta biler ve sonuç da sedimentin yukselmesine sebep olabilirler.

Sediment yönetimi, özellikle sediment hareketinin kontrolü, oyulma-birikme, nehir mühendisliğinde karşılaşılan en zor problemlerden biridir. Nehir yatağındaki hız ve derinliğin zamanla değişmesinin yanı sıra su alma yapısına giren akım miktarı da zamanla değişebilir. Nehir kıyılarında güç santrallerinin soğutma suyu, endüstri su ihtiyacı, sulama vb. Amaçları karşılamak için kullanılan su alma yapılarının etrafı sık

sık sediment birikimi dolayısıyla kuşatılır. Bu sebeple nehir tesislerindeki su alma yapılarında aşınma ve birikme problemleri göz önünde bulundurulmalı ve sediment girişini minimum tutacak şekilde tasarlanmalıdır. Akım ve sediment ile ilgili değişkenlerdeki belirsizlikler sebebiyle oyulma ve birikme hakkında kesin bir yargıya varılamamıştır. Bu sebeple sediment kontrol yapılarının tasarımı ve sıralanışı optimum çözümün elde edilebilmesi için fiziksel model çalışmalarınadayandırılmalıdır. Bu ihtiyaç özellikle üç boyutlu akımın olduğu su alma yapıları civarında ortaya çıkmaktadır. Kıvrımlı nehirlerin dış şevindeki yatak oyulması şevlerin zayıflamasına ve toprak kaybına sebep olur. Sediment birikimi nehrin akım taşıma kapasitesini düşürür ve ulaşım için faydalanılan nehirlerde gemi ulaşımına engel olur.

Çoklu değişkenler sedimentin doğasına ve akım hidroliğine etki etmekteler. Diğer taraftan tortu taşınması çok karmaşık bir konudur ve genel olarak teorik veya yarı teorik bir şekilde araştırılır. Genel olarak araştırmalar teorik olarak bazı basit tahminlere dayandırılır ve ideal olarak dikkate alınması gereken suyun debisi, akım ortalama hızı, enerji eğimi ve kayma gerilmesi gibi önemli etkenlerden bir veya iki tanesi seçilerek belirlenir. Bilim adamları sayesinde bir takım formüller elde edilmiştir ve bu konu gün geçtikçe gelişmektedir. Bazen bilimadamları birbirlerininkine yakın sonuçlar elde etmektedirler ve bazen de zıtlıklar oluşmaktadır. Sonuç olarak bilim adamları bu konuda evrensel olarak anlaşmaya varamamışlardır. Öte yandan günümüzde teknolojinin gelişmesiyle ve bilgisayarın kullanımıyla Yapay Sınır Ağları (YSA) ve ANFIS gibi bilgisayar programlarının ortaya çıkmasıyla tortu taşınması konusunda güvenilirliği yüksek formüller çeşitli bilimadamları tarafından elde edilmiştir.

Bugünlerde MATLAB gibi Bilgisayar Destekli Programların Gelişimi Araştırmacılar İçin Hesaplamaları Hızlı ve Etkin Bir Biçimde Yapmanın Yolunu Açtı. Sediment Taşınımında, Yapay Sinir Ağları (YSA) ve ANFIS Laboratuvar Verisini Yada Gerçek Bir Nehrin Verisini Değerlendirmek İçin Yoğun Bir Şekilde Kullanıldı. Yang (1983) Araştırmaları Diyagramlar Halinde Sunulmuştur. Bahsi Geçen Diyagramlar Su Akımı, Ortalama Hız, Su Yüzey Eğimi, Kayma Gerilimi, Akış Gücü ve Toplam Sediment Akımlı (TSA) Birim Akış Gücü Arasındaki İlişkiler Hakkında.
Giriş Veri Değerlerini Elde Etmek İçin Get Data Graph Digitizer Programı Kullanıldı. Ayrıca, 79 Veri Kümesi Nitelendirilmiştir. Her Biri İçin, Duşey Değerlerinin Ortalaması Hesaplanmış ve Değerlendirme İçin Gözlemlenmiş Çıkış Verisi Olarak Kullanılmıştır. ANN'in İleri Geri Beslemeli Yayılım (İGBY) Türünden, ANFIS'in Sugeno Türüne Dayanan Geri Yayılım (GY) Türlerinden İki Sınıfta Deneme ve Test Olarak Veri Analizinde ve Sonuçlar Vermede Faydalanıldı.

Layerların sayılarını 2 ile 4 arası ve nöronların sayılarını 1 ile 4 arası (İGBY)'ye dayanarak genel alternative senaryolar geliştirerek TSD' yi tahmin etmeye yardımcı oluyor. İlerleme sırasında hataların tipi RMSE ve korelasyonları elde etmede bizim içinönemlidir. Böylece TSD modellemesiiçin en iyive en optimum alternative Yapay Sınır Ağlarının (İGBY)' ye dayanarak iki gizli layerlıve her bir layerı iki nöron sayılı bir kombinasyon ile 0.99 R2 ve 0.017 RMSE olacak şekilde öneriliyor. TSD'yi tahminederken R2 içinyaklaşık 1 değeri ve çok küçük RMSE değeri (<0.04) bu metodun yüksek kapasitesini göstermektedir.

Öteyandan ANFIS programıylagirdiüyelikfonksiyonuolarak, Gauss ve Gauss 2; çıktı üyelik fonksiyonu olarak sabit ve lineer tippler kullanıldı. Sonuç olarak ANFIS program ile HYBRİD ve BP metotlarına odaklanırken genel kapsamlı TSD tahmin metodolojileri kullanıldı. TSD'yi tahmin etmek için gösterildiği gibi çok büyük R2 değerleri ve çok küçük RMSE değerlerine dayanarak HYBRİD ve BP metodlarının yüksek kapasitesi sağlanmaktadır.

DahaSonra, Tahmin Edilen ve Gözlenen Değerler Arasındaki İlişki Diyagramlar Halinde Gösterildi. YapılanÇalışmada 0.99'dan DahaYüksek Tespit Katsayısı (R2) Bağıntısı ANN ve ANFIS'in Toplam Sediment Akımını Tahmin Etmek İçin Uygunluğunu ve Yeterliliğini Kanıtlamıştır.

1. INTRODUCTION

1.1 General

Surface erosion, sediment transport, scour and deposition have been the subjects of study by engineers and geologists for centuries due to their importance to economic and cultural developments. Most ancient civilizations existed along rivers in order to use the water supply for irrigation and navigation. All rivers carry sediments, due to surface erosion from watersheds and bank erosion along the river. Our understanding of the dynamic equilibrium between sediment supply from upstream and a river's sediment transport capability is important for the success of river engineering design, operation, and maintenance. Engineers built levees along rivers for flood control purposes. Reservoirs are built to ensure water supply and flood control. Canals are built for water supply and navigation. Sustainable use of these hydraulic structures depends on our understanding of the erosion and sedimentation processes and how to apply them to hydraulic designs.

Rivers play an important role in continental erosion as they are the primary agents of transferring erosion products to the ocean. Understanding of rivers and their transport pathways will improve the perception of many processes of global significance, such as biogeochemical cycling of pollutants and nutrients, atmospheric CO_2 drawdown, soil formation and their erosion, crust evolution in short the interaction between the atmospheric and the lithospheric compartment of the Earth´s system (Allen, 2008).

In tropical regions around the globe, large river basins play an important role in river sediment transport. Large river basins often display mixed river channel forms, as they usually constitute a rapidly eroding sediment source and associated depositional areas in the lowlands (Filizola et al. 2009).

There are many variables that affect the hydraulics of flow and the nature of sediment transport in any natural stream. As indicated by Yang et al. (1996), the Yellow River in China is notorious because it carries enormous amount of sediment. The total average annual sediment discharge to the sea in China is about

1.94×10^9tons of which 59% comes from the Yellow River. A concentration of 911kg/m^3 was measured on September 7, 1977, at the Saumenxia station near the entrance of the lower Yellow River. The condition of incipient sediment motion is important in a large variety of problems associated with sediment transport. For more than two centuries workers in this field have attempted to formulate the conditions of incipient motion. Many research programs have been devoted to the study of the sediment transport in channels. Detailed information can be found by Vanoni (1984), Yalin (1963, 1972) and Yang (1972, 1973). Millions of dollars are spent to erection of water structures and their maintenance in many countries. Even a small sensibility and attention may result in a remarkable save in reparation costs. Erroneous evaluation and improper design may lead to devastation, extra costs and even human deaths. For instance, in the case of a poor design for dams and miscalculation of sediment yield, it is probable to observe the dam filled by sediment. Consequently, the dam and its connected components such as power plants may cease to perform. Even at that time, in the case of a huge rate of precipitation, dam's overflow, floods and failure of dam may happen.

On the other hand, sediment transport is complex and often subject to semi-empirical or empirical treatments. Most theoretical treatments are based on some idealized and simplified assumptions that the rate of sediment transport could be determined by one or two dominant factors, such as water discharge, average flow velocity, energy slope, and shear stress. Numerous equations have been published and each equation is supported by limited laboratory and occasional field data. The calculated results from various equations often differ drastically from each other and from the measured data. Consequently, none of the published sediment transport equations have gained universal acceptance in confidently predicting sediment transport rates, especially in rivers.More recently, computer models have been developed to simulate and predict the erosion and sediment transport, scour, and deposition processes. There are many sediment transport text books, such as those by Graf (1971), Yalin (1972), Simons and Sentürk (1977), Chang (1988), Julien (1995), and Yang (1996).

The main purpose of this thesis is to construct an artificial inteligent model for the experimental data provided by Yang(1983).

1.2 Literature Review

Although there are many analytical, empirical, statistical and stochastic approaches for sediment yield estimated, recently artificial intelligence methods become available for such predictions. For instance, Cigizoglu et al. (2004) used artificial neural networks (ANN) to estimate the daily total suspended sediment load on rivers. Two different ANN algorithms, namely, the feed-forward back-propagation (FFBP) method and the radial basis functions (RBF) were used for this purpose. The neural networks are trained using rainfall, runoff and suspended sediment load data from the Juniata Catchment in USA. The simulations provided satisfactory results in terms of the selected performance criteria that compare well with conventional multi-linear regression(MLR). Similarly, the simulated sediment load hydrographs obtained by two ANN methods are found closer to the observed ones again compared with multi-linear regression.

On the other hand, Mei Zhu et al. (2006) used ANN to model the monthly suspended sediment flux in the Longchuanjiang River, the Upper Yangtze Catchment, China. They provided the average rainfall, temperature, rainfall intensity and water discharge as inputs. It is demonstrated that ANN is capable of modeling the monthly suspended sediment flux with fairly good accuracy when proper variables and their lag effect on the suspended sediment flux are used as inputs. As they compare with MLR and power relation (PR) models, ANN can generate a better fit under the same data requirement. In addition, ANN can provide more reasonable predictions for extremely high or low values, because of the distributed information processing system and the non-linear transformation involved.

Rajaee et al. (2008) used ANNs, neuro-fuzzy (NF), MLR and conventional sediment rating curve (SRC) models for time series modeling of suspended sediment concentration (SSC) in rivers. They ran the artificial intelligence systems, FFBP method and Sugeno inference system for ANNs and NF models, respectively. They trained models using daily river discharge and SSC data belonging to Little Black River and Salt River gauging stations in the USA. Their results demonstrate that ANN and NF models are in good agreement with the observed SSC values; while they depict better results than MLR and SRC methods. The values of cumulative suspended sediment load estimated by ANN and NF models are closer to the observed data than the other models. Briefly, their results illustrate that NF models present better performance in SSC prediction in compression to other models. Furthermore, the results indicated that the NF model could reasonably estimate cumulative suspended sediment load and simulate hysteresis phenomenon. It was concluded that these models could be suitable substitutes for the conventional MLR and SRC methods.

In the meantime, Cobaner et al. (2008) used an adaptive NF approach to estimate suspended sediment concentration in rivers. Their main focus was to analyze the performances of an adaptive NF computing technique in daily suspended sediment prediction using the daily rainfall, streamflow and SSC data from Mad River Catchment near Arcata in USA. They put various combinations of current daily rainfall, streamflow and past daily streamflow, suspended sediment data as inputs to the NF computation technique so as to estimate current suspended sediment. Subsequently they compared the potential of NF technique with those of the three different ANN techniques, namely, the generalized regression neural networks (GRNN), radial basis neural networks (RBNN) and multi-layer perceptron (MLP) and two different SRC. As a result it has been shown that the NF models perform better than others in daily suspended sediment concentration estimation for the particular data sets used in their study.

Kabiri-samani et al. (2009) proposed fuzzy logic and neural network to estimate long-shore sediment transport rate (LSTR). Predictions of LSTR are a vital task for coastal engineers in the determination of erosion or accretion along coasts. Many scientists have tried to find empirical method for the estimation of LSTR in the past decades. However, due to the influence of significant number of parameters and randomness of the data, the existing empirical methods provide quite different results and have limited applications. Based on Kabiri-Samani fuzzy logic methods such as; heuristic and gradient descent, are accurate tools for this kind of studies, for both trained and non-trained input data.

Yang et al. (2009) have compared the results of ANN and some total bed material load sediment transport formulas to indicate the importance of variables, which can be used in developing sediment transport formulas. They focused on ANN model using four dominant parameters of sediment transport formulas. They used average flow velocity, V, water surface slope, S, average water depth, D, and median particle diameter, d50, as inputs for training the model as dominant parameters to estimate total bed material load.

Their experimental results show that the ANN model developed in their study using minimum number of dominant factors is a reliable and uncomplicated method to predict total sediment transport rate or total bed material load transport rate. They found that the accuracy of formulas in descending order are those by Yang (1973), Laursen (1958), Engelund and Hansen (1972), Ackers and White (1973) and Toffaleti (1969). Their ranking is similar to the ranking of accuracy of sediment transport formulas by the ASCE Sedimentation Committee (1982) without using the ANN approach. Briefly, they also showed that the formulas based on the physical laws of sediment transport, like those formulas that were developed based on power concept, are more accurate than other formulas for estimating total bed material sediment load in rivers.

Recently, Melesse et al. (2011) estimated suspended sediment loads for three major rivers (Mississippi, Missouri and Rio Grande) in USA using ANN modeling approach. They trained a MLP ANN with an error back propagation algorithm, using historical daily and weekly hydro-climatologic data [precipitation, P(t), current discharge, Q(t), antecedent discharge, Q(t−1), and antecedent sediment load, SL(t−1)], to predict the suspended sediment load SL(t) at the selected monitoring station. They evaluated performance of the ANN using different combinations of input data sets, length of record for training, and temporal resolution (daily and weekly data). They compared the results from ANN model with results from MLR, multiple non-linear regression (MNLR) and autoregressive integrated moving average (ARIMA) process using correlation coefficient, R, mean absolute percent error (MAPE) and model efficiency (E). ANN predictions for most simulations were superior compared to predictions using MLR, MNLR and ARIMA approaches. The modeling approach, which they presented in their work, can be potentially used to reduce the frequency of costly operations for sediment measurement, where hydrological data is readily available

Finally, Azamathullaa et al. (2012) focused on sediment transport in pipes, which is a complex phenomenon. The nature and motivation of traditional models differ significantly. To overcome the complexity and uncertainty associated with bed load estimation, they demonstrated that an ANFIS model could be applied for accurate prediction. The performance of the ANFIS model was compared with the regression analysis and also the proposed ANFIS approach gave satisfactory results compared to the existing predictor. Overall, particularly for laboratory measurements, the ANFIS models could give better predictions than the traditional regression models. The ANFIS model successfully predicted the bed load transport in storm sewers. According to their study the high value of the coefficient of determination (r^2 = 0.98), and RMSE = 0.002431, indicate that the ANFIS model is an excellent fit for the measured data.

1.3 Outline of report

After a general intorduction to sediment transport and literature review in Chapter one, Chapter two encompasses classic methodologies in sediment transport formulation. Chapter three precisely focuses on modern methodologies such as ANN and ANFIS and their applications in hydraulics. Chapter four is about the application of ANN and ANFIS in total sediment discharge using Yang's experimental data. Finally in Chapter five, conclusions and recommendations are proposed with future recently diversions.

2. CLASSICAL METHODOLOGIES

2.1 Introduction

Having studied a number of books and with regard to the former researches conducted by scientists it is possible to approach a variety of classifications in sediment transport. This chapter encompasses the above-mentioned topic.

2.2 Regime Approach

An alluvial regime channel is in dynamic equilibrium without noticeable long-term aggradations, degradation, or change of channel geometry and profile. Some site-specific quantitative relationships exist among sediment transport rates or concentration, hydraulic parameters, and channel geometry parameters. The so-called "regime theory' or "regime equations" are empirical results based on long-term observations of stable canals in India and Pakistan. Here in we can summarizes the range of regime channel data as in Table 2.1

Table 2.1 : Regime canal data range

Variable	Range
Particle size,*d*,(mm)	0.10-0.60
Silt grading	log probability
Concentration per 10^5	0 to about 3
Suspended load (%)	0-1
Water temperature (^{O}F)	50-86
Channel sides material	Clay, smooth
Width-depth ratio, B/D	4-30
V^2/D, ft/s^2	0.5-1.5
VB/ῡ*	10^6-10^8
Water discharge, Q (ft^3/s)	1-10,000
Bed form	Dunes
D/d	1,000

* = V = Average flow velocity, D = depth, B = width, ῡ = viscosity, Q = discharge

The regime equations derived from the regime concept are mainly obtained from the regression analysis of regime channel data.Another sets of regime equations have been proposed by some investigators, (Kennedyand Lacy). Due to their investigations, applications of regime equations have limitations such as, steady bed-sediment discharges,duned sand bed with the particle size distribution,insufficient suspended load to affect the equations, steep, cohesive sides that are erodible, straightness in the plan, uniform section and slope, constant water viscosity and range of important parameters as shown in Table 2.1.

The equations are unlikely to apply if the width-depth ratio falls below about 5 or the depth below about 400 mm. The two most important effects to be considered in regime equations, arethe channel-forming discharge and sediment load or silt factors which are useful tools for stable channel designs. However, they have been subject to criticism for their lack of rational and physical rigors, applications of regime equations to conditions outside the range of data used in deriving them could lead to erroneous results.The concept of "regime" "dynamic equilibrium" and "hydraulic geometry" are similar concepts. Lacy (1929)has presented the regime equation describing the relationships among channel slope *S*, water discharge Q, silt factor f_s, for sediment transport as follows

$$S=0.0005423\,\frac{{f_s}^{5/3}}{Q^{1/6}} \qquad \textbf{(2.1)}$$

On the other hand Leopold and Maddockprovided hydraulic geometry relationships as,

$$W= aQ^{b} \qquad \textbf{(2.2)}$$

$$D= cQ^{f} \qquad \textbf{(2.3)}$$

$$V= kQ^{m} \qquad \textbf{(2.4)}$$

where W = channel width, D = channel depth, V = average flow velocity, Q = water discharge, and a, *b*, c, *j k*, *m* = site-specific constants. Furthermore, Yang, et al. applied the unit stream power theory for sediment transport,, and the hydraulic geometry relationships shown in equations (2.2) through (2.4) to derive the relationship between Q and S as,

$$S=iQ^{j} \qquad \textbf{(2.5)}$$

with constant i, j.The theoretically derived j value is $\frac{-2}{11}$, which is very close to the empirical value of $\frac{-1}{6}$ shown in equation (2.1).

2.3 Regression Approach

As we know, sediment transport is a complex phenomenon that no single hydraulic parameter or combination of parameters can be found to describe sediment transport rate under all conditions. Instead of trying to find a dominant variable that can determine the rate of sediment transport, many researchers recommended the use of regressions based equations with the laboratory and field data. The parameters used in these regression equations may or may not have any physical meaning relating to the mechanics of sediment transport. For instance, Shen and Hung(1972)proposed the following regression equation based on 587 sets of laboratory data for the sand size,

$$\log C_t = -107{,}404.45938164 + 324{,}214.74734085Y - 326{,}309.58908739Y^2 + 109{,}503.87232539Y^3 \quad \textbf{(2.6)}$$

Where $Y = (VS^{0.57}/\omega^{0.32})^{0.00750189}$; C_t = total sediment concentration in ppm by weight, and ω= average fall velocity of sediment particles.

Theyran a sensitivity analysis on the importance of different variables. The dimensionally non-homogeneous parameters are used and the lack of ability to reflect the effect of depth change limits the application of equation (2.6) in the laboratory flumes and small rivers with sand size particles.

