ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

SUSPENDED SEDIMENT LOAD PREDICTION BY USING WAVELET-FUZZY LOGIC COMBINATION MODEL

M.Sc. THESIS

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Department of Civil Engineering

Hydraulics and Water Resources Engineering Programme

Thesis Advisor: Assoc. Prof. Mehmet ÖZGER

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

SEDİMENT TAŞINIMININ BULANIK MANTIK VE DALGACIK ANALİZİ KOMBİNASYONU METODUYLA TAHMİN EDİLMESİ

YÜKSEK LİSANS TEZİ

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MAYIS 2014

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FOREWORD

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May 2014

Mehmet Burak Kabataş

Civil Engineer

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ABBREVIATIONS

TEMA	**:** The Turkish Foundation for Combating Soil Erosion for Reforestation and the Protection of Natural Habitats
TUBITAK	**:** The Scientific and Technological Research Council of Turkey
DSI	**:** General Directorate of State Hydraulic Works
YEGM	**:** General Directorate of Renewable Energy
NF	**:** Neuro-Fuzzy Approach
NN	**:** Neural Network Approach
ANN	**:** Artificial Neural Network
WANN	**:** Wavelet-Artificial Neural Network
MLR	**:** Multilineer Regression
SRC	**:** Sediment Rating Curve
ANFIS	**:** Adaptive Neuro Fuzzy Inference System
GEP	**:** Gene Expression Programing
WNF	**:** Wavelet analyses and Neuro-Fuzzy method
WFL	**:** Combined Wavelet-Fuzzy Logic Approach
FL	**:** Fuzzy Logic Approach
PPM	**:** Parts Per Million

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SUSPENDED SEDIMENT LOAD PREDICTION BY USING WAVELET-FUZZY LOGIC COMBINATION

SUMMARY

Sediment transport is one of the most important processes in hydraulic engineering studies. Measurement of pollution in rivers, calculation of reservoir storage volume, determination of hydraulic structure economic life, safety of water structure's equipment, continuation of natural life, etc. are the some examples of understanding the importance of sediment load. Sediment load prediction is investigated in this study. Firstly, sediments; properties of sediment, disadvantages of sediments, empirical methods and calculation of sediment in Turkey were studied. After that, sediment rating curve, fuzzy logic and fuzzy logic-wavelet analyses methods were applied. Data was provided from General Directorate of State Hydraulic Works of Turkey. Data obtained from 12 measurement stations scattered in Miscellaneous Eastern Blacksea Basin (7 stations) and Coruh Basin (5 stations) are used to predict sediment load for 1999-2005 period.

There are many methods that can be applied to predict sediment load such as sediment rating curve (SRC), fuzzy logic method (FL), empirical methods, artificial neural network (ANN) and others. In situ measurement at station is the safest way to determine sediment amount but it is not applicable for most of the time and it is costly. Sediment rating curve is used to predict sediment load generally. Results of this study showed that SRC has a limited capacity for prediction due to its lower correlation coefficient (between 0,66 and 0,86) and requires concurrent discharge measurement. On the other hand, Fuzzy Logic (FL) and Wavelet-Fuzzy Logic combination (WFL) methods were applied to predict one-month ahead sediment load values. Takagi-Sugeno approach was used for fuzzy logic modelling. Gauss and triangular fuzzy membership were chosen for the model. While stand-alone FL approach could not improve the prediction results, a significant improvement is seen in the application of WFL approach. Correlation coefficient is found to be ranging between 0,94 and 0,99 for WFL method. Continuous wavelet transform was employed to decompose original time series into its sub-bands. Mexican Hat wavelet type was used in the wavelet transformation. In the prediction of sub-bands same fuzzy logic approach is used as in the stand-alone FL model. As a final step, reconstruction was applied to obtain the prediction results.

In summary, wavelet and fuzzy logic combination method consist of 3 parts. Firstly, the signal is decomposed into sub-bands by using wavelet transform. Modeling of these sub-bands is the second step. Finally, all modelled band are reconstructed to

obtain predicted time series. Inverse continuous wavelet transform is used in the final step.

It is seen that combination model of wavelet transform and fuzzy logic approach could give statistically significant results. It is believed that better results would be obtained by developing these kind of methods.

SEDİMENT TAŞINIMININ BULANIK MANTIK VE DALGACIK ANALİZİ KOMBİNASYONU METODUYLA TAHMİN EDİLMESİ

ÖZET

Sediment taşınımı, su mühendisliği için çok önemli bir husustur. Akarsularda kirliliğin belirlenmesi, baraj ömrünün tespiti ve baraj haznesinin hesabı, hidroelektrik tesislerin işletilmesi, su yapılarının teçhizatlarının emniyeti, doğal yaşamın devamı gibi hususlarda sediment miktarının tahmin edilmesi önem arz eder. Sediment taşınımı iki türlü meydana gelmektedir. Bunlardan ilki taban yükü, ikincisi ise askıda sediment yükü olarak isimlendirilir. Bu çalışmada askıda sediment taşınımı çeşitli modeller ile tahmin edilmiştir. Çalışmada ilk olarak, sedimentler ve özellikleri incelendi, sonrasında sedimentlerin verdiği zararlara yer verildi ve sediment hesabında kullanılan ampirik yöntemlere yer verildi. Ardından, Türkiye'de sediment taşınımının hesabı ve hesap adımları incelenmiştir. Daha sonrasında sediment anahtar eğrisi, bulanık mantık ve dalgacık analizi ve bulanık mantık yöntemleri üzerinde çalışılmıştır.