Karim and Kennedy (1990*)* used nonlinear, multiple-regression analyses to derive relations between flow velocity, sediment discharge, bed-form geometry, and friction factor of alluvial rivers.They found the relationships between sediment discharge and velocity as general forms which shown in equations 2.7 and 2.8 as

$$\log\frac{q_s}{(1.65gd_{50}^3)^{1/2}} = A_0 + A_{ijk}\sum_i\sum_j\sum_k \log X_i \log X_j \log X_k \quad \textbf{(2.7)}$$

$$\log\frac{q_s}{(1.65gd_{50}^3)^{1/2}} = B_0 + B_{pqr}\sum_p\sum_q\sum_r \log X_p \log X_q \log X_r \quad \textbf{(2.8)}$$

Where q_s= volumetric total sediment discharge per unit width, g = gravitational acceleration, d_{50}= median bed-material particle diameter, V= mean velocity, A_o, A_{ij}

$_k$, B_o, and $B_{p\,q\,r}$= constants determined from regression analyses, and X_i, X_j, X_k, X_p, X_q, and X_r are nondimensional independent variables.

If the equation is applied to conditions similar to those from where the equation was derived a regression equation may give fairly accurate results for engineering purposes. Application of a regression equation outside the range of data used for deriving the regression equation should be carried out with caution. In general, regression equations without a theoretical basis and without using dimensionless parameters should not be used for predicting sediment transport rate or concentration in natural rivers.

2.4 Probabilistic Approach

Einstein (1950) made sediment transport studies from the probabilistic approach point of view. He assumed that the beginning and easing of sediment motion can be expressed in terms of probability and that the movement of bedload is a series of steps followed by rest periods. In spite of the sophisticated theories used, the Einstein bedload transport function is not a popular one for engineering applications. The approach is based on the mode of transport, total sediment load consisting of bedload and suspended load. Also we can derive total load into measured and unmeasured load. The original Einstein function has been modified by others for the estimation of unmeasured load. However, the "modified Einstein method" is not a predictive function. The method can be used to estimate bedload or unmeasured load based on measured suspended load for the estimation of total load or total bed-material load.

One of the most commonly used modified Einstein methods for the computation of total bed-material load isThe method proposed by Colby and Hembree.

2.5 Deterministic Approach

A deterministic approach assumes the existence of one-to-one relationship between independent and dependent variables. Conventional, dominant and independent variables used in sediment transport studies are water discharge, average flow velocity, shear stress, and energy or water surface slope. The use of stream power and unit stream power have gained increasing acceptance recently as important parameters for the determination of sediment transport (ST) rate or concentration.

Other independent parameters are sediment particle diameter, water temperature or kinematic viscosity as in Table2.1. The accuracy of a deterministic (ST) formula depends on the generality and validity of the assumption of whether a unique relationship between dependent and independent variables exists. Deterministic ST formulas can be expressed by one of the following expresssions (Yang 1983).

$$q_s = A_1(Q - Q_C)^{B_1} \quad \textbf{(2.9)}$$

$$q_s = A_2(V - V_C)^{B_2} \quad \textbf{(2.10)}$$

$$q_s = A_3(S - S_C)^{B_3} \quad \textbf{(2.11)}$$

$$q_s = A_4(\tau - \tau_C)^{B_4} \quad \textbf{(2.12)}$$

$$q_s = A_5(\tau V - \tau V_C)^{B_5} \quad \textbf{(2.13)}$$

$$q_s = A_6(VS - VS_C)^{B_6} \quad \textbf{(2.14)}$$

Figure 2.1(a) shows the relationship between the total sediment discharge and water discharge. For a given value of Q, on the horizontal axis two different values of q can be obtained on the vertical axis. Furthermore, Gilbert's data indicate that no correlation exists at all between water and sediment discharges. Apparently, different (given) sediment discharges can be transported by the same (different) water discharges.The same sets of data in Figure 2.1(a) are plotted in Figure 2.1(b) to show the relationship between total sediment discharge and average velocity, where qincreases steadily with increasing V, and it is apparent that for approximately the same value of V, the value of q, can differ considerable, owing to the steepness of the curve. Some of Gilbert's data also indicate that the correlation between qand varies very weak. Figure 2.1(c) indicates that different amounts of total sediment discharges can be obtained at the same slope, and different slopes can also produce the same sediment discharge.However, Figure 2.1(d) shows that a fairly well-defined correlation exists between total sediment discharge and shear stress when total sediment discharge is in the middle range of the curve. For either higher or lower sediment discharge, the curve becomes vertical, which means that for the same shear stress, numerous values of sediment discharge can be obtained.On the other hand, it is apparent from Figure 2-1(a-d) that more than one value of total sediment discharge can be obtained for the same value of water discharge, velocity, slope, or shear stress.If we plot the same data sets on Figure 2.1(e), with stream power as the independentvariable, the relationship between the two variables improves and futher

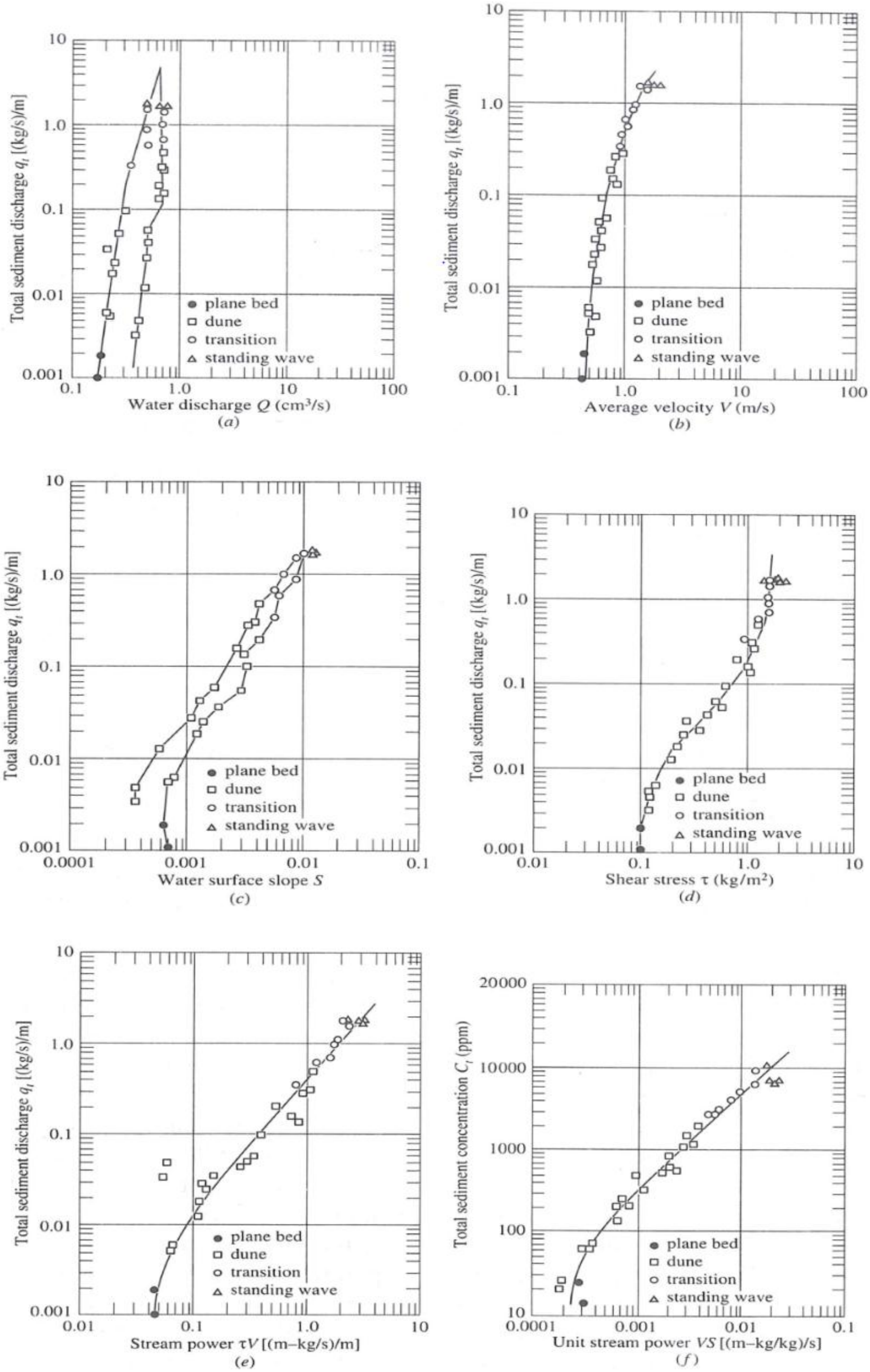

Figure 2.1: Relationships between total sediment discharge and (a) water discharge, (b) velocity, (c) slope, (d) shear stress, (c) stream power, and (f) unit stream power, for 0.93-mms and in an 8-ft wide flume (Yang, 1972, 1983).

improvementcan be made by using unit stream power as the dominant variable as in Figure 2.1(f). In spite of the presence of different bed forms, this close correlation exists such as plane bed, dune, transition, and standing wave.

It is recognizable by Gilbert's data (Figure2.2) that a family of curves exists between gravel concentration and shear stress, with water discharge, so These results shows that bedload may not be determined by using shear stress, or water discharge as the dominant variable. More than one value of gravel concentration can be obtained In each case at the given value of shear stress or water discharge.The fundamental reason for discrepancies between computed and measured results under different flow and sediment conditionsmay be the lack of well-defined strong correlation between sediment load or concentration and a dominant variable selected for the development of a sediment transport equation.

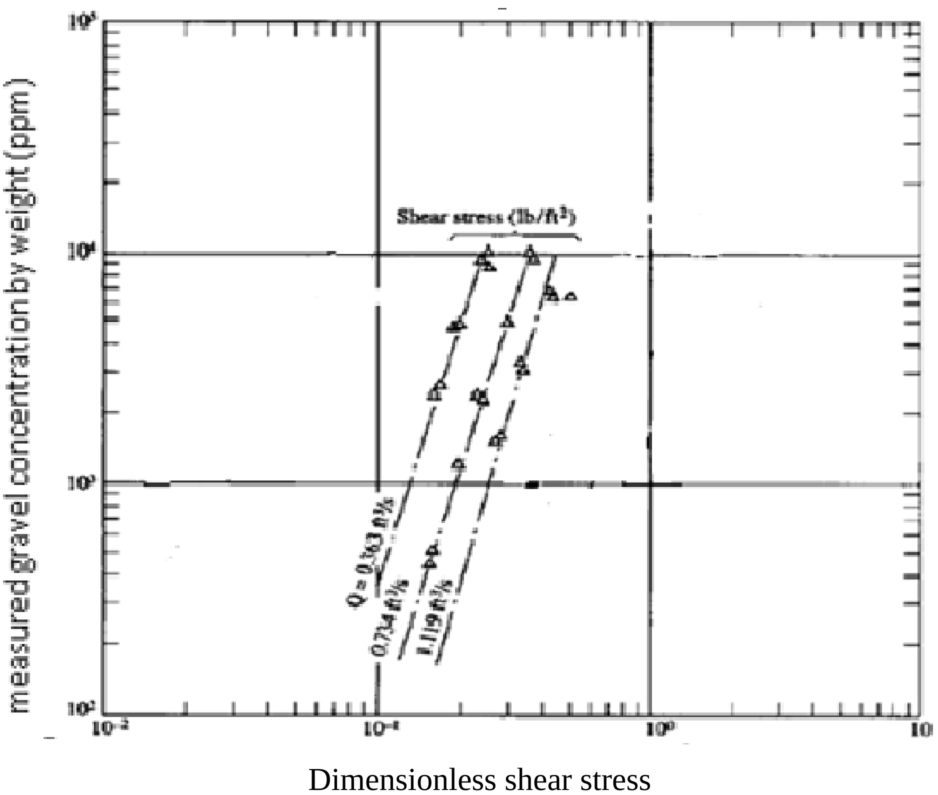

Figure2.2 : Relationship between shear stress, and 4.94mm gravel concentration modified from Yang(1983)

2.6 Stream Power Approach

Bagnold defines the stream power concept for sediment transport based on general physics. So after a while this concept was used by Engelund and Hansen and Ackers and White as the theoretical basis for developing their sediment transport functions (Yang, 2003).

2.6.1 Bagnold's Approach

The rate of energy used in transporting materials is belong to the rate of materials being transported. Bagnold illustrated stream power τVas the power per unit bed area which can be used to transport sediment. Bagnold's basic relationship is,

$$\frac{\gamma_s - \gamma}{\gamma} q_{bw} \tan \alpha = \tau V e_b \qquad \textbf{(2.15)}$$

Where γ_S and γ = specific weights of sediment and water, respectively, q_{bw} = bedload transport rate by weight per unit channel width, tan α = ratio of tangential to normal shear force, τ = shear force acting along the bed, V = average flow velocity, and e_b= efficiency coefficient.We can define the rate of work needed in transporting the suspended load as,

$$Q_s = \frac{\gamma_s - \gamma}{\gamma} q_{sw} \frac{\omega}{\bar{\upsilon}_s} \qquad \textbf{(2.16)}$$

where q_{sw}= suspended load discharge in dry weight per unit time and width, $\bar{\upsilon}$ = mean transport velocity of suspended load, and ω = fall velocity of suspended sediment.The rate of energy available for transporting the suspended load can be written as follows,

$$Q'_S = \tau V (1 - e_b) \qquad \textbf{(2.17)}$$

However, the rate of work being done should be related to the power available times the efficiency of the system, so

$$\frac{\gamma_s - \gamma}{\gamma} q_{sw} \frac{\omega}{\bar{\upsilon}_s} = \tau V (1 - e_b)\, e_S \qquad \textbf{(2.18)}$$

where e_S = suspended load transport efficiency coefficient. We can rewrite Equation (2.18) as,

$$\frac{\gamma_s - \gamma}{\gamma} q_{sw} = (1 - e_b)\, e_S \frac{\bar{\upsilon}_s}{\omega} \tau V \qquad \textbf{(2.19)}$$

Assuming $\bar{\upsilon}_s$ = V, from flume data Bagnold found $(1 - e_b)\, e_s = 0.01$. Thus, the suspended load can be computed by,

$$\frac{\gamma_s - \gamma}{\gamma} q_{sw} = 0.01 \tau V^2 / \omega \qquad \textbf{(2.20)}$$

The total load in dry weight per unit time and unit width is the sum of bedload and suspended load; that is, from Equations (2.15) and (2.20) one can write,

$$q_t = q_{bw} + q_{sw} = \frac{\gamma}{\gamma_s - \gamma} \tau V \left[\frac{e_b}{\tan a} + 0.01 \frac{V}{\omega} \right] \quad \textbf{(2.21)}$$

where q_t = total load [in (Ib/s)/ft].

2.6.2 Engelund And Hansen's Approach

Engelund and Hansenapplied Bagnold's stream power concept and the similarity principle to obtain a sediment transport function,

$$f'\phi = 0.1\theta^{5/2} \quad \textbf{(2.22)}$$

$$f' = \frac{2gSD}{V^2} \quad \textbf{(2.23)}$$

$$\phi = \frac{q_t}{\gamma_s} \left[\left(\frac{\gamma_s - \gamma}{\gamma} \right) g d^3 \right]^{-1/2} \quad \textbf{(2.24)}$$

$$\Theta = \frac{\tau}{(\gamma_s - \gamma) d} \quad \textbf{(2.25)}$$

where g = gravitational acceleration, S = energy slope, V = average flow velocity, q_t = total sediment discharge by weight per unit width, γ_S and γ = specific weights of sediment and water, respectively; d = median particle diameter, and τ = shear stress along the bed.

2.6.3 Ackers And White's Approach

Dimensional analysis applied to express mobility and sediment transport rate in terms of some dimensionless parameters by Ackers and White. Their mobility number for sediment transport is,

$$F_{gr} = U_*^n \left[gd \left(\frac{\gamma_s}{\gamma} - 1 \right) \right]^{-1/2} \left[\frac{V}{\sqrt{32} \log\left(\frac{aD}{d}\right)} \right]^{1-n} \quad \textbf{(2.26)}$$

where γ_S= shear velocity, *n* = transition exponent, depending on sediment size, *a* = coefficient in rough turbulent equation (= l0), *d* = sediment particle size, and D = water depth.They also expressed the sediment size by a dimensionless grain diameter.

$$d_{gr} = \left[\frac{g\left(\frac{\gamma_s}{\gamma - 1}\right)}{V2} \right]^{1/3} \quad \textbf{(2.27)}$$

where υ = kinematic viscosity. A general dimensionless sediment transport function can then be expressed as,

$$G_{gr} = f\,(F_{gr},\, D_{gr}) \qquad \textbf{(2.28)}$$

and

$$G_{gr} = \frac{XD}{d\frac{\gamma_s}{\gamma}}\left(\frac{U_*}{V}\right)^n \qquad \textbf{(2.29)}$$

where x = rate of sediment transport in terms of mass flow per unit mass flow rate; i.e. concentration by weight of fluid flux. We can also define the generalized dimensionless sediment transport function as follows.

$$G_{gr} = C\,\left(\frac{F_{gr}}{A} - 1\right)^m \qquad \textbf{(2.30)}$$

Ackers and White determined the values of A, C, m, and n based on best-fit curves of laboratory data with sediment size greater than 0.04 mm and Froude number less than 0.8. For the transition zone with $1 < d_{gr} \leq 60$,

$$n = 1.00 - 0.56 \log d_{gr} \qquad \textbf{(2.31)}$$

$$A = 0.23 d_{gr}^{-1/2} + 0.14 \qquad \textbf{(2.32)}$$

For coarse sediment, $d_{gr} > 60$, n= 0.00,A = 0.17, m= 1.50, c= 0.025.

Yang (2003) provided step-by-step derivations to show that Ackers and White's basic transport function that can be derived from Bagnold's stream power concept. The original Ackers and White formula is known to over-predict transport rates for fine sediments (smaller than 0.2 mm) and for relatively coarse sediments.

2.7 Power Balance Approach

A sediment transport function based on power balance between total power available and total power expenditure in a stream is derived by Pacheco-Ceballos.

$$P = P_1 + P_S + P_B + P_2 \qquad \textbf{(2.33)}$$

where P = total power available per unit channel width, P_1 = power expenditure per unit width to overcome resistance to flow, P_s = power expenditure per unit width to transport suspended load, P_b = power expenditure per unit width to transport bedload, and P_2 = powerexpenditure per unit width by minor or other causes which will not be considered here. According to Bagnold,

$$P= \tau_0 V= \rho gDSV \qquad \textbf{(2.34)}$$

where P= density of water, g= gravitational acceleration,D= average depth of flow, S= slope and V= velocity. According to Einstein and Chien,

$$P_S = (\rho_s - \rho)g\, \frac{Q_s\, \omega}{BV} \qquad \textbf{(2.35)}$$

where P_s= density of sediment, Q_s= suspended load, ω= fall velocity of sediment and B = channel width. According to the power concept and balance of acting force it is possible to write,

$$P_b = g\, Q_b \frac{\rho_s - \rho}{B} \tan\varphi \qquad \textbf{(2.36)}$$

where Q_b= bedload, and tan φ = angle of repose of sediments.If it is assumed that a certain portion of the available power is used to overcome resistance to flow, then,

$$P_1 = K_{0P} = k_0 \rho gSQ/B \qquad \textbf{(2.37)}$$

where k_0= proportionality factor, Q = water discharge and B = width. Substitution of equations (2.34) through (2.37) into equation (2.33) yields,

$$K= \frac{VQtan\varphi+\omega Qs}{QVS} \qquad \textbf{(2.38)}$$

The total sediment concentration can be expressed in the following general form:

$$C_t = \frac{KVS}{K''Vtan\varphi+(1-K'')\omega} = K'VS \qquad \textbf{(2.39)}$$

where C_t = total sediment concentration,K " = ratio between bedload and total load, K′ = parameter, , and VS = Yang's unit stream power.

3. MODERN METHODOLOGIES

3.1 General

Artificial Neural Network (ANN) and Artificial Neuro-Fuzzy Inference Systems (ANFIS) methods are described shortly in this chapter as a preliminary preparation for their applications in the next chapter. In their proper applications FFBP in ANN and Hybrid and Back Propagation (BP) in ANFIS are used for modeling the sediment yield estimation.

3.2 Artificial neural network (ANN)

ANNs are flexible mathematical structures that are capable of identifying complex non-linear relationships or patterns between input and output data sets that are capable of estimating output values based on training and learning processes separately. The main differences between the various types of ANNs are arrangement of neurons (network architecture) and the many ways to determine the weights and functions for inputs leading to neurons,training. (Caudill and Butler, 1992). Furthermore, ANNs can be coupled with feed forward and recurrent networks according to the direction of the information flow.

A feed forward network is an artificial neural methodology where connections between the units do not form a directed cycle. This is different from recurrent neural networks. The feed forward neural network was the first and arguably simplest type of ANN devised. In this network, the information moves in one direction only as forward from the input nodes through the hidden layer nodes and finally to the output nodes. There are no cycles or loops in such a network.The FFBP is the most popular ANN training method in water resources literature (Sen, 2004). The universal approximation theorem for neural networks states that every continuous function that maps intervals of real numbers to some output interval of real numbers can be approximated arbitrarily and closely by a multi-layer perceptron with just one hidden layer. This result holds only for restricted classes of activation functions, e.g. for the sigmoidal functions. The general architectural structure of ANN is presented in Figure 3.1 with input, hidden and output layers.

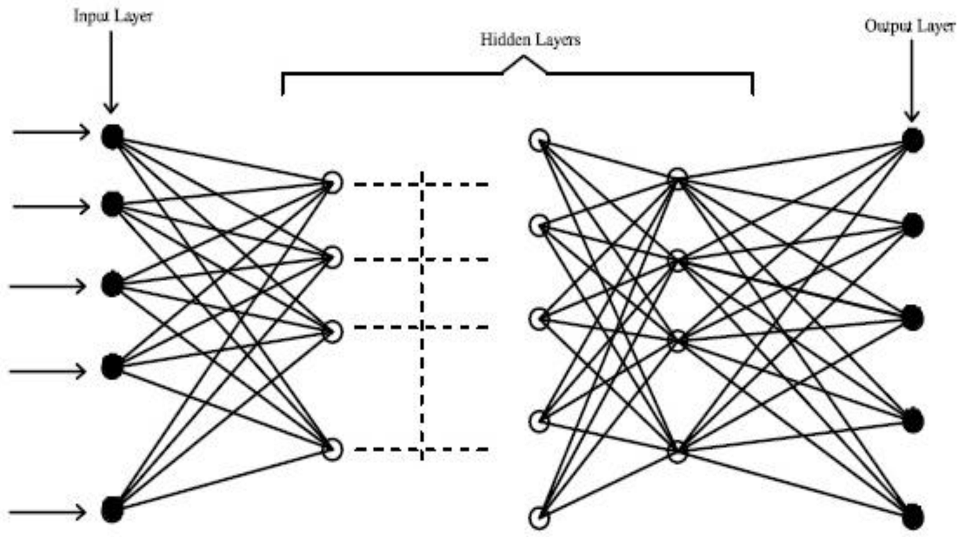

FIGURE 3.1 : A multiple hidden layer neural network

However, in this thesis the ANN architectural structure as in Figure 3.2 is employed with five input variables, 2-4 hidden layers and a single output neuron. In the same Figure considered input and output variables are given explicitly.

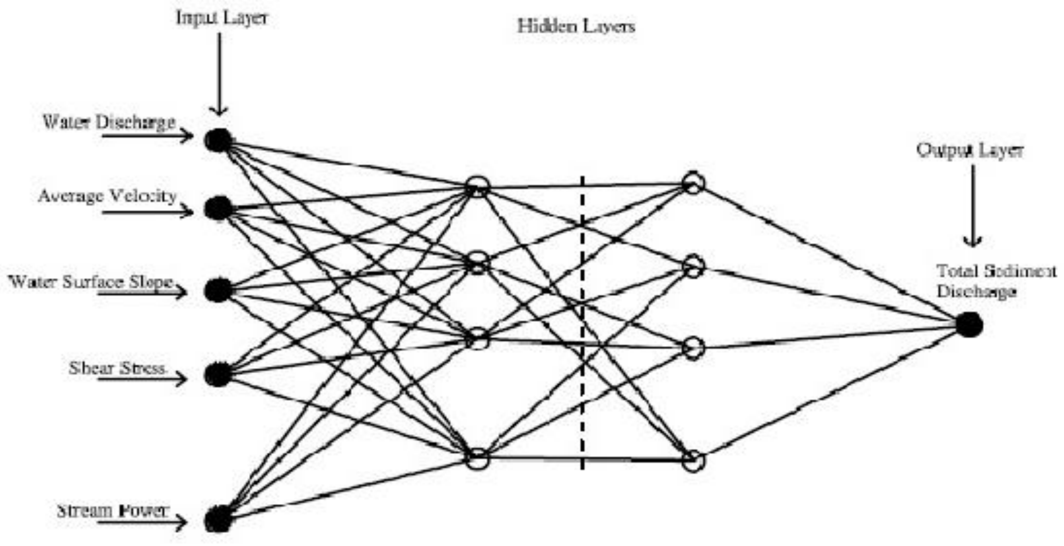

FIGURE 3.2 : Sample architectural structure of ANN

The connections between the input and the middle or hiddenlayer neurons contain weights, which are usually determinedthrough training the system. The hidden layer sums the weighted inputs and uses the transfer function to create an output value. Thetransfer function is a relationship between the internal activationlevel of the neuron (called activation function) and the outputs.The function of hidden neurons is to intervene between the external input and the network output in some useful manner. By adding one or more hidden layers, the network is enabled to extract higher order statistics. In a rather loose sense, the network acquires a global perspective despite its local connectivity due to the extra set of synaptic connections and the extra dimension of (Neural Network) NN interconnections (Haykin, 1994). The ability of hidden neurons to extract higher order statistics is particularly valuable when the size of the input layer (i.e. its number of neurons) is large. The source nodes in the input layer of the network supply respective elements of the activation pattern (input vector), which constitute the input signals (variable data) applied to the neurons (computation nodes) in the second layer (i.e. the first hidden layer). The output signals of the second layer are used as inputs to the third layer, and so on for the rest of the network. Excluding the input layer, which has one input to each of its neurons, typically, the neurons in each subsequent layer of the network have as their inputs, the output signals of all the neurons from the preceding layer only. The set of the output signals of the neurons in the output layer of the network constitutes the overall response of the network to the activation patterns applied by the source nodes in the input (first) layer.

3.3 Adaptive neuro based fuzzy inference system (ANFIS)

ANFIS was first introduced by Jang (1993). It is a network structure consisting of a number of nodes connected through directional links. Each node is characterized by a node function with fixed or adjustable parameters.A basic ANFIS is shown in Figure 3.3.ANFIS is a combination of Fuzzy Inference System (FIS) and ANNs. It is a multilayer feed-forward network, which uses neural network learning algorithms and fuzzy reasoning to map an input space to an output space.The fuzzy decision rules are implemented as membership functions (MFs) and the model learns the best fitting parameters of the MFs. A MF is a curve that defines how each point in the input space is mapped to amembership value (or degree of membership) between 0 and 1 inclusive.

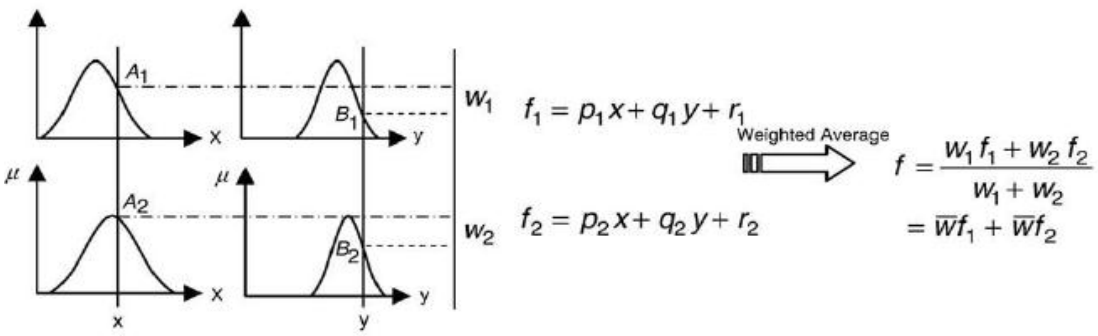

Figure 3.3 : Sugeno's fuzzy if–then rule and fuzzy reasoning mechanism

FIS was based on a set of IF-THEN rules, such that one can obtain the relation between input and output variables by these rules. Depending on the high uncertainty conditions of input and output data, the classic estimating methods, regression for instance, do not considered uncertainty of data well, and therefore the use of FIS becomes preferable as a prediction model.

Learning or training phase of a neural network is a process to determine parameter values (weightings) so as to sufficiently fit the training data. The basic learning rule is the well-known back propagation method, which seeks to minimize some measure of error, usually sum of squared differences between networks' outputs and observed outputs. Depending on the types of inference operations upon IF-THEN rules, most FISs can be classified into three types; Mamdani, Sugenoand Tsukamoto system. Although Mamdani system is the most commonly used, meanwhile, Sugeno system is more compact and computationally efficient; its output is crisp, so without time consuming and involved mathematical calculations it escapes the defuzzification operation in the Mamdani system. These make the Sugeno system by far the most popular candidate for sample-data based fuzzy modeling and it lends itself to the use of adaptive techniques. As will be explained in the next chapter the outputs in each rule base has been taken as linear functions of the input variables, which is the most frequently used approach in any ANFIS system. Detailed information about the ANFIS system can be found in a textbook by Sen (2010).

4. APPLICATIONS

4.1 Introduction

The applications of the two methodologies mentioned in the previous section needs preparation of suitable data prior to actual modeling work. It has already been mentioned in Chapter 2 that Yang (1972, 1983) various other authors' experimental data have been adopted in the model implementations. Hence, this chapter mainly focuses on application and utility of data in ANN and ANFIS methods.

4.2 Data Sources

Laboratory data collected by Guy et al. (1966) were used by Yang (1972, 1983) for sediment yield estimation by classical techniques that have already been explained in Chapter 2. Figure 2.1 has already shown the results derived by Yang analyses. This figure also shows the relationship between water discharge, velocity, slope, shear stress, stream power and unit stream power with total sediment discharge (TSD). Get Data Graph Digitizer software was used to extract the initial data. Due to the scarcity of original data and the fact that ANN and ANFIS require for more data, a number of lines parallel to the horizontal axis with the same vertical distance from each other are drawn. This procces is show in figure 4.1.

Hence, the intersections of each horizontal line with the general trend have been considered as initial data for ANN and ANFIS methods. In total 79 data sets were obtainedand transferred to EXCELL sheet conveniently. In this step, the mean of data assigned to TSDs has been obtained. These data have offered a chance in this study to compare the observed and computed ones. In order to use these data in ANN and ANFIS methods, they are classified into two groups, as testing and training stages.

For increasing the accuracy of computations, the training data set are randomly drawn and categorized into ascending order. The first 39 data set is used for training

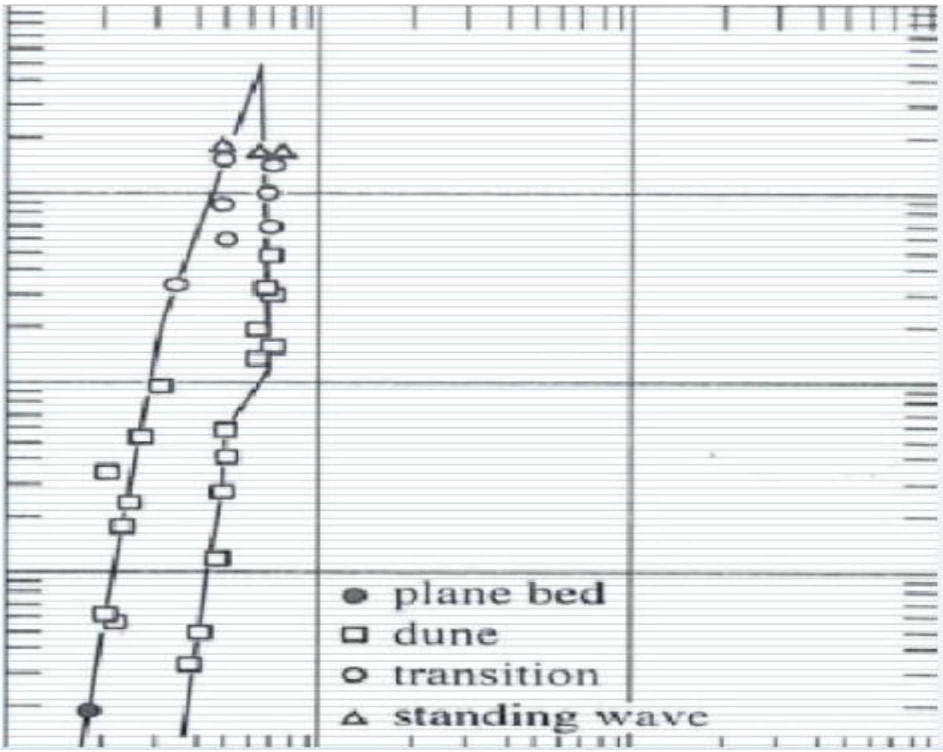

FIGURE 4.1 : The sample method of adjustments with Get data graph digitizer software

and the remaining 40 data sets are for testing. The detailed information of these date sets are given in Table 4.1-2. The values given in these tables are based on the logarithms of the data, because there are very big difference between the smallest and the biggest data value. The logarithmic transformation arranges them nicely into a common variation range.

Table 4.1 : Statistic logaritmic parameters of training data used in ANN model

Data		Variable	Average	Max	Min
Training or Calibration Data	Input Data	Water Discharge	0.282	0.495	0.175
		Velocity	0.706	1.417	0.433
		Slope	$3.15*10^{-3}$	0.0098	$6.39*10^{-4}$
		Shear Stress	0.656	1.632	0.099
		Stream power	0.503	2.407	0.046
	Output Data	Total Sediment Discharge	0.211	1.412	0.001

Table 4.2: Statistic logaritmic parameters of testing data used in ANN model

Data		Variable	Average	Max	Min
Testing or Verification Data	Input Data	Water Discharge	0.282	0.486	0.175
		Velocity	0.700	1.354	0.449
		Slope	$3.06E*10^{-3}$	0.0097	$6.43*10^{-4}$
		Shear Stress	0.642	1.623	0.099
		Stream power	0.471	2.259	0.046
	Output Data	Total Sediment Discharge	0.190	1.284	0.001

4.3 ANN Application

In this model six groups of data including five inputs (water discharge, velocity, slope, shear stress, stream powerand an output (TSD) are employed, currently (see Figure 3.2). These columns of data are available for both testing and training stages. Now, there are four groups of data sets encompassing input and output training, and at the same time input and output testing. Subsequently, in MATLAB and ANN environment the data sets should be transposed because of software requirements. Settings that are used in ANN are given in Table 4.3.

Table 4.3 : The used adjustments in ANN software

Name	Applied Changes
Network Type	FFBP
Input Data	In Train
Output Data	Out Train
Training Function	TRAINLM
Adaption Learing Function	LEARNGDM
Performance Function	MSE
Number of Layers	2-4
Number of Neurons	1-4
Transfer Function	PURELIN

Note that the number of neurons and layers are varying for different networks. With regard to the 79 data sets, the choices in this thesis for selecting number of layers and neurons are restricted.In both testing and training data, computed TSDs are obtained after this process.In order to determine the most convenient and least error solution, numerous trial and error procedures are applied by trying different alternatives and changing the number of hidden layers from two to four and the number of neurons within each hidden layers. After numerous trials and their solutions, the optimum ANN architecture is reached as in Figure 4.2.

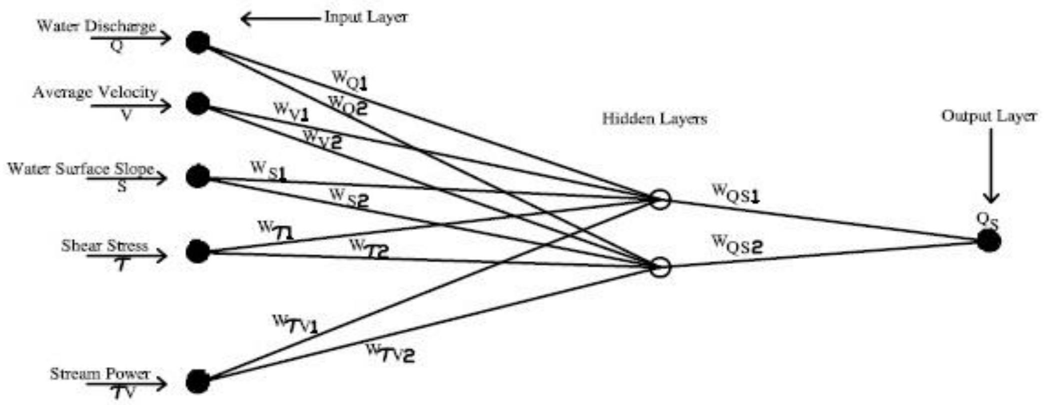

FIGURE 4.2 : The optimum used ANN architecture

The relationships between observed and computed TSDs are shown in Figures 4.3 - 4.22 in scatter plots.

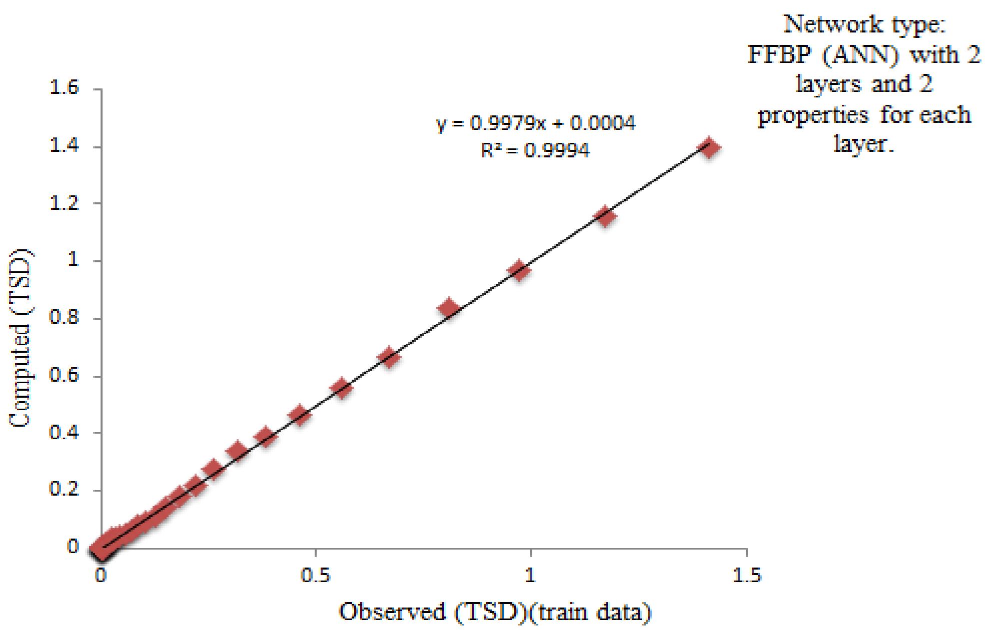

Figure 4.3: The scatter plot between observed and computed total sediment discharge of training data. (ANN 1)