Sediment anahtar eğrisi yöntemiyle askıda sediment yükü ve debi arasında ilişki kurularak bağıntı oluşturulmuştur ve buna göre tahminde bulunulmuştur. Bunun yanında, yalnızca bulanık mantık modeli ve önerdiğimiz dalgacık analizi ve bulanık mantık kombinasyon modelinde iki önceki sediment yükü verisi kullanarak bir sonraki sediment yükü tahmininde bulunulmuştur. Bu yöntemlerin hesabında Doğu Karadeniz Havzası ve Çoruh Havzasında, 1999-2005 yılları arasındaki Devlet Su İşleri verilerinden yararlanılmıştır. Bu veriler 12 istasyondan alınmıştır ve bu istasyonların 7'si Doğu Karadeniz havzasından, 5 tanesi Çoruh havzasından alınmıştır. Doğu Karadeniz havzasında İyidere-Şimşirli; Fol Deresi-Bahadırlı; Fırtına Deresi-Topluca; Melet çayı-Arıcılar; Terme Çayı-Gökçeli Köprüsü; Değirmenderesi-Esiroğlu ve Bolaman çayı-Örencik istasyonlarının askıda sediment verileri kullanılmıştır. Çoruh havzasında ise Çoruh nehri-İspir Köprüsü; Oltusuyu-Aşağıkumlu; Oltusuyu-Coşkunlar; Berta suyu-Bağlık ve Çoruh nehri-Çamlıkaya istasyonlarının askıda sediment verileri kullanılmıştır.

Sediment taşınımı yükünün hesabı sediment anahtar eğrisi, bulanık mantık, ampirik yöntemler gibi çeşitli yollarla yapılmaktadır. Sediment gözlem istasyonlarından yapılan sediment yükü ölçümleri en güvenilir yol olmasına rağmen zaman ve maliyet bakımından dezavantaj oluşturur. Sediment taşınımının elde edilmesinde diğer bir yol da sediment anahtar eğrisidir. Bu yöntem sıkça başvurulan bir yöntemdir. Genellikle üstel fonksiyonlar yardımıyla, debi ile sediment verimi arasında ilişki kurulur. Çalışmada bu yönteme ile çalışılmıştır. Elde edilen sonuçları incelediğimizde 0,66 ile 0,86 aralığında korelasyon katsayısına ait olduğu

görülmüştür. Ortalama mutlak hata sonuçları ise 26,3 ile 3940,7 t/gün aralığında bulunmuştur.

Yalnızca bulanık mantık modellemesi ve bu çalışmada önerdiğimiz bulanık mantık ve dalgacık analizi kombinasyonu modeli ile de sediment taşınımı tahmini yapılmıştır. Bulanık mantık modelinde Takagi-Sugeno bulanık sistemi kullanılmıştır. Gauss tipi ve üçgen tipi bulanık üyelik fonksiyonları modelleme için seçilmiştir. Üyelik fonksiyonlarının seçimi modelimiz tarafından deneme-yanılma yoluyla bulunmuştur. Bulanık mantık yönteminin tek başına uygulandığı durumda korelasyon katsayılarının oldukça düşük çıktığı görülmüştür, buna ek olarak ortalama mutlak hatalarda oldukça yüksek çıkmıştır. Sediment taşınımını, dalgacık analizi ve bulanık mantık kombinasyonuyla incelediğimiz durumda, korelasyon katsayılarının oldukça yüksek sonuçlar verdiği görülmüştür. Önerilen yöntemle 0,94 ile 0,99 arasında değişen korelasyon değerleri elde edildiği görülmüştür. Bunun yanı sıra diğer metotlar ile karşılaştırıldığı zaman ortalama mutlak hata değerleri oldukça minimize olduğu görülmüştür. Önerdiğimiz modelin dalgacık dönüşümü kısmında, sürekli dalgacık analizi uygulanmıştır. Sürekli dalgacık dönüşümü, dalgacık formunun kaydırılıp ölçekle çarpılıp, sonrasında zaman alanı boyunca toplanması olarak tanımlanır. Sürekli dalgacık fonksiyonu uygulandığında sinyalin farklı bölgelerinde farklı ölçeklerde katsayı elde ediyor. Bu katsayılar orijinal sediment yükü zaman serisinin regresyon sonucunu gösterir. Dalgacık analizi kısmında, Meksika şapkası dalgacık formu kullanılmıştır. Bulanık mantık kısmı, aynı sadece bulanık mantık modeli oluşturulacak gibi yeniden Gauss ve üçgen tipi üyelik fonksiyonlarından biri seçilmiş, bulanıklaştırma yapılmış ve sonrasında yeniden birleştirme yapılarak sonuçlar elde edilmiştir.

Dalgacık analizi ve bulanık mantık kombinasyon modelinin en önemli noktası sinyali homojen olarak alt bantlara ayırmaktır. İyi bir dalgacık analizi ve bulanık mantık kombinasyonu modeli 3 aşamalı olarak uygulanır. İlk adım ayrıştırmadır. Bu adımda araştırma konusu olan sinyal dalgacık analizi yardımıyla bantlara ayrılmıştır. Tüm istasyonlarda 5 adet alt banda ayrıştırma yapılmıştır. Oluşturduğumuz bantların genellikle düşük periodikliğe sahip ilk iki bandı gürültü verilerinden oluşmuştur ve son iki bandı da uzun dönem değişikliklerini göstermektedir. İkinci adım olan tahmin bölümünde ise bu ayrılan bantlar bulanık mantık yardımıyla ayrı ayrı modellenmiştir. Bulanık mantık bölümünde alt küme olarak düşük sediment yükü ve yüksek sediment yükü olarak seçtik. İki önceki ayı girdi olarak kullanıp, bir sonraki ayı tahmin etmeye çalıştık. Bu sayede modelimiz tarafından 4 adet kural tabanı oluşturuldu. Son adım olan tekrar birleştirmede ise, her bir modellenen bant tahmin edilmiş zaman serilerini elde etmek için tersine sürekli dalgacık dönüşümü yardımıyla tek bir sinyal elde edilmiştir.

Bu çalışmada görülmüştür ki, sediment taşınımı için önerdiğimiz dalgacık analizi ve bulanık mantık kombinasyonu modeli istatiksel olarak anlamlı sonuçlar vermiştir. Korelasyon katsayıları ve ortalama mutlak hataların sonuçları karşılaştırılarak bulanık mantık ve dalgacık analizi kombinasyon modelinin diğer metotlara göre daha tutarlı sonuçlar verdiğini görülmüştür. Bunun yanında önerdiğimiz model, pik noktaları yakalamakta da oldukça başarılı olmuştur. Literatürde de dalgacık analizi ve bulanık mantık kombinasyon modelinin birçok örneği bulunmaktadır. Bunlar arasında otomotiv sektörü, su mühendisliği, insan bilimi, trafik sistemleri ve elektronik sistemler gibi birçok değişik bölüm vardır. Bu örneklerin yanında bu çalışmada da görüldüğü üzere, önerilen yöntem bulanık mantık ve dalgacık analizi kombinasyon modeli oldukça geniş yelpazeye sahip, geliştirilebilir ve uygulaması rahat bir yöntem olarak önerilebilir.

1. INTRODUCTION

1.1 Sediments

According to Random House dictionary, erosion is the process which the surface of the earth is worn away by the action of water, glaciers, winds, waves etc. The most effective agents that lead to erosion can be counted as water and wind. It is assumed that the reduced woodland is the main reason of erosion. In addition, it depends on climate, topography, soil structure, vegetation cover and land management.

Erosion is a natural process that it could not be prevented. However, in natural situation, soil adapt itself again. That soils, stripped itself, turns into a fertile land on the mouth of a river.

According to TEMA, The Turkish Foundation for Combating Soil Erosion for Reforestation and the Protection of Natural Habitats, 743 million ton soil is disappered due to the erosion.

Flow is defined as a mixture of nonhomogenous water, suspended sediment and air. Stream bed and flow is a system which is always in interaction. The system is called stream. It is clear that natural balance is disturbed by outside effects.

In the stream, water carries sediments while it flows. Mostly, sediment is consisted as a result of erosion action. Sediments make a set of abrasion on stream bed or if flow is low, sediments sink on stream bed so collepse is formed. As a result of sediments transport, river morpohlogy could be changed, and water structures could be damaged, in terms of solidity and functionality. Moreover water quality could be reduced.

1.2 Properties of Sediment

To understand sediment transportation, its main properties such as size, shape, fall velocity, mineral composition etc. should be described. Water and sediment particle properties, open channel flow and characteristics and bed forms are described in the following section.

1.2.1 Water Properties

1.2.1.1 Density(ρ)

Density is defined as mass of per unit volume. It is shown in the following;

$$\rho = \frac{M}{V_h} \tag{1.1}$$

where M= Mass(kg)

V_h=Volume(cm^3)

Density shows differences in as much as salt concentration and pollution of matter.

1.2.1.2 Specific Weight(γ)

It is defined as weight per unit volume and its formula is;

$$\gamma = \rho g \tag{1.2}$$

where γ=Specific weight of water (N/m^3)

ρ=Density (kg/m^3)

g=Gravity (m/s^2)

1.2.1.3 Surface Tension

Surface tension effects radial. It shows differences in terms of liquid type. For water, it is 73 mN/m.