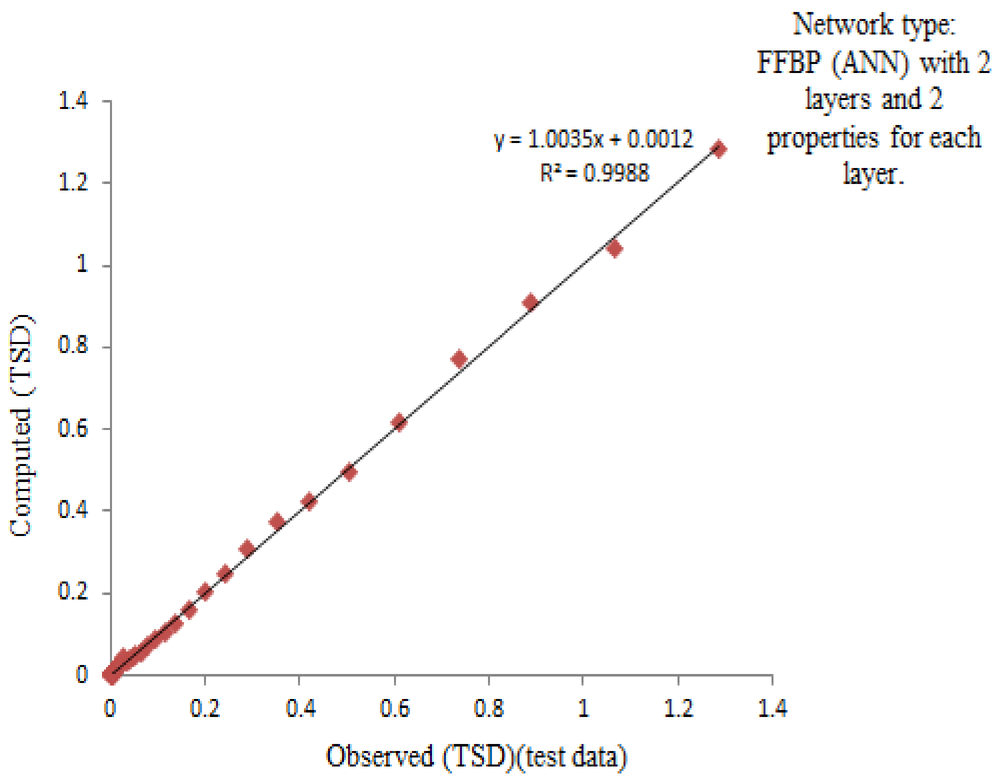

Figure 4.4 : The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 2)

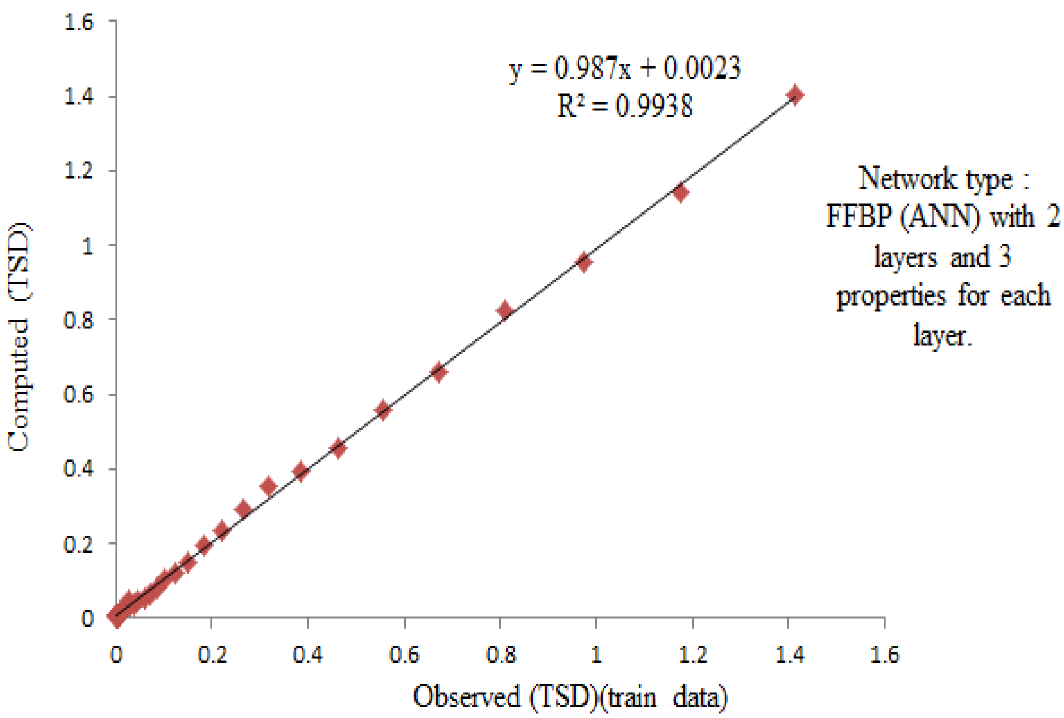

Figure 4.5: The scatter plot between observed and computed total sediment discharge of training data. (ANN 3)

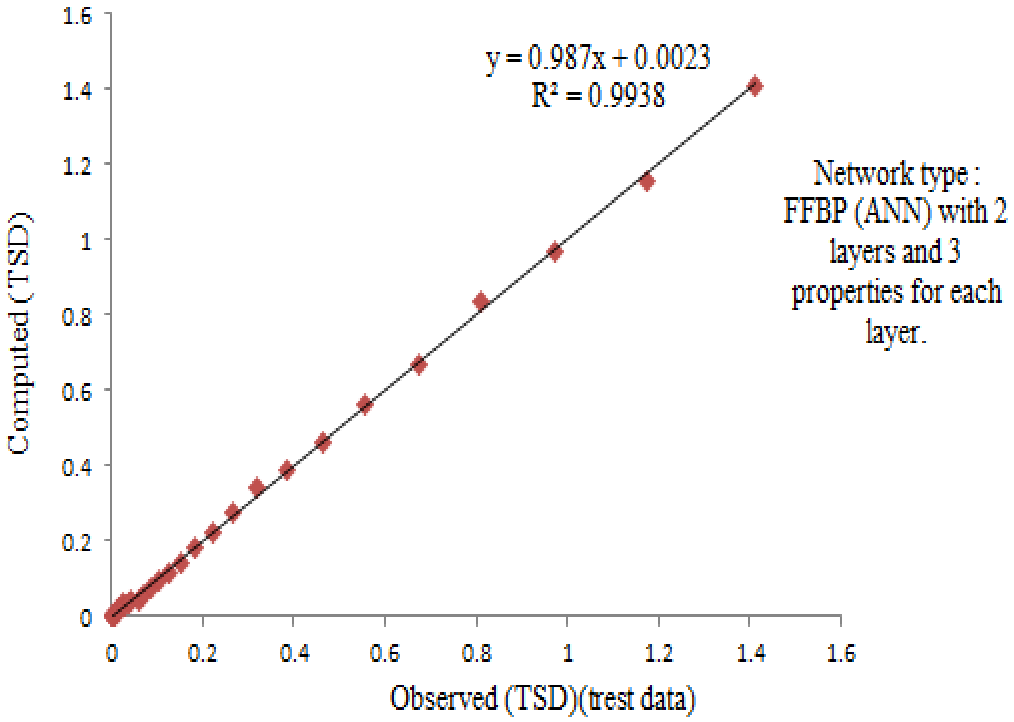

Figure 4.6: The scatter plot between observed and computed total sediment discharge of testing data. (ANN 4)

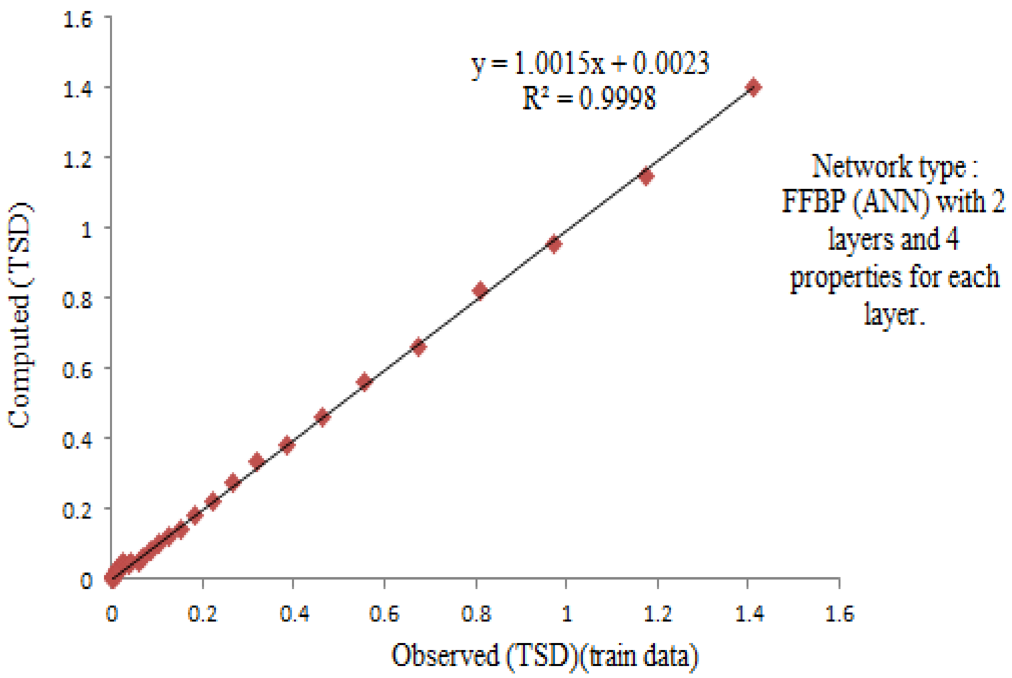

Figure 4.7 : The scatter plot between observed and computed total sediment discharge of training data. (ANN 5)

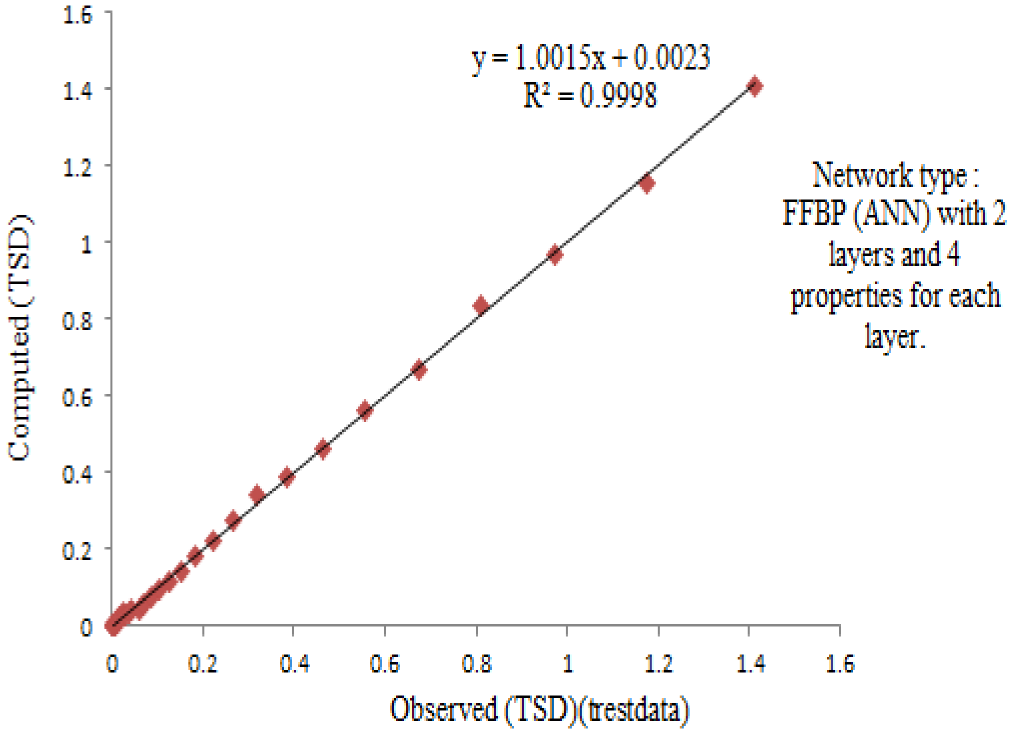

Figure 4.8: The scatter plot between observed and computed total sediment discharge of testing data. (ANN 6)

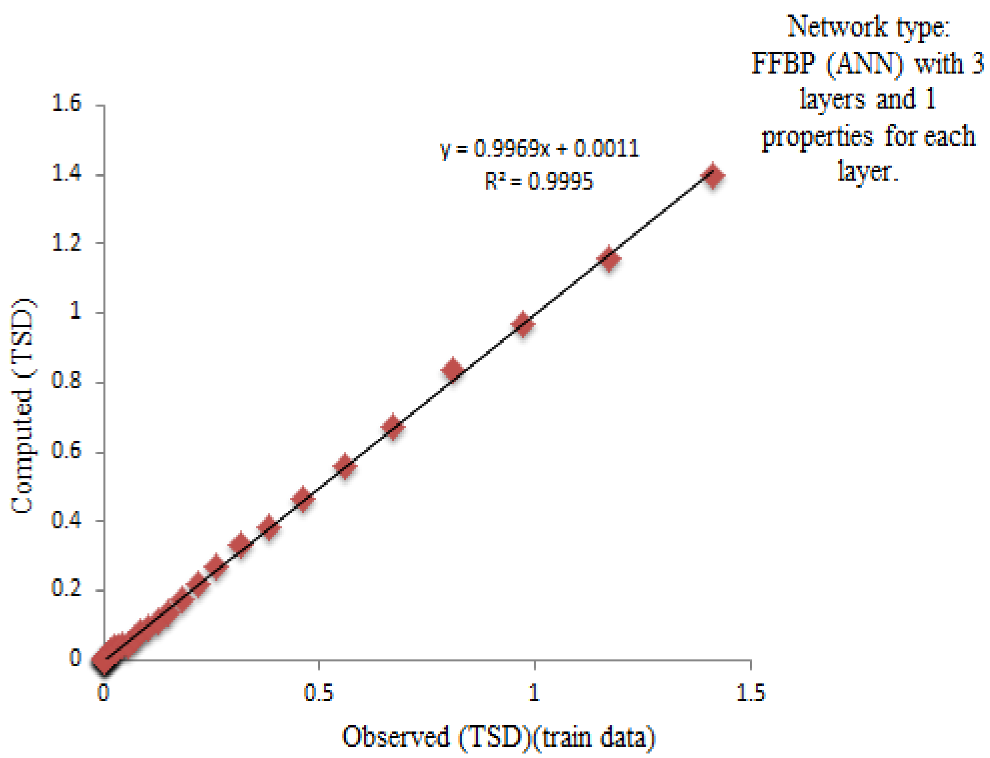

Figure 4.9: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 7)

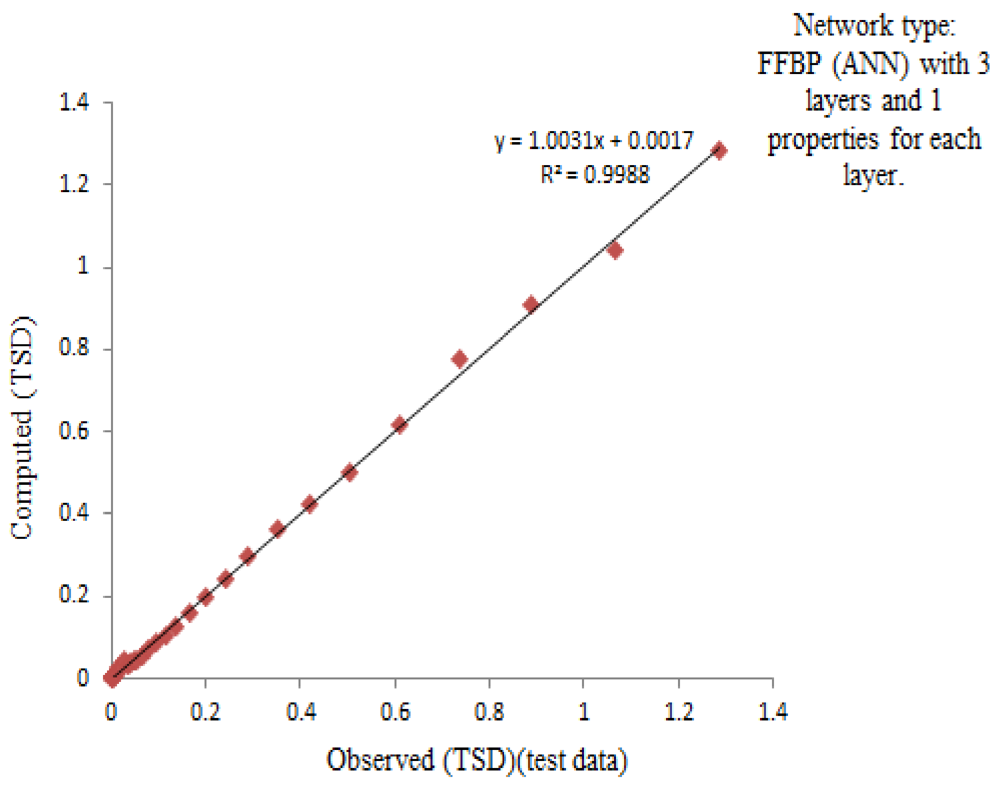

Figure 4.10 : The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 8)

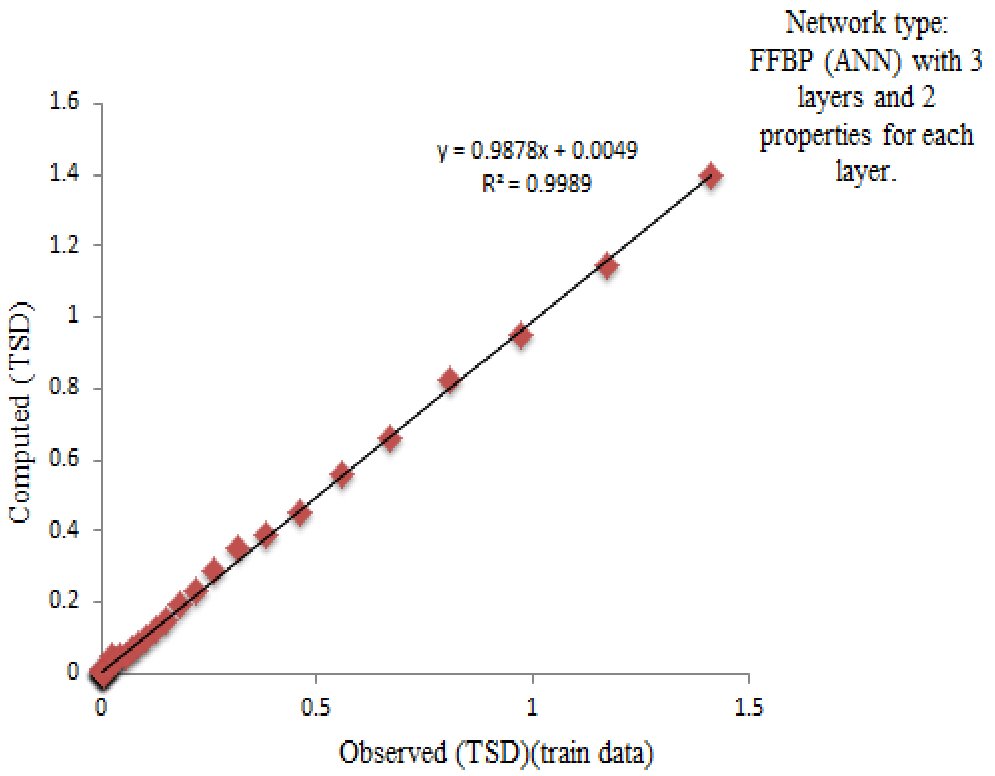

Figure 4.11: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 9)

To have comprehensive test and get the best architecture of using ANN this process is continuing with changing the number of layers and neurons in each layer.