1.2.1.4 Viscosity

Viscosity is the resistance of fluid against shear stress. It is shown in the following;

$$\tau = \mu \frac{du}{dy} \tag{1.3}$$

where $\frac{du}{dy}$ =Velocity gradient

τ = Shear stress

This formula represents dynamic viscosity. There is another defination which is called as kinematic viscosity. It is defined as ratio of dynamic viscosity to density.

$$V= \frac{\mu}{\rho} \tag{1.4}$$

where μ=Dynamic viscosity(Ns/m^2)

ρ=Density(kg/m^3)

V=Kinematic viscosity(m^2/s)

1.2.1.5 Vapour Pressure of Water

Under pressure, water boils in lower degrees. Vapour pressure is an important feature and it should be observed that pressures are always greater than vapour pressure to avoid cavitation.

1.2.2 Particle Properties

1.2.2.1 Particle Size

Sediment is formed by particles. These particles shows variable sizing due to its rock weathering. The classification presented in Table 1.1 can be used to categorize the particles.

Table 1.1: Classification of particles

Type	Diameter (mm)	Type	Diameter (mm)
Clay	$<2*10^{-3}$	Coarse sand	$600*10^{-3}$- 2
Fine silt	$2*10^{-3}$- $6*10^{-3}$	Fine gravel	2,00-6,00
Mid-silt	$6*10^{-3}$- $20*10^{-3}$	Mid-gravel	6,00-20,00
Coarse silt	$20*10^{-3}$- $60*10^{-3}$	Coarse gravel	20,00-60,00
Fine sand	$60*10^{-3}$- $200*10^{-3}$	Stone	60,00-200,00
Mid-sand	$200*10^{-3}$- $600*10^{-3}$	Rock	>200,00

1.2.2.2 Particle Shape

Particle shape is defined as sphericity. According to Wadell's description in 1935, the sphericity of a particle is the ratio of the surface area of a sphere (with the same volume as the given particle) to the surface area of the particle. Shape factor of grain is computed by the formula, $\frac{c}{\sqrt{ab}}$. It is utilized in computing velocity of settling. a, b, c is the longest, middle and the shortest axises respectively. Shape factor of particle classify according to particle basic rock.

1.2.2.3 Particle Specific Weight and Density

Sediment's specific weight show a change values due to the carried matter. Generally, sediment consists of sand and gravel, and its density is calculated 2650 kg/m^3 with experiments. Particle specific weight is defined as weight per unit volume. Grain and water's specific weight's rate is defined as grain specific weight in water.

1.2.2.4 Fall Velocity

Fall velocity is an important parameter to obtain sediment discharge and research suspended sediment in river. Grain, which is released into river, gains momentum increasingly and finally its velocity becomes a limit value. The limit velocity is called as fall velocity of particle. It is computed with Stokes's law for laminer flows. The equation;

$$w = \frac{1}{18}\frac{\gamma_s-\gamma}{\gamma} g \frac{d_0^2}{v} \quad \textbf{(1.5)}$$

where w= Fall velocity of particle

γ_s= Specific weight of grain (kg/m^3)

γ= Specific weight of water (kg/m^3)

d_0= Mean diameter of grain (m)

g= Acceleration of gravity (m/s^2)

v= Kinematic viscosity of water (m^2/s)

Density, viscosity based upon thermal, roughness of sediment, size distribution and shape of grain and concentration of sediment are effective on rate of settling.

1.2.2.5 Other Features

Size distribution and porosity are other important features of sediments. Size distribution can not be determined one by one. Statistical methods or sieve analysis are used to obtain the size distribution of a sample. Grain-size curve is plotted on statisticals methods. d_{10}, d_{35}, d_{50}, d_{65}, d_{90} are used for this purpose. Mean grain diameter's formula is;

$$d_0 = \sum_{i=1}^{n} i_b d_i \quad \textbf{(1.6)}$$

i_b shows availability percentage of d_i diameter in sediment simple.

Geometric average is computed by using $d_{84,1}$ and $d_{15,9}$;

$$d_g = (d_{84,1} d_{15,9})^{1/2} \quad \textbf{(1.7)}$$

Porosity is used in stored sediment volume problem. Its formula is presented in the following;

$$P = \frac{V_t - V_s}{V_t} \quad \textbf{(1.8)}$$

where P= Porosity

V_t= Total sediment volume

V_s= Sample sediment volume

1.2.3 Open Channel Flow

Flow has a free surface in open channel. Bed bottom slope is the key factor for open channel flows.

1.2.3.1 Uniform Flow

Flow is uniform, if flow depth does not change in cross-section to cross-section. Bed slope, cross-section, roughness and discharge is constant in uniform flow. Energy loss by friction force is recuperated with bed slope. Bed bottom is parallel to surface of water and energy gradeline.

1.2.3.2 Gradually Varied Flow in Open Channel

When uniform flow condition is corrupted, open channel flows in two ways naming as sudden changed or gradually varied. In these flows, flow parameters are not same in all cross-section. Gradually varied flow is a permanent movement. Bed slope is not same with surface of water or energy gradeline. All of them show different values. In gradually varied flow, surface of water form cannot be known. Lots of formula are used for solving. Some of them is given in the following;

a) Numerical integration method

b) Finite elements method

c) Bakhmeteff method

d) Energy method

e) Momentum method

1.2.4 Bed Forms

Flow resistance, sediment transport and bed forms have a relationship. The activating of the sediment particles may need the flow consume a certain amount of energy, flow velocity near the bed bottom and especially turbulance characteristic and range of shear stress will change by particles starting to move. The change becomes more important as the percentage of particles gets bigger. Regime gives various forms into bed bottom like sediments. Flow regime and its relationship to bed forms and other characteristics figure is given in the following;

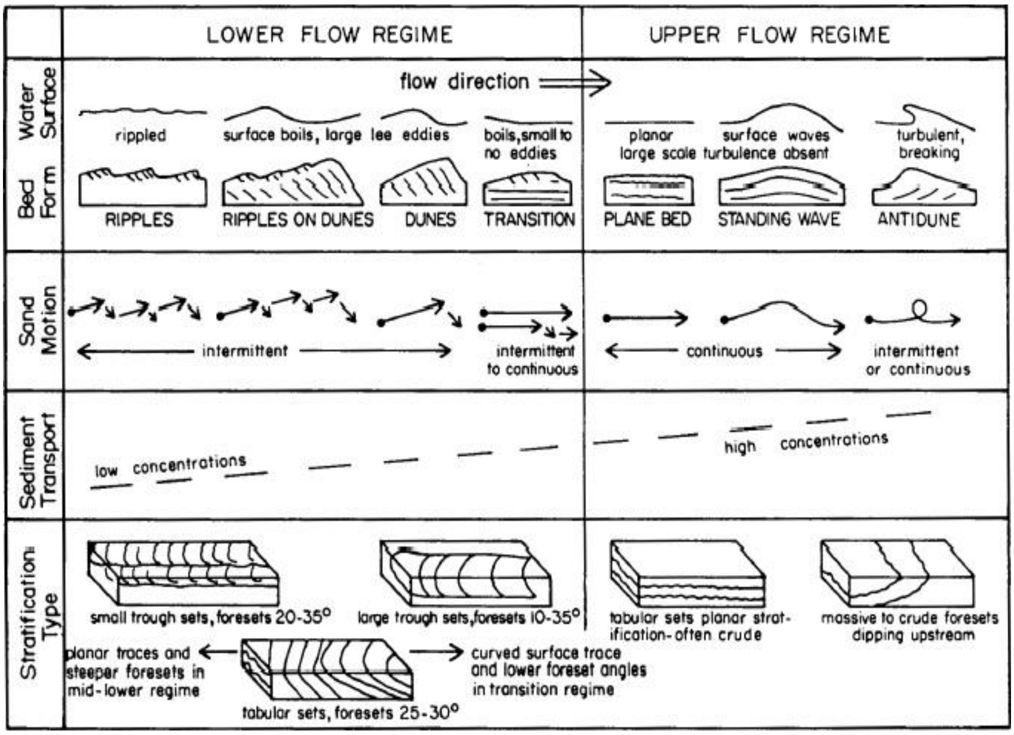

Figure 1.1: The relationship between flow regime and characteristic features (Lewis,1984)

Flow regime is determined by Froude number;

$$Fr = \frac{V}{\sqrt{gD}} \quad \textbf{(1.9)}$$

where Fr= Froude number

V= Velocity

g= Acceleration of gravity

D= Hydraulic depth (cross sectional area of flow/top width)

when;

Fr=1 Critical flow (transitional flow regime)

Fr < 1 Subcritical flow (lower flow regime)

Fr > 1 Supercritical flow (upper flow regime)

According to regime, bed forms can be classified into three section;

a) Lower flow regime with plane bed, ripples and dunes,

b) Transitional flow regime with washed-out dunes,

c) Upper flow regime with plane bed, anti-dunes, pool and chute.

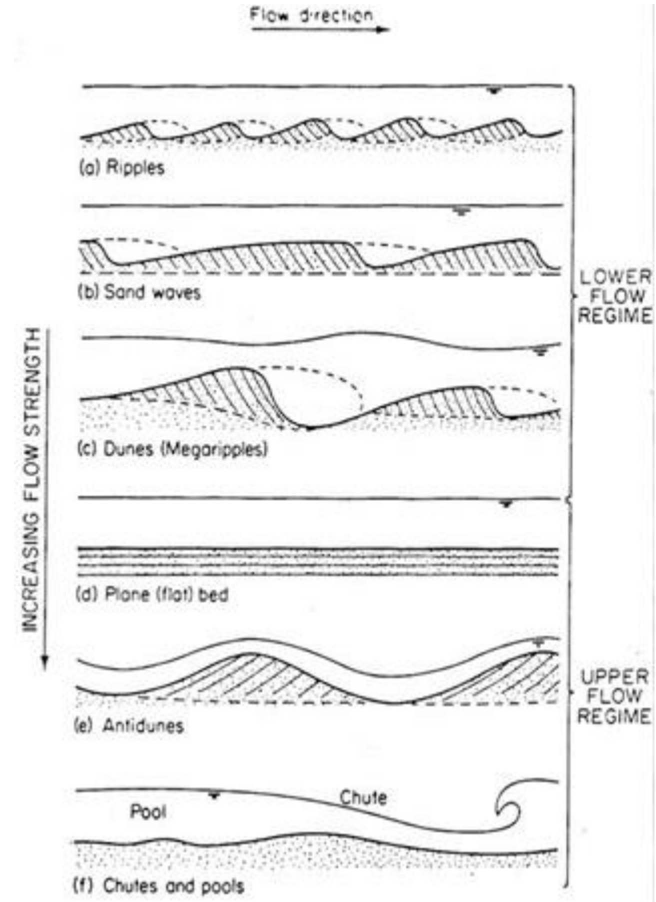

Figure 1.2: Bedform's presentation (Allen, 1977)

The main bed forms are described in the following.