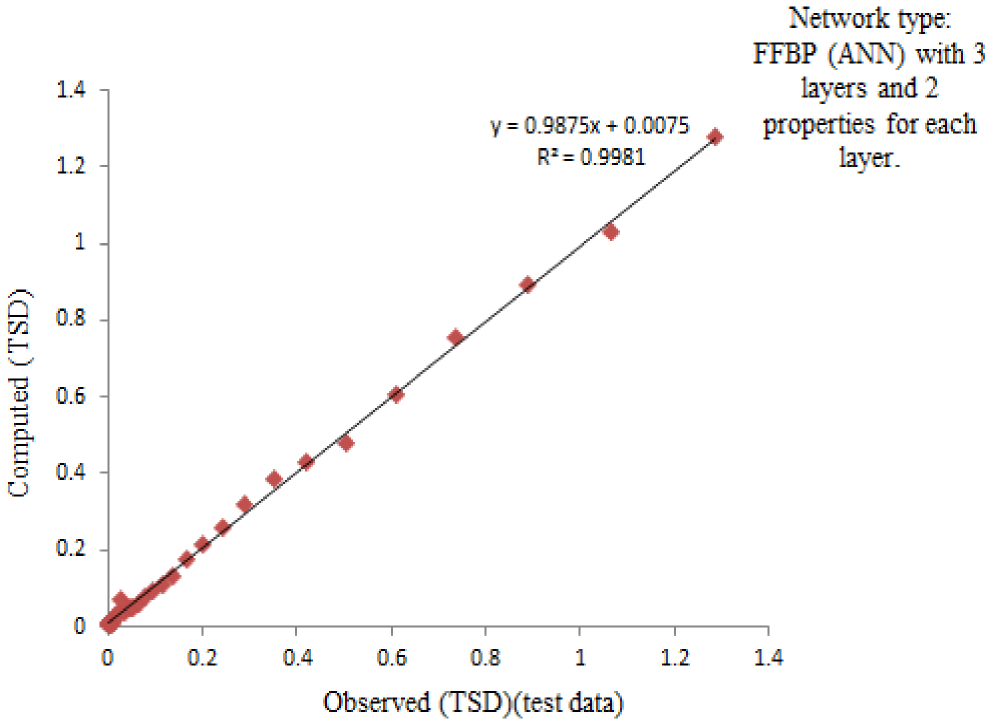

Figure 4.12: The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 10)

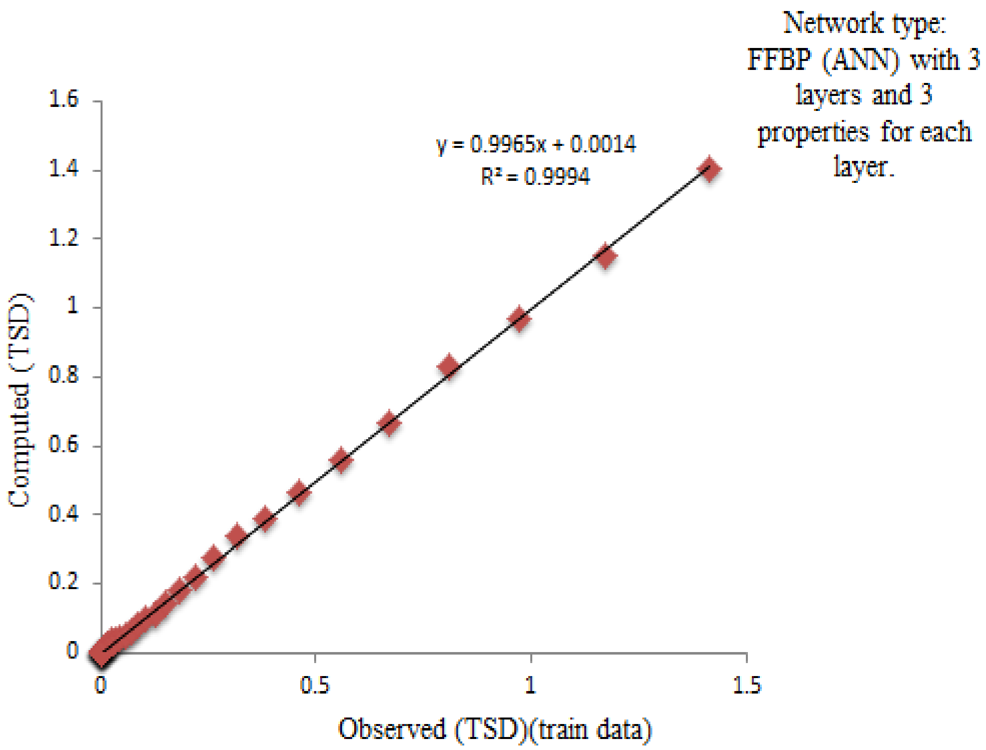

Figure 4.13: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 11)

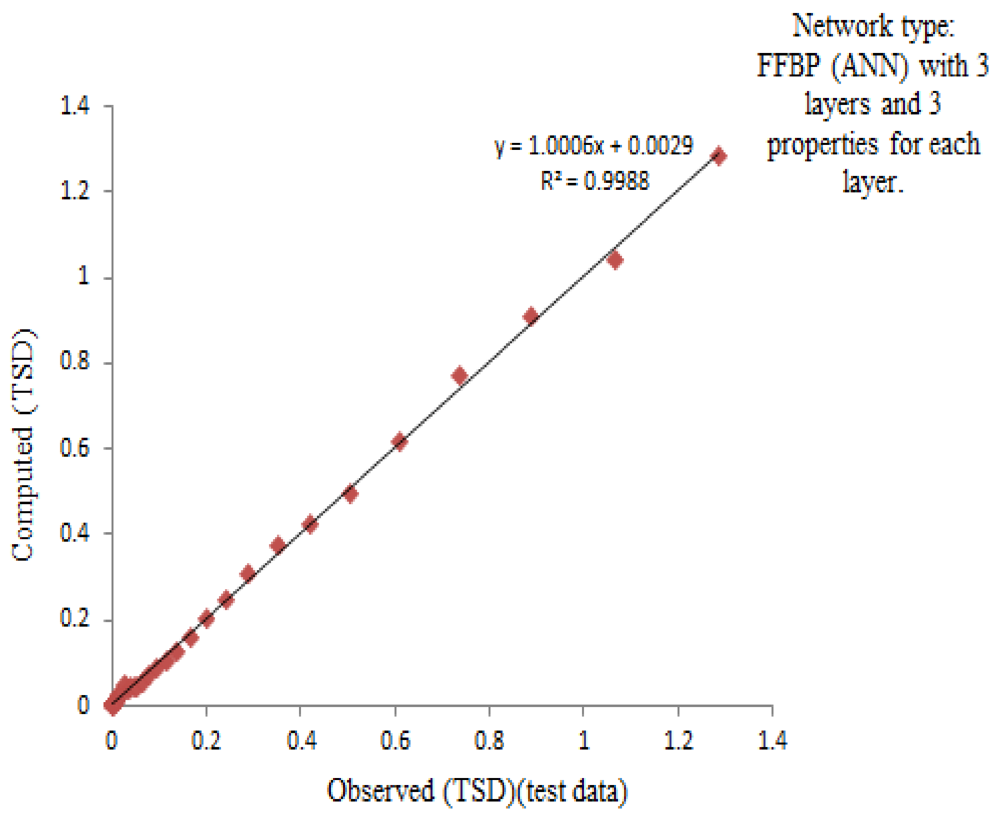

Figure 4.14: The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 12)

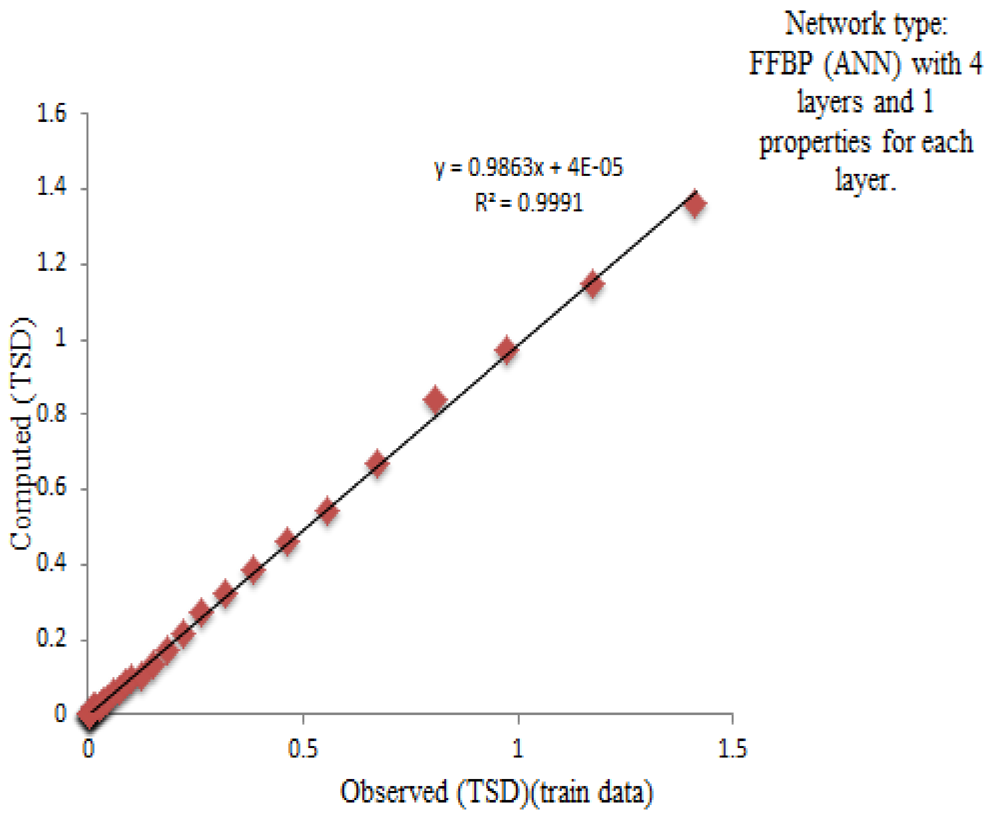

Figure 4.15: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 13)

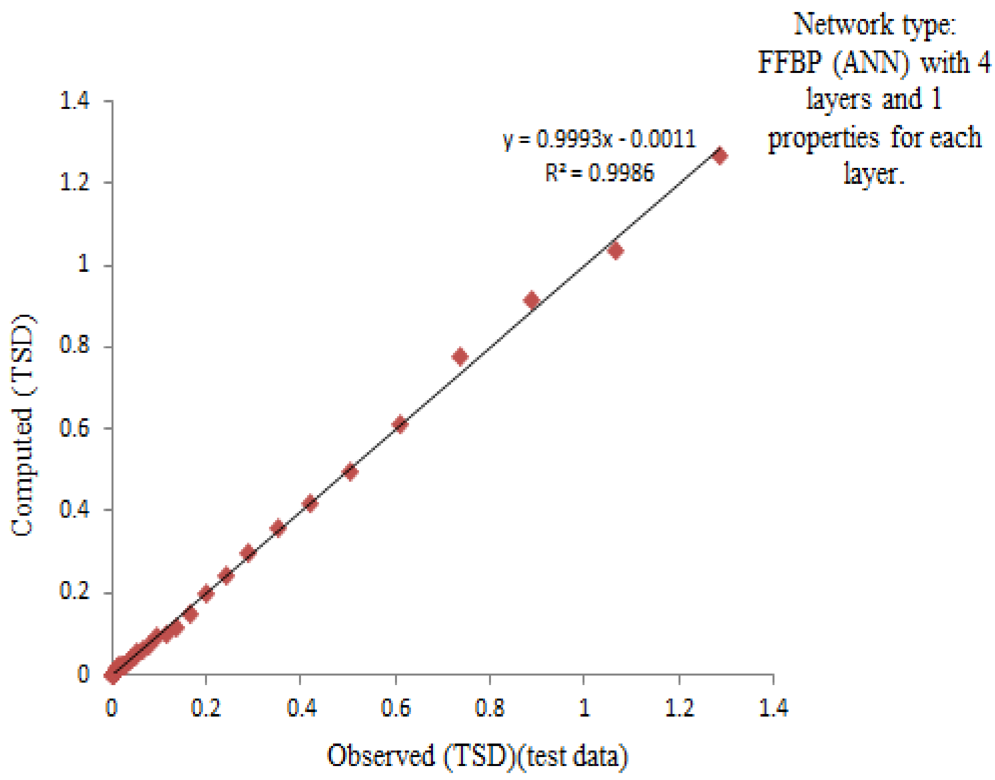

Figure 4.16: The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 14)

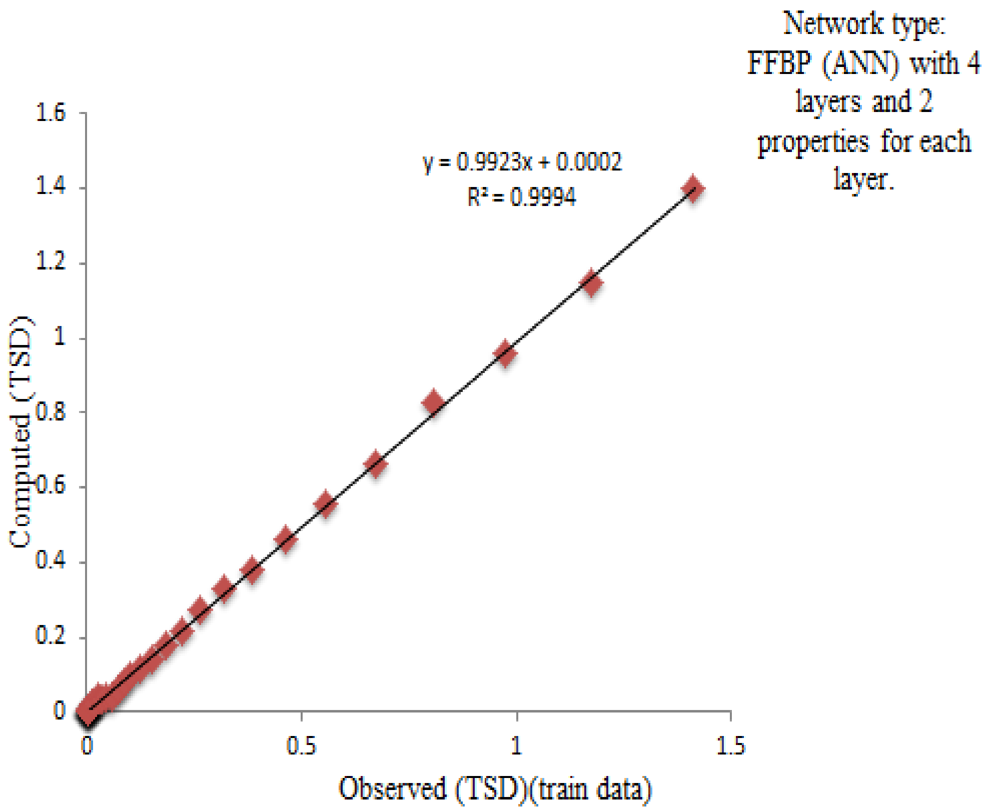

Figure 4.17: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 15)

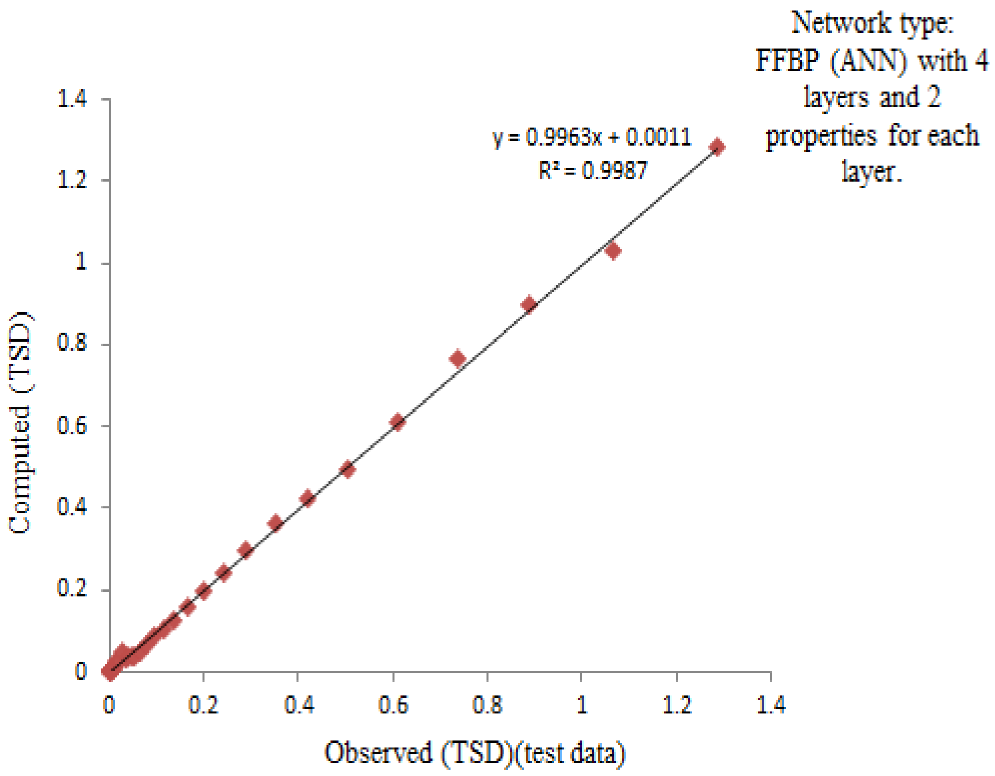

Figure 4.18: The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 16)

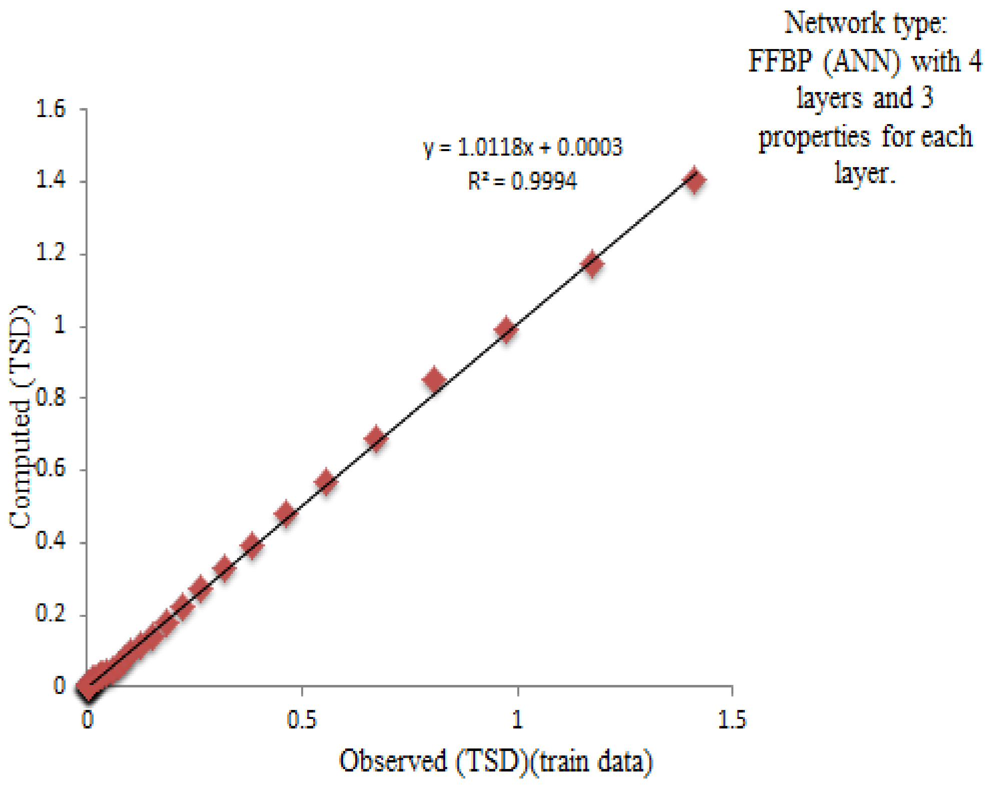

Figure 4.19: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 17)

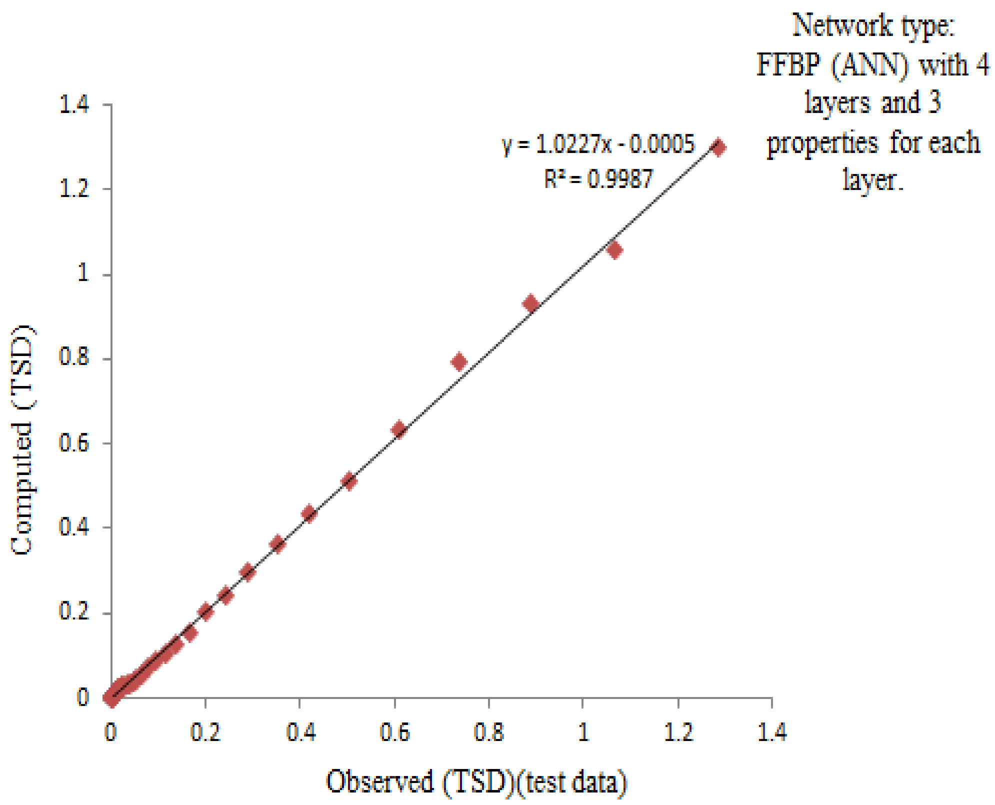

Figure 4.20: The scatter plotbetween observed and computed total sediment discharge of testing data. (ANN 18)