1.2.4.1 Plane Bed

Some grain particules are energised with minor vibration when flow acceleration approaches critical value. Sediment particules starts moving like rolling, sliding or moving by saltation and then stop again and bed shape keep its form. This kind of bedform is called as a plane bed.

1.2.4.2 Ripple Marks

It is shaped like ripple which has less than 5 cm height and 30 cm lenght. Usually, its profile is triangular, downstream direction is vertical, upstream direction is canted. It is usually seen with V_{kr} in deep water depth (h/d>1000) where V_{kr} is actuating sediment particules.

1.2.4.3 Sand Waves

It is formed in several ways like deflection point of stream or junction point between two tributaries.

1.2.4.4 Dune

It is smaller than sand waves but bigger than ripple marks in terms of lenght and height. It is independent from water surface profile.

1.2.4.5 Transition State

This condition occurs between plane bed form and dune form. Formation of this state is hard to predict or observe.

1.2.4.6 Anti-Dune

Bed and water surface are compatible in this bedform. Flow moves through downstream meanwhile sand and water surface moves through upstream. It is generally appeared in shooting flow condition and has bigger value than Froude number 1,0. Base current flows direction of flow in streaming flow on the other hand in shooting flow, it flows contrary direction to flow. It can be easily explained. Sediment transport increases in case of flows acceleration. Increasing sediment transport in direction of flow causes current base height's deceleration according to continuous equation, so wave moves though direction of flow. Contrary to that situation, in shooting flow, sediment transport decreases along the upstream and it causes wave height increment so wave moves backset.

1.2.4.7 Pool and Chute

It is happened in high acceleration and sediment concentration on high slope. It contains extensity of sediment deposition.

1.3 Sediment Transport Types

Sediment transport occurs in two ways naming as "suspended sediment" and "bed load". If transporting occurs on stream bed, it is called as bed load, if it floats, it is called as suspended sediment. Total discharge of sediments is described with sum of bed loads discharge and suspended sediments discharge and it is presented on (1.10). Total discharge of sediment is not constant, it depends on time.

$$\phi_{ts} = \phi_{ss} + \phi_{bs} \tag{1.10}$$

where, ϕ_{ts}= Total sediments discharge

ϕ_{bs}= Bed load discharge

ϕ_{ss}= Suspended sediment discharge

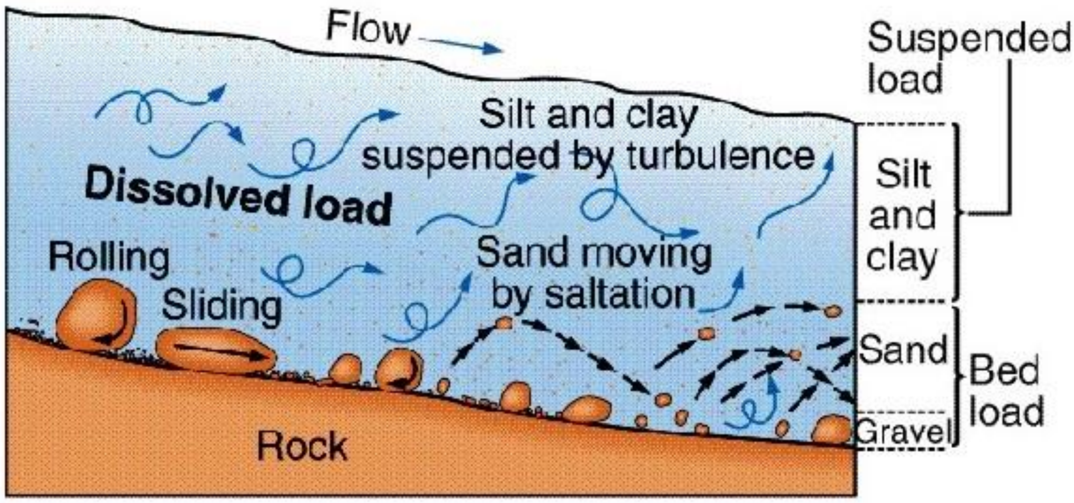

Figure 1.3: Contents of Stream Bed

1.4 Sediment Disasters

Sediment disasters cause several damage directly or indirectly to people lives or properties and environment. The damage is happened in many ways; the ground on which buildings and farmland are situated are lost due to a landslide or an erosion; houses are ruined by the destructive forve of soil and rock during their movement; houses and farmland are buried underground by a large-scale accumulation of discharged sediment; aggradation of a river-bed and burial of a reservoir are caused by sediment discharge along a river system, which may start flooding, disorder of water use functions, and deterioration of the environment.

The results of sediment disasters cause several problems. For instance, materials such as sand, clay, silt and gravel shorten the economic life of reservoirs by filling dams with sediments and reducing their storage capacity as well as reducing overall lifetime of the dams. Moreover, increased sediment concentration destroys fertile landcovers, reduces soil infiltration, increases flood probablity, increases repairment and maintenance expenses of irrigation and drainage systems, changes the ecology by changing the aquatic life and etc.

1.5 Sediment Variables

Sediment transport problems have many variables. It is presented in the following;

$$Q_t = f(Q_w, h, \tau, v, \rho, \varepsilon, \rho_s, d_o, w, g) \quad \textbf{(1.11)}$$

In this function; Q_t : Total sediment flow (tone/day)

ε: Coefficient of sediments mixture

Q_w : Water flow (m^3/s)

ρ_s: Specific mass of sediment(kgs^2/m^4)

h: Water depth (m)

d_o: Grain diameter of sediment (mm)

τ : Shear stress (kg/m^2)

w : Rate of precipitation of sediments grain (m/s)

v : Kinematic viscosity of water (m^2/s)

g :Acceleration of gravity (m/s^2)

r: Specific mass of water (kg s^2/m^4)

As it is seen, it is categorized into four titles;

a) Features of Flow (Q_w, h, τ)

b) Features of Liquid (v, r, ε)

c) Features of Sediment (ρ_s, d_o, w)

d) Acceleration of Gravity (g)

1.6 Sediment Studies

The empirical studies have been using for prediction of sediment load for a long time. Some of important studies are given in the following;

1.6.1 Du Boys (1879)

Du Boys asserted bed shear stress's existence and bed loads movements in case of stratified. Du Boys's most important approach was that hydrolic shear stress and bed load critical shear force difference defined as sediment transport. Besides, he showed that average cross-section is calculated by using hydraulic parameters. Du Boys assumed that shear stress gradually decreases as the thickness of the layer decreases in vertical direction. It gives good results in uniform flow, high velocity, upright slope and coarse-grained rivers.

The Du Boys function is presented in the following;

$$q_T = \psi_{T_0}(\tau_0 - \tau_c) \quad \textbf{(1.12)}$$

where q_T= rate of sediment transport per unit width of river

ψ= a coefficient that depends on characteristics of the sediment

τ_c= a value established by experiment

The sediment coefficient,ψ, and critical shear stress, τ_c, have a relationship in Du Boys equality. It is displayed in the following;

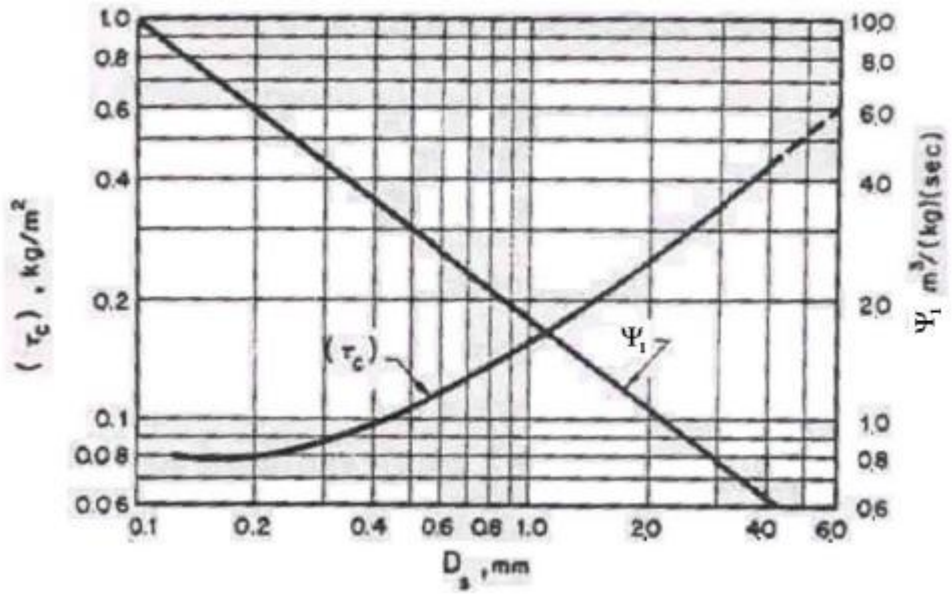

Figure 1.4: The sediment coefficient ψ and critical shear stress T_c in Du Boys equality (Du Boys, 1879)