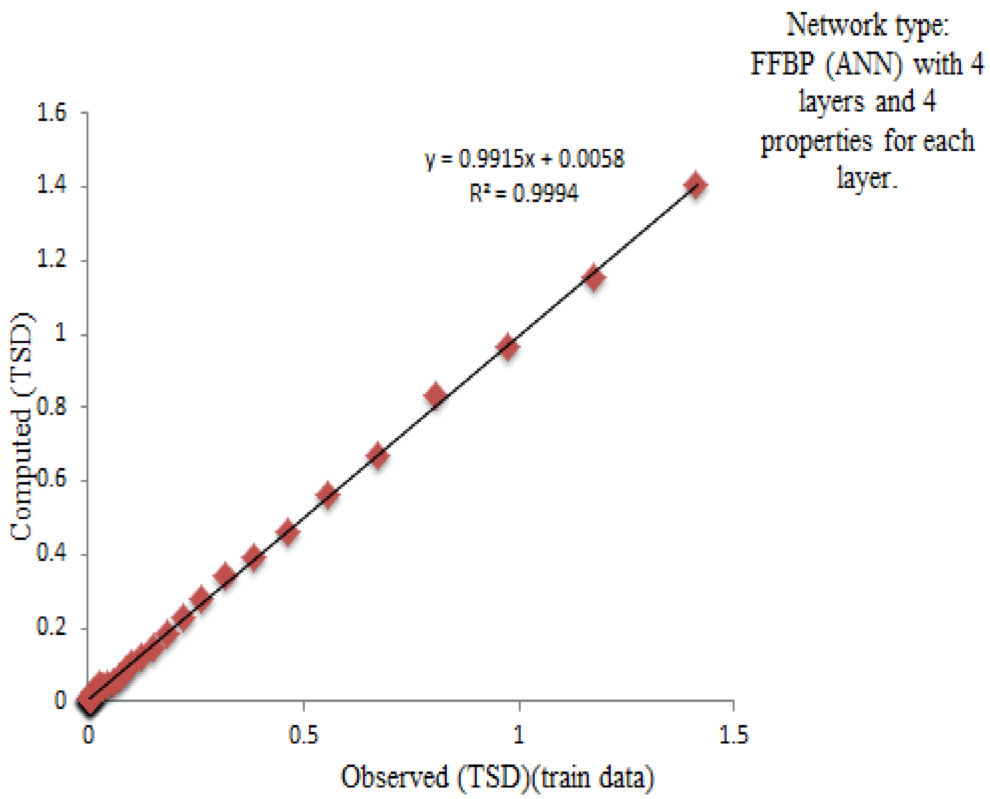

Figure 4.21: The scatter plotbetween observed and computed total sediment discharge of training data. (ANN 19)

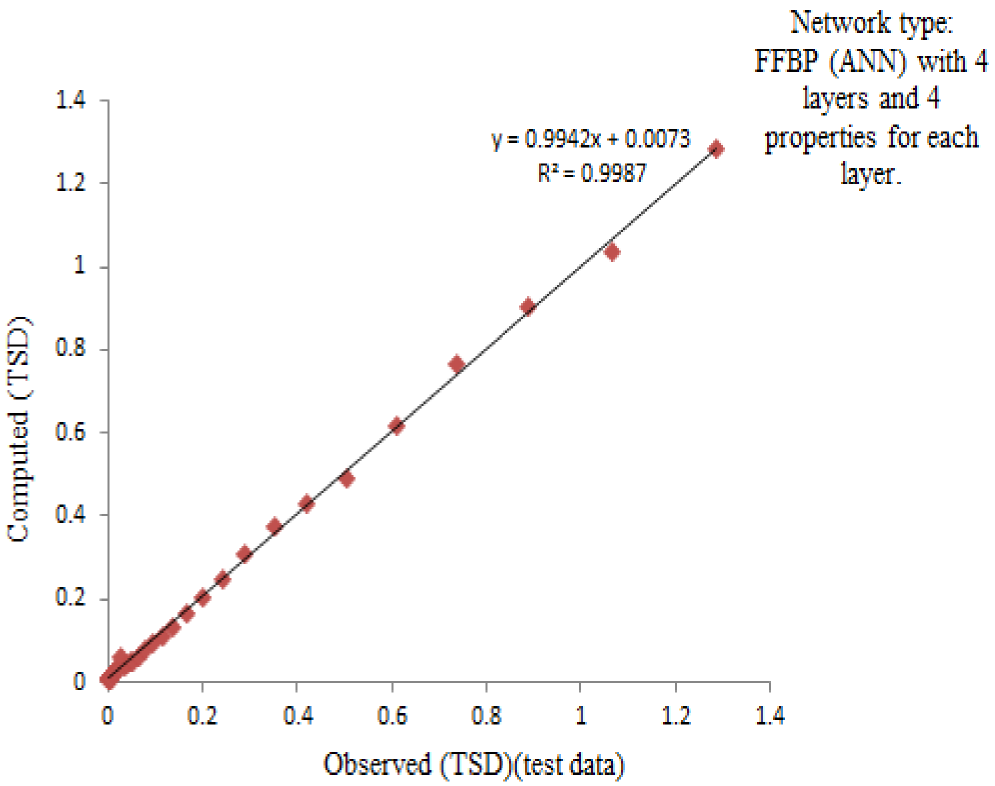

Figure 4.22: The scatter plotbetween observed and computed total sediment discharge of testing data. ANN 20)

It is obvious from these figures that the ANN application provides scatter of observed and predicted total sediment yield values along 45^{o} line, which provides the convenience of this approach visually. Almost all the points lie on this straight line, which indicates the validity of the ANN.

TABLE 4.4 : The final architectures, RMSE and R^2 statistics of the ANN models for training phase.

ANN name	Number of hidden layers	Number of neurons in each layer	RMSE	R^2
#1	2	2	0.017	0.99
#2	2	3	0.020	0.99
#3	2	4	0.023	0.99
#4	3	1	0.016	0.99
#5	3	2	0.023	0.99
#6	3	3	0.023	0.99
#7	3	4	0.016	0.99
#8	4	1	0.035	0.99
#9	4	2	0.018	0.99
#10	4	3	0.020	0.99
#11	4	4	0.017	0.99

On the other hand, the objective numerical validation has been given in Tables 4.3 and 4.4 for various number of hidden layer and neurons in each layer on the basis of Root Mean Square Error (RMSE) and the coefficient of determination (R^2). Very low values of RMSEs and high values (close to 1) of R^2 indicate the numerical verification that the ANN is capable to model total sediment yield sufficiently.

TABLE 4.5 : The final architectures, RMSE and R^2 statistics of the ANN models for testing phase.

ANN name	Number of hidden layers	Number of neurons in each layer	RMSE	R^2
#1	2	2	0.021	0.99
#2	2	3	0.023	0.99
#3	2	4	0.022	0.99
#4	3	1	0.022	0.99
#5	3	2	0.025	0.99
#6	3	3	0.023	0.99
#7	3	4	0.021	0.99
#8	4	1	0.026	0.99
#9	4	2	0.022	0.99
#10	4	3	0.025	0.99
#11	4	4	0.022	0.99

4.4 ANFIS Application

Data sets that were in hand are exported from EXCEL to ANFIS for two classifications, training and testing stages similar to the ANN application. In this thesis, the data sets related to training and testing are separately exported. As for processing the data in ANFIS, the Sugeno system method is used. Five data sets for input and one data set are considered for output data, respectively, in both training and testing applications. A sample setting that is used in ANFIS is given in Table 4.5 with numbers of membership functions (MF) and their types as Gauss and Gauss2 for input variables for fuzzification. The outputs are considered in two different forms as constants and as linear function of the input variables.

The application of the ANFIS procedure through Matlab software provides results automatically according to the arrangements in Table 4.5. Here again, similar scatter diagrams between the observed and computed (predicted) total sediment discharge values are given in Figures 4.23- 4.38. Likewise to ANN case again the data sets are entered into the model on logarithmic scale. Visual inspection of each one of these

Table 4.6: The used adjustments in ANFIS software

Name	Applied Changes
Train FIS optimisation method	Hybrid , Back Propagation
Number of MFs	2 2 2 2 2
Input MF type	Gauss, Gauss 2
Output MF type	Constant, Linear

Figures shows obviously that in each case the agreement between the observed and modeled outputs is very satisfactory as the model convenience.

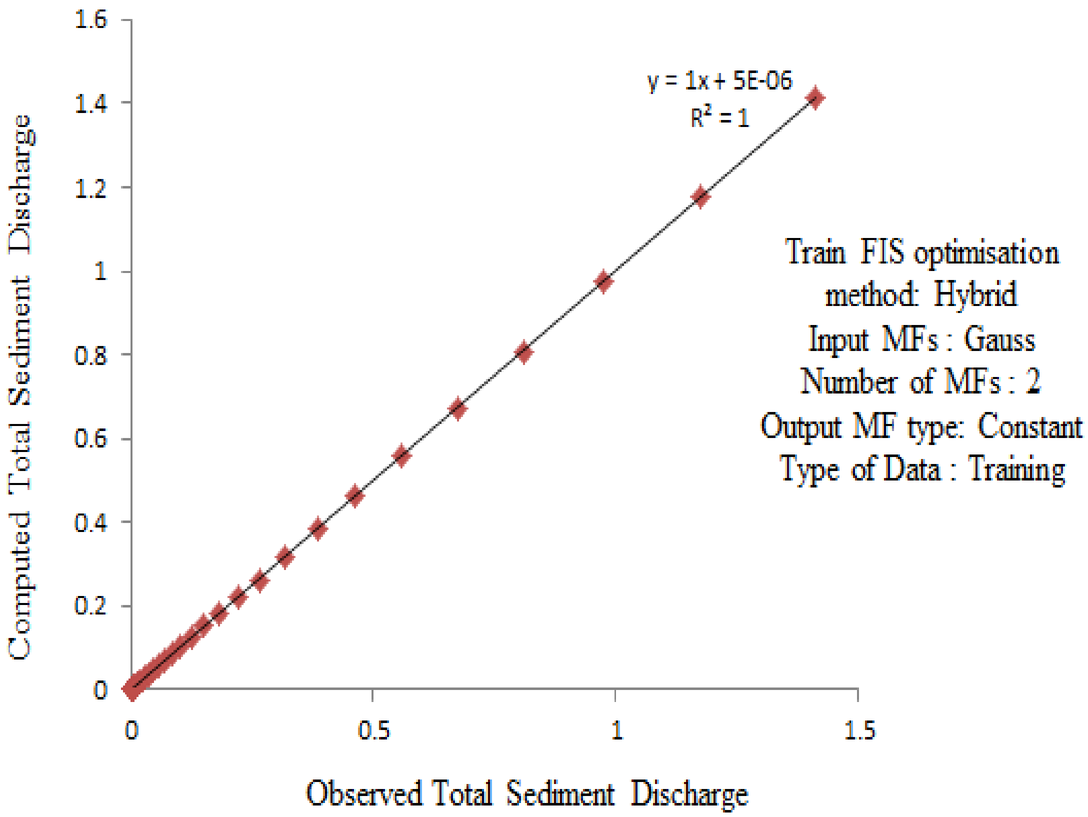

Figure 4.23: The scatter plotbetween observed and computed total sediment discharge data. (ANFIS 1)

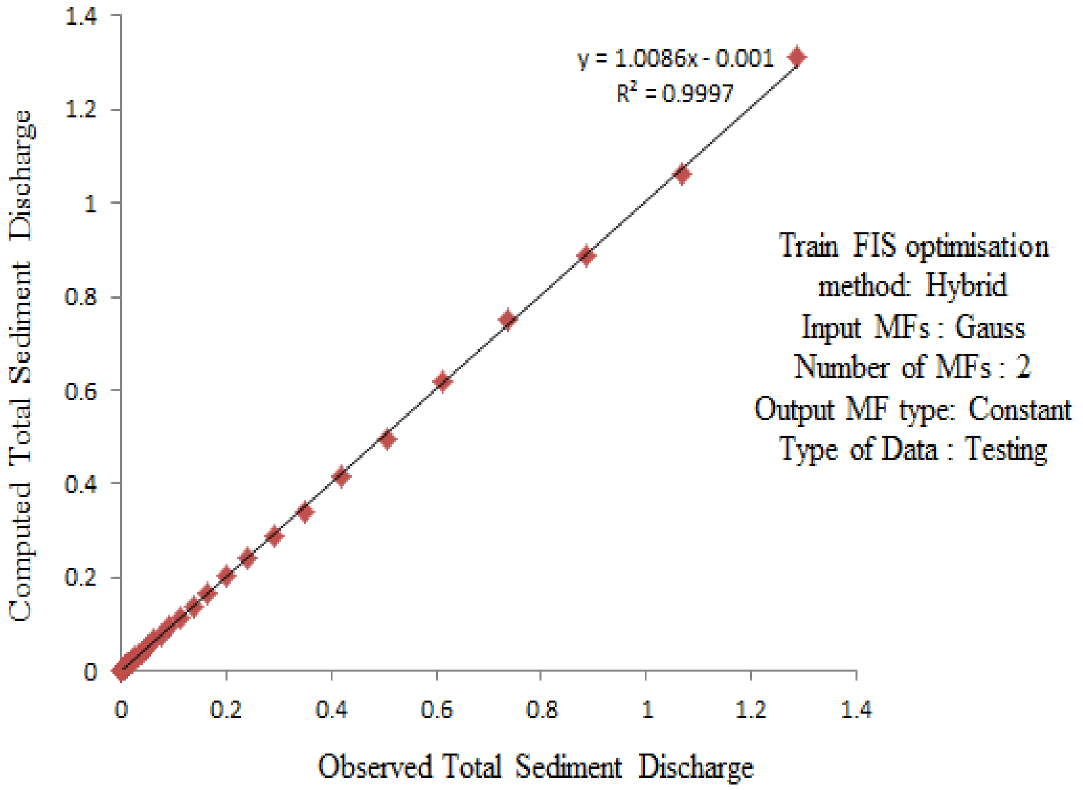

Figure 4.24: The scatter plotbetween observed and computed total sediment discharge data. (ANFIS 2)

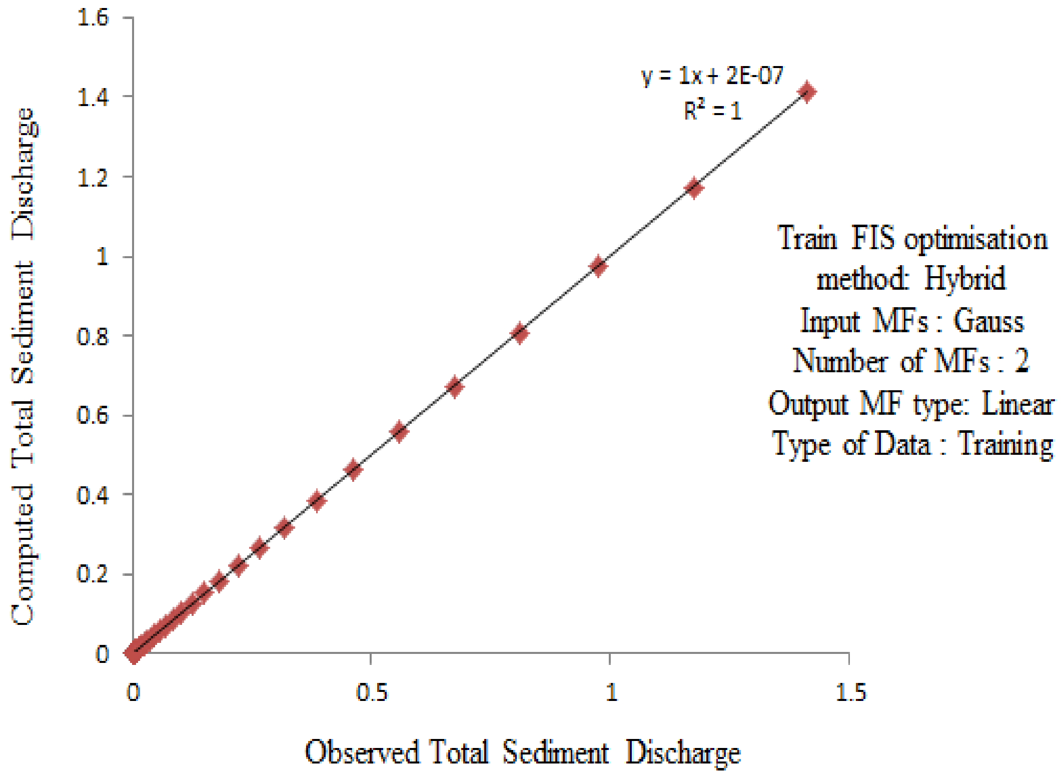

Figure 4.25: The scatter plotbetween observed and computed total sediment discharge data. (ANFIS 3)

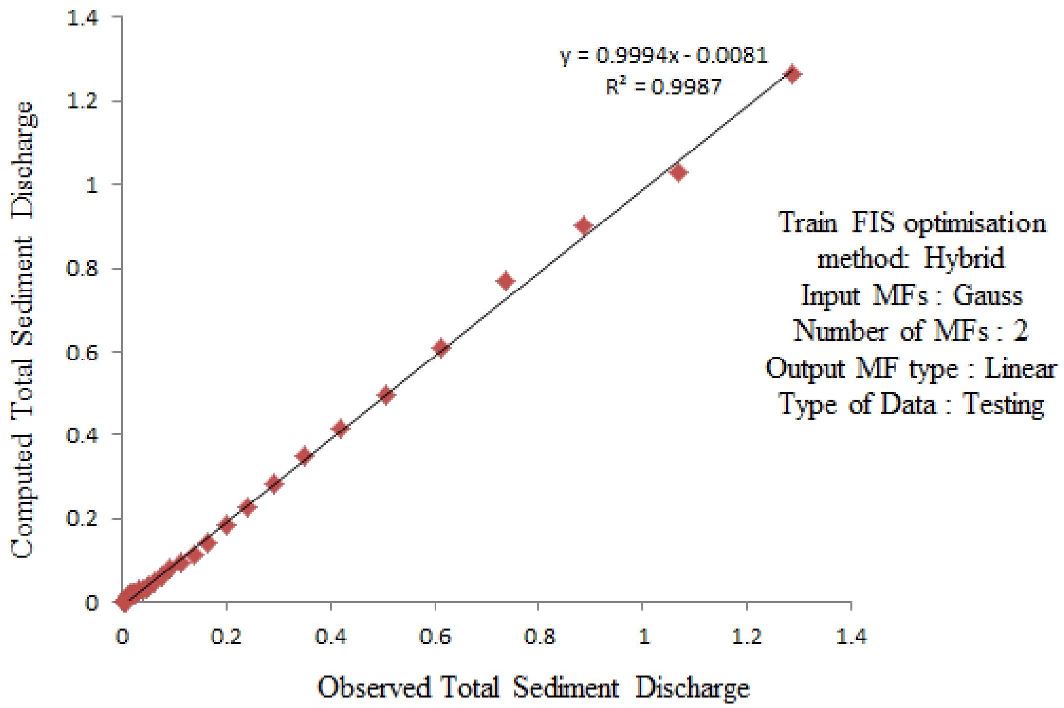

Figure 4.26: The scatter plotbetween observed and computed total sediment dischargedata. (ANFIS 4)

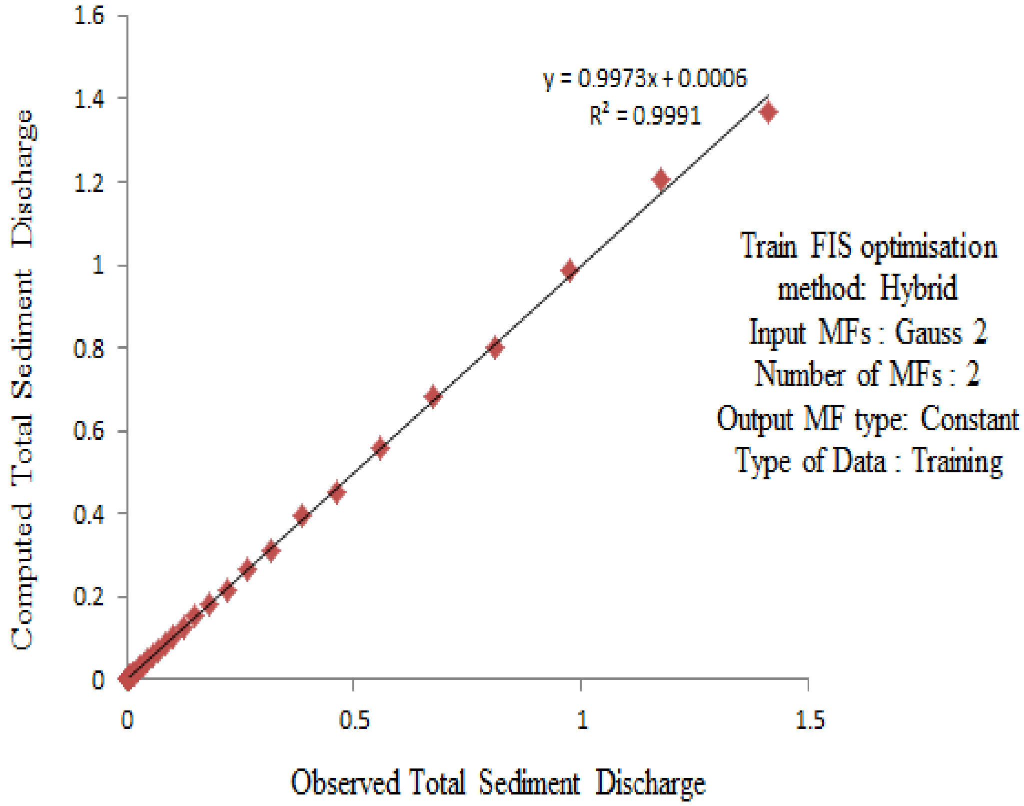

Figure 4.27: The scatter plot between observed and computed total sediment discharge data. (ANFIS 5)

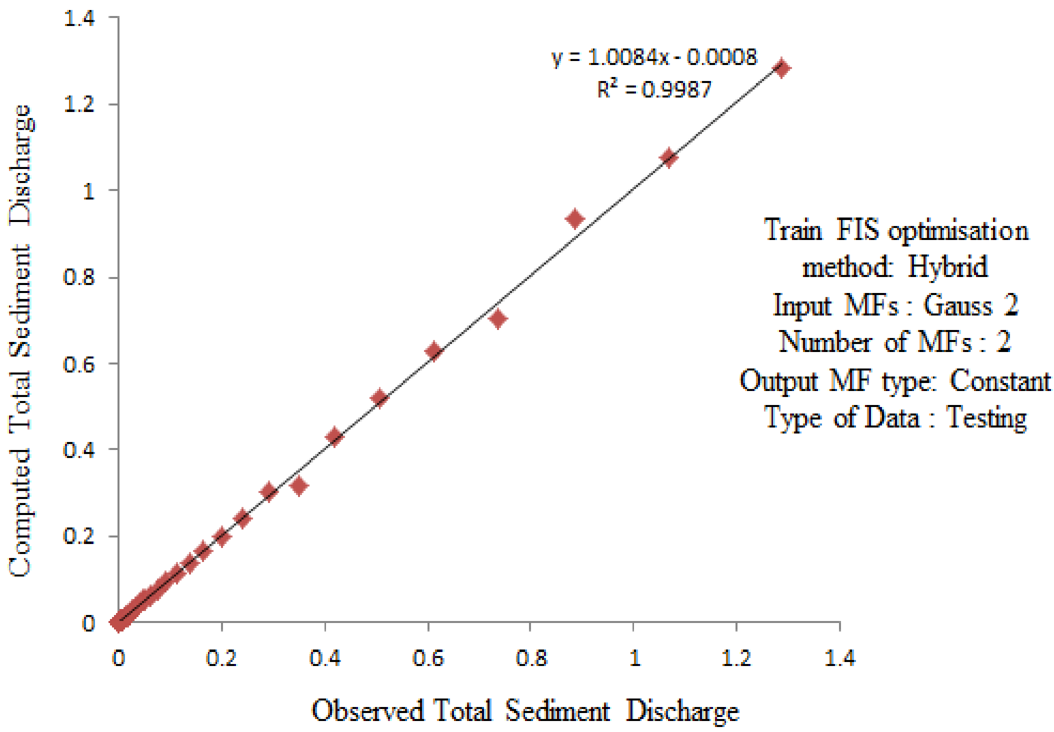

Figure 4.28: The scatter plot between observed and computed total sediment discharge data. (ANFIS 6)

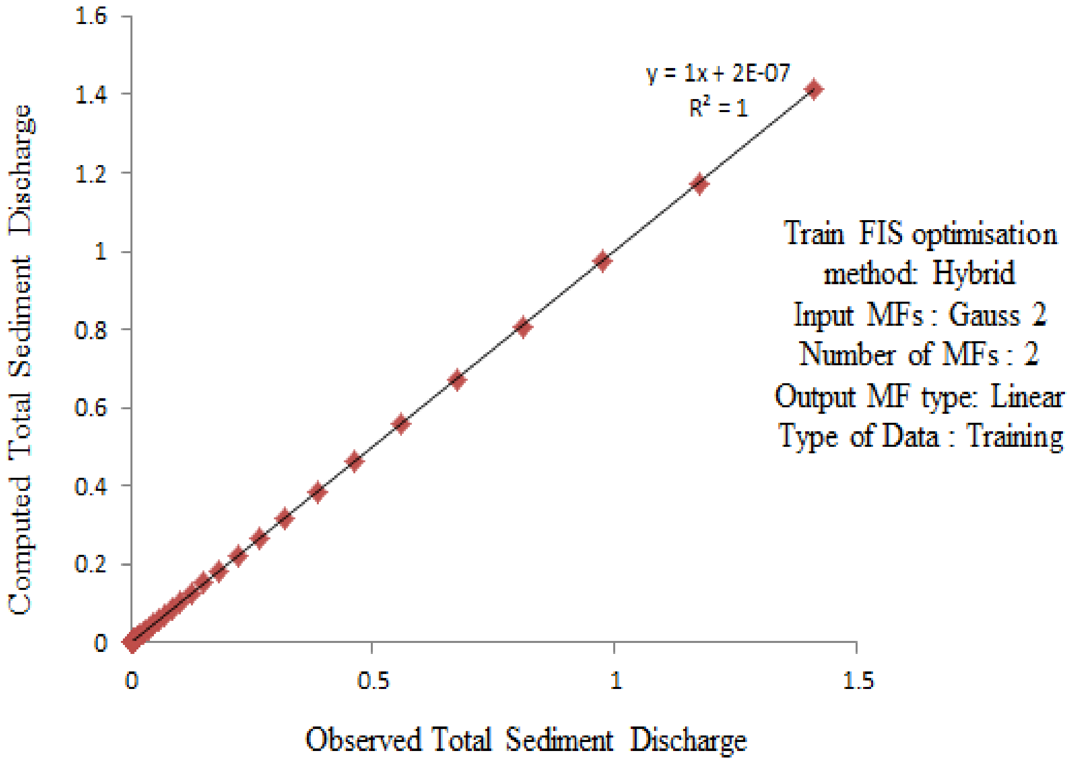

Figure 4.29 : The scatter plot between observed and computed total sediment discharge data.(ANFIS 7)

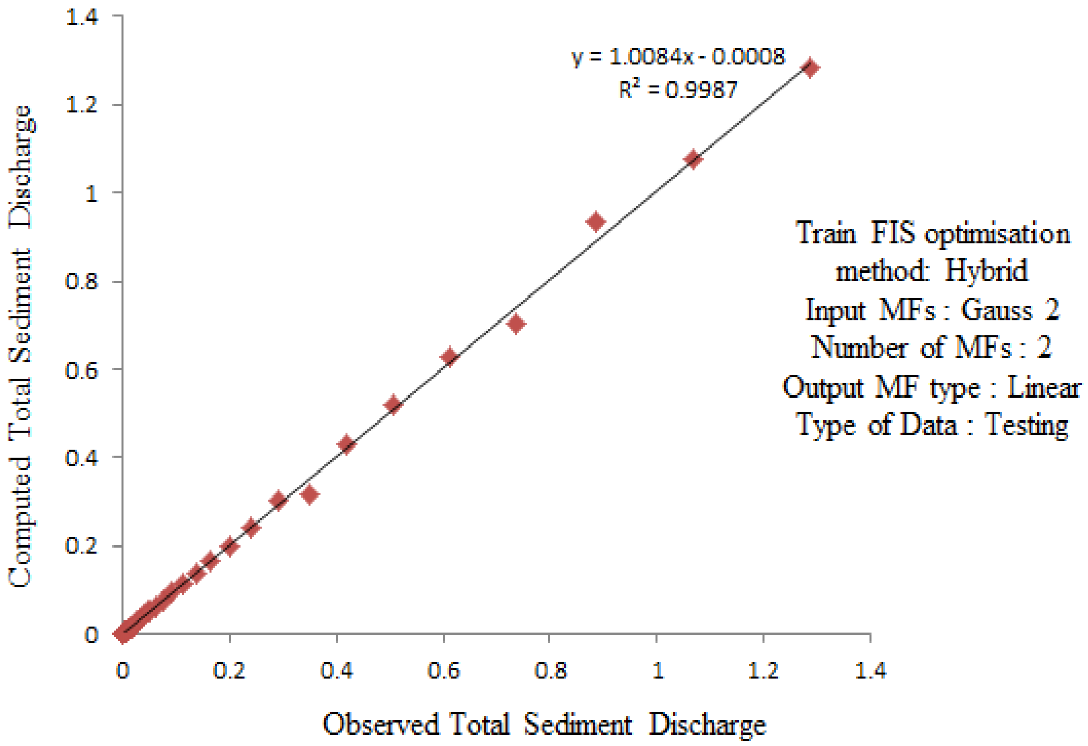

Figure 4.30 : The scatter plot between observed and computed total sediment discharge data. (ANFIS 8)

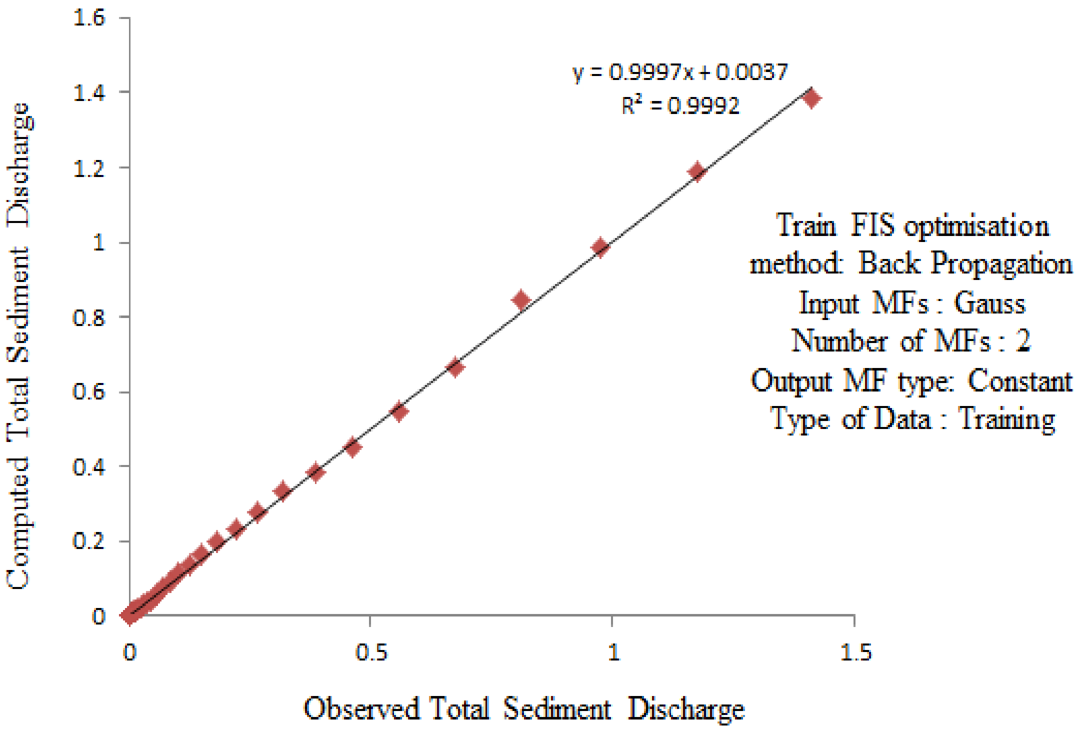

Figure 4.31 : The scatter plot between observed and computed total sediment discharge data.(ANFIS 9)

To have comprehensive test and get the best architecture of using ANFIS this process is continuing with changing the MF typesboth in input and output stages.

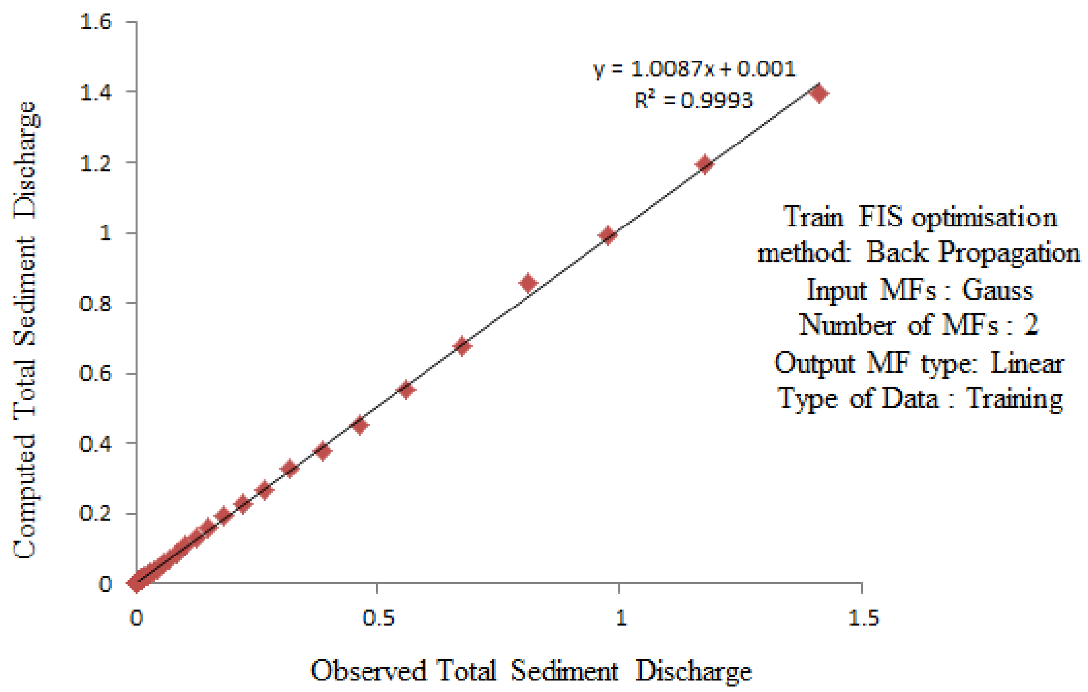

Figure 4.32 : The scatter plot between observed and computed total sediment discharge data.(ANFIS 10)

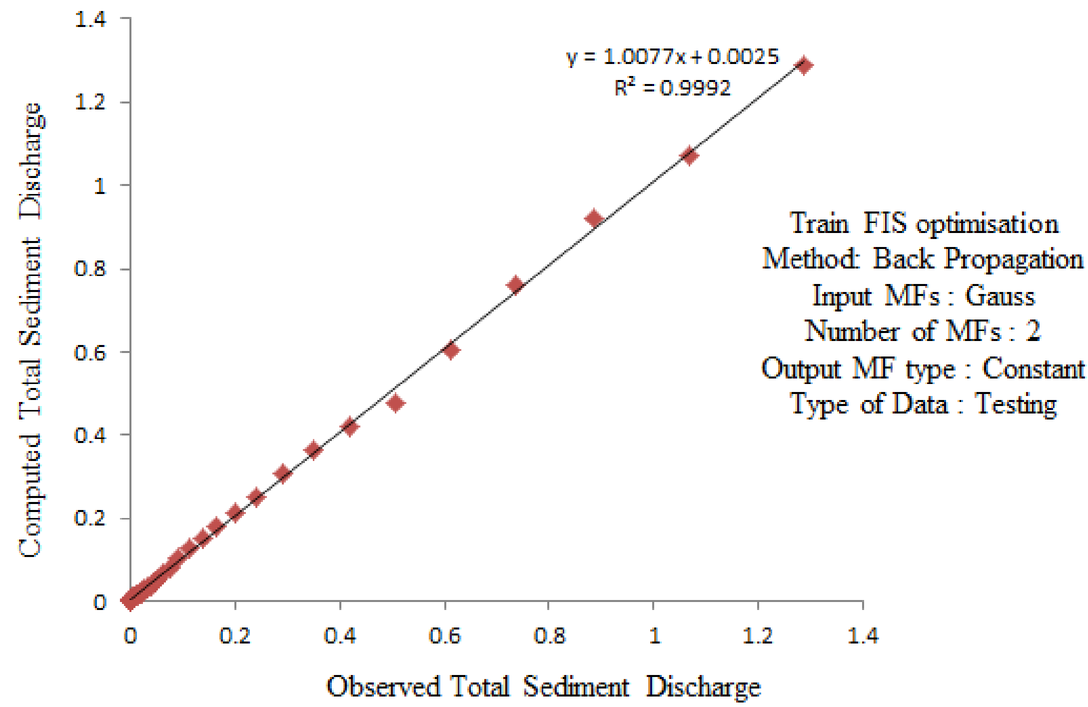

Figure 4.33: The scatter plot between observed and computed total sediment discharge data. (ANFIS 11)

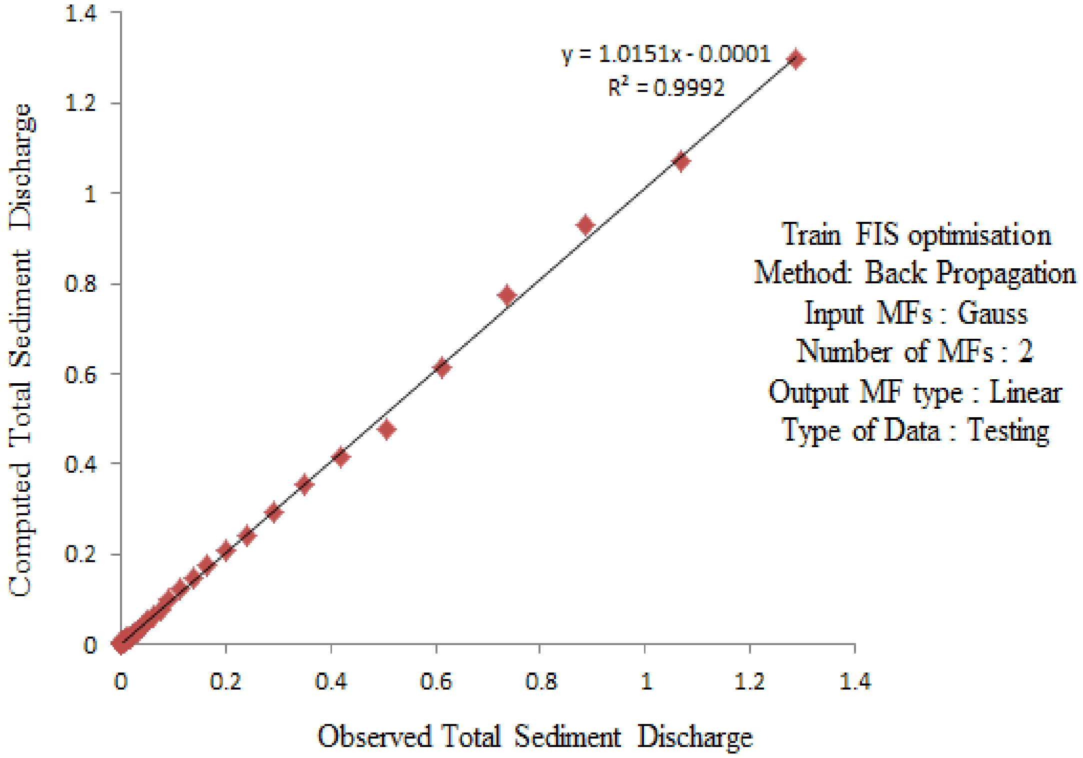

Figure 4.34 : The scatter plot between observed and computed total sedimentdischarge data. (ANFIS 12)

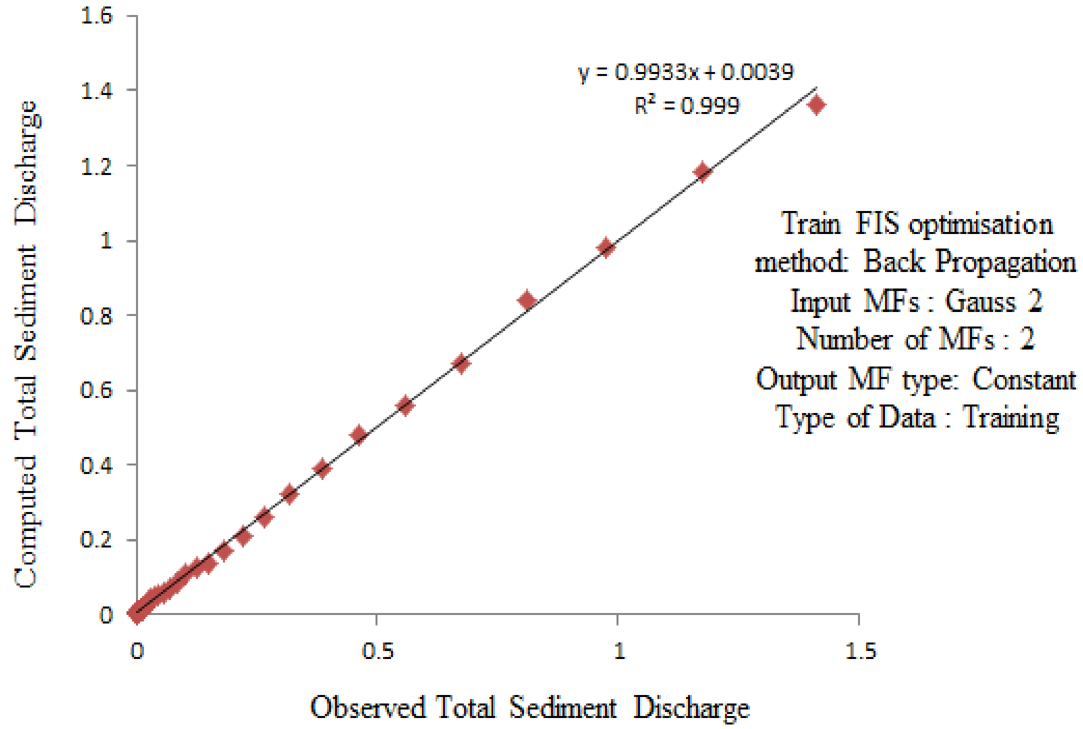

Figure 4.35 : The scatter plot between observed and computed total sediment discharge data.(ANFIS 13)

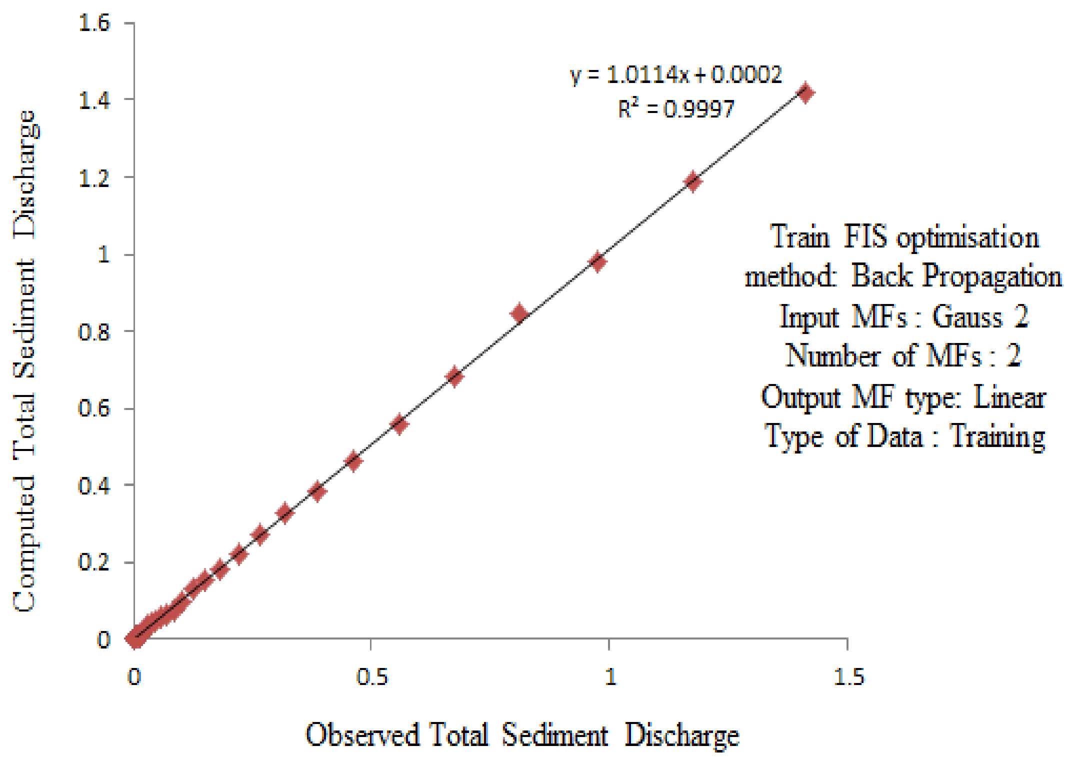

Figure 4.36 : The scatter plot between observed and computed total sediment discharge data.(ANFIS 14)

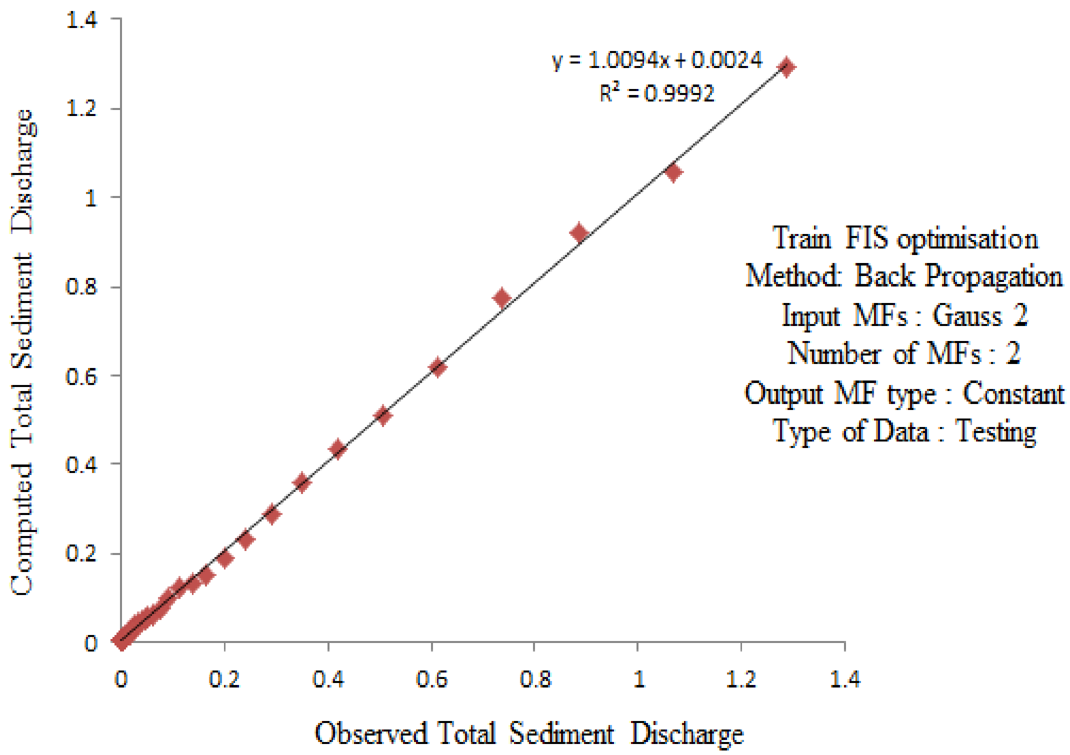

Figure 4.37: The scatter plot between observed and computed total sediment discharge data. (ANFIS 15)

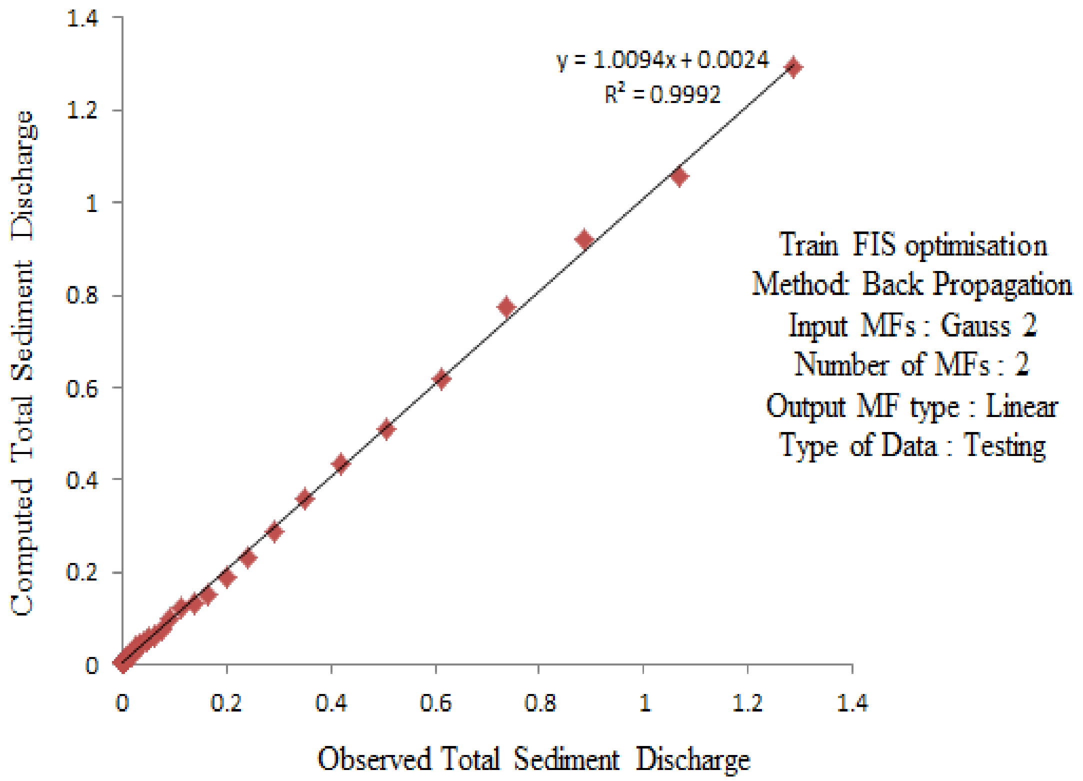

Figure 4.38 : The scatter plot between observed and computed total sediment discharge data. (ANFIS 16)

TABLE 4.7 : The final architectures, RMSE and R^2 statistics of the ANFIS models

Data set	Train FIS Optimization Method	Input MF Type	Output MF Type	Number of MFs	RMSE	R^2
Training	Hybrid	Gauss	Constant	2 2 2 2 2	0.001	~1
Testing	Hybrid	Gauss	Constant	2 2 2 2 2	0.016	0.99
Training	Hybrid	Gauss	Linear	2 2 2 2 2	0.003	~1
Testing	Hybrid	Gauss	Linear	2 2 2 2 2	0.007	0.99
Training	Hybrid	Gauss 2	Constant	2 2 2 2 2	0.02	0.99
Testing	Hybrid	Gauss 2	Constant	2 2 2 2 2	0.03	0.99
Training	Hybrid	Gauss 2	Linear	2 2 2 2 2	0.001	~1
Testing	Hybrid	Gauss 2	Linear	2 2 2 2 2	0.023	0.99
Training	Back Propagation	Gauss	Constant	2 2 2 2 2	0.025	0.99
Testing	Back Propagation	Gauss	Constant	2 2 2 2 2	0.019	0.99
Training	Back Propagation	Gauss	Linear	2 2 2 2 2	0.025	0.99
Testing	Back Propagation	Gauss	Linear	2 2 2 2 2	0.023	0.99
Training	Back Propagation	Gauss 2	Constant	2 2 2 2 2	0.034	0.99
Testing	Back Propagation	Gauss 2	Constant	2 2 2 2 2	0.021	0.99
Training	Back Propagation	Gauss 2	Linear	2 2 2 2 2	0.017	0.99
Testing	Back Propagation	Gauss 2	Linear	2 2 2 2 2	0.026	0.99

Details of each scenario as suggested earlier in Table 4.5 are given in the first 5 columns with the RMSE and R^2 values in the last two columns, respectively. It is possible to see from the comparison of Table 4.3-4.4 and Table 4.6 that ANFIS method provides superiority over the ANN approach in many cases, because in few cases the R^2 values are very close to 1 i.e. ~1.

5. CONCLUSIONS AND RECOMMENDATION

Total Sediment Discharge (TSD) rate is a very complicated matter which is influenced by many random variables. Although it has been predicted depending on a set of input variables by classical techniques, but they have rather high error percentages. In order to decrease such errors in this thesis Artificial Neural Network (ANN) and Artificial Neuro-Fuzzy Inference Systems (ANFIS) intelligence expert system modelings are applied to a set of experimental data. In the presented study, the relations between water discharge, average velosity, water surface slope, shear stress and stream power are used to investigate TSD by FFBP method of ANN and Hybrid and BP methods of ANFIS methodology in various combinations.

Changing the number of layers betweentwo to four and neurons form one to four as an alternative comprehensive scenarios through FFBP helped to estimate TSD. In order to appreciate error amounts Root Mean Square Error (RMSE) and the coefficient of determination (R^2) criteria are employed. So with 0.99 of R^2 and 0.017 of RMSE, it is recommended to select combination the case of two hidden layers each with two neurons become the most suitable alternative in TSD modeling as the optimum model through FFBP concept. So reaching high values of R^2 (close to 1) and very low values of RMSE (<0.04) indicates the capability of this method to predict the TSD.On the other hand, Gauss and Gauss2 types as input membership functions (MFs) are used with two alternative output cases as constant to linear fonction of theinput variables. Finally, focusing on both hybrid and Back Propogation (BP) methods a set of comprehensive TSD prediction methodologies are affected through ANFIS system. As already shown in the text the very high values of R^2 (~1) and very low values of RMSE (0.035) indicate the capability of Hybrid and Bpmethods to estimate TSD. Having ~1 of R^2 and 0.001 of RMSE for Hybrid method using Gauss as input and Constant as output MF types prepares the optimum solution of using ANFIS for estimatting TSD.

The predicition of TSD carries significance for water resources projects such as dam reservoir constructions. Therefore, the results of this study which shows FFBP method of ANN and Hybrid and BP methods of ANFIS are important tools in TSD simulation. The application of these methodologies could be considered as progress for the solution of such problems in the future.

REFERENCES

Ackers, P., and W.R. White.(1973). "Sediment Transport: New Approach and Analysis," Journal of the Hydraulics Division, ASCE, vol. 99, no. HY 11, pp. 2041 -2060.

Allen, P, A. (2008). From landscapes into geological history.Nature, reprinted from vol. 451, no. 7176 (supplement), pp. 274-276.

ASCE.(2000). Task Committee.Artificial neural networks in hydrology.II: Hydrologicalapplications. J HydrolEng ASCE;5(2):124–37.

Azmathulla, H, Md., Ghani, A, Ab., Fei, S, Y. (2012).ANFIS-based approach for predicting sediment transport in clean sewer

Bagnold, R.A. (1966). An Approach to the Sediment Transport Problems from General Physics, U.S. Geological Survey Professional Paper 422-5.

Cigizoglu, H, K., Alp, M. (2005). Suspended sediment load simulation by two artificial neural network methods using hydrometeorological data.

Cigizoglu, H, K., Kisi, O. (2006). Methods to improve the neural network performance in suspended sediment estimation

Cobaner, M., Unal, B., Kisi, O. (2009). Suspended sediment concentration estimation by an adaptive neuro-fuzzy and neural network approaches using hydro-meteorologicaldata

Colby, B.R. (1964). "Practical Computations of Bed-Material Discharge," Journal of the Hydraulics Division, ASCE, vol. 90, no. HY2.

Einstein, H.A. (1950). The Bedload Function for Sediment Transport in Open Channel Flow, U.S. Department of Agriculture Soil Conservation Technical Bulletin No. 1026.

Engelund, F., and E. Hansen.(1972). A Monograph on Sediment Transport in Alluvial Streams, TekniskForlag, Copenhagen.

Filizola, N., Guyot, J., Martinez, J., Wittmann, H. (2009). The significance of suspended sediment transport determination on the Amazonian hydrological scenario.

Gyr, A., **Hoyer, K.** (2006). Sediment transport, A Geophysical Phenomenon, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Hassanzadeh, Y.,(2007). “Evaluation of Sediment Load in a Natural River” Journal of Water International, Vol.32, No.1, Pg.145-154.

Jang, R., Shing, J.(1993).ANFIS : Adaptive-Network-Based Fuzzy Inference System.

Kabiri-Samani, A, R,.Aghaee-Tarazjani, J,.Borghei, S, M,.Jengh, D, S. (2011). Application of neural networks and fuzzy logic models to long-shore sediment transport.

Karim, M.F., and J.F. Kennedy. (1990). "Means of Coupled Velocity and Sediment Discharge Relationships for Rivers," Journal of Hydraulic Engineering, ASCE, vol. 1 16, no. 8, pp. 973-996.

Lacy, G.(1929).Stable channel in alluvium, institute of civil Engineers, proceeding paper no. 4736.

Leopold, L.B., and T. Maddock, Jr. (1953). The Hydraulic Geometry of Stream Channels and Some Physiographic Implications, U.S. Geological Survey Professional Paper 252.

Melesse, A, M., Ahmad, S., Mccain, M, E., Wang, X., Lim, Y, H. (2011).Suspended sediment load prediction of river systems: An artificial neural network approach

Pacheco-Ceballos, P.(1989). "Transport of Sediments: Analytical Solution," Journal of Hydraulic Research, vol. 27, no. 4, pp. 501 -5 18.

Rajaee, T., Mirbagheri, S, A., Zounemat-Kermani, M., Nourani, V. (1988).Daily suspended sediment concentration simulation using ANN and neuro-fuzzy models

Sen, Z. (2004). Artificial Neural Networks, Water Foundation Publication, 183 pp.

Sen, Z. (2010). Fuzzy Logic and Hydrological Modeling. Taylor and Francis Group, CRC Press, New York, 340 pp.

Shen, H.W., and C.S. Hung.(1972)."An Engineering Approach to Total Bed Material Load by Regression Analysis," Proceedings of the Sedimentation Symposium, ch. 14, pp. 14-1 through 14-17.

Takagi T, Sugeno M. (1985).Fuzzy identification of systems and its applications tomodeling and control. IEEE Trans Syst Man Cybernet;15:116–32.

U.S. Department of Boreau of The Interior Reclemation.(2006). Erosion and sedimentation manual, Reclamation managing water in the west.

Yang, C. T. (2003).Sediment transport, theory and practice, The McGraw-Hill Companies, Inc., New York (reprint by Krieger Publishing Company, Malabar, Florida, 2003).

Yang, C. T.,Molinas, A., WU, B. (1996).Sediment transport in the yellow river,"journal of hydraulic engineering, ASCE, in press.

Yang, C. T., Marsooli, Reza,.Aalami, M, T. (2009).Evaluation of total load sediment transport formulas using ANN

Zhu, Y. M., Lu, X, X., Zhou, Y. (2007). Suspended sediment flux modeling with artificial neural network: An example of the Longchuanjiang River in the Upper Yangtze Catchment, China

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