1.6.2 Schochlitsch(1934)

Schochlitsch developed a bedload formula by using Gilbert's (1914) flume measurements. Schocklitsch assumed that sediment consists of homogenous particules. Schochlitsch formula in English units is given in the following;

$$q_B = \frac{86,7}{\sqrt{d_{50}}} S^{3/2}(q - q_0) \quad \textbf{(1.13)}$$

where q_B= Unit bedload disharge (pounds per second per foot of width)

d_{50}= Medium size of sediment (inches)

$$q_0 = 0,00532 \frac{d_{50}}{{S_0}^{4/3}} \quad \textbf{(1.14)}$$

1.6.3 Shields (1936)

Shields developed a bed load formula as the following;

$$g_B = 10\frac{(\tau_0-\tau_c)qS}{\Delta^2 d_s} \quad \textbf{(1.15)}$$

where, g_B= Bedload weight

τ_c= Critical shear stress

τ_o= Bed shear stress

d_s= Average size of sediment

S= Bed slope

q= Intensity of discharge

$$\Delta=\frac{(\gamma_s-\gamma)}{\gamma} \quad \textbf{(1.16)}$$

where, γ_s=sediment specific weight, γ=water specific weight

The formula was calculated in flow, which width range from 40 cm to 80 cm, and by using five sediments, which specific weight is ranging from 1,06 to 4,2 g/cm^3. The lightest sediment was amber particle. The formula became a bed load function because observing sediments had big size and low shear stress. It gives good results in laminated flow and homogenous situations. Shields curve is displayed in the following;

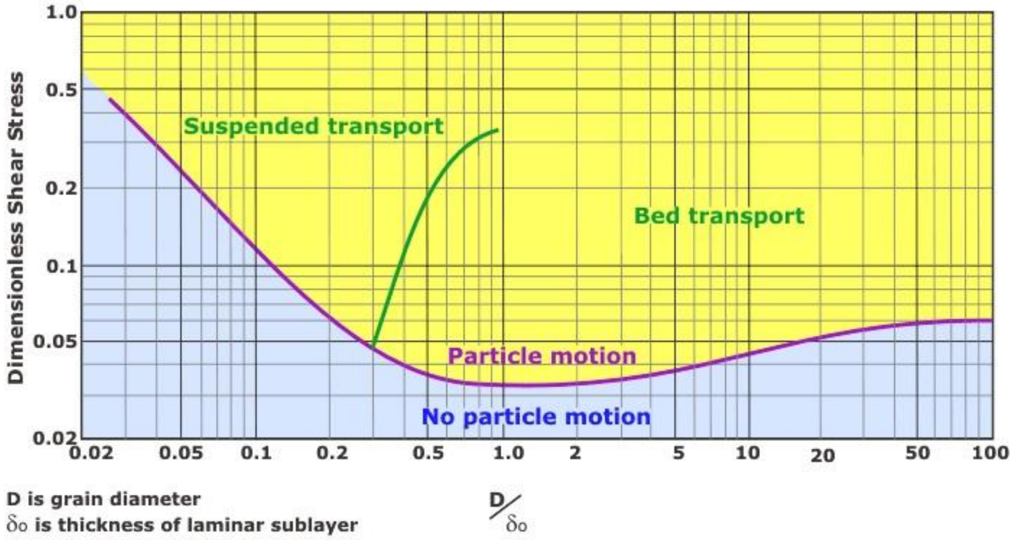

Figure 1.5: Shields Curve(Lemke, 2010)

1.6.4 Meyer-Peter Muller (1948)

Meyer-Peter and Muller suggested a function for bulky bed material rivers. Transporting of suspended sediment is not included on their experiments. It also gives good result for flood situations. The experiments was performed ranging from 15 cm to 2 m width, 0,0004 to 0,02 slope, 1 cm to 120 cm water depth and 1,25 to 4 g/cm^3 specific weight. The suggested function is given in the following;

$$\gamma(\frac{K_s}{K_r})^{3/2}RS = 0.047(\gamma_s - \gamma)d_s + 0.25\rho^{1/3}g_b{}^{2/3}\Delta^{2/3} \quad \textbf{(1.17)}$$

where R= Hydraulic radius

$K_r = \frac{26}{D_{90}^{1/6}}$

$K_s = 1/n$; n= Manning roughness coefficient

S=Bed slope

ρ= Water density(kg/m^{4}s^2)

g_B= Bedload weight

$\Delta = \frac{(\gamma_s - \gamma)}{\gamma}$; γ_s=sediment specific weight, γ=water specific weight

Solid volume bed material discharge q_s were transformed into nondimensional in the following;

$$q_* = \frac{q_s}{\sqrt{d_s{}^3 g\Delta}} \quad \textbf{(1.18)}$$

After transforming, the main function is turned into;

$$\phi = 8(\tau^* - \tau_c^*) \quad \textbf{(1.19)}$$

where, T_c^* = 0,047

Wong(2003) researched Meyer, Peter and Muller’s studies and suggested two equations;

$$\emptyset = 4{,}93(\tau^* - \tau_c^*)^{1.6} \quad \textbf{(1.20)}$$

$$\emptyset = 3{,}97(\tau^* - \tau_c^*)^{1.5} \quad \textbf{(1.21)}$$

Wong suggested to use τ_c^*= 0,047 and τ_c^*= 0,0495 in equations respectively.

1.6.5 Einstein and Brown (1950)

According to Einstein, if lifting force that affect the grain is a function of flow velocity, all grain particules on bed would start moving in no turbulance, when flow velocity would reach in proper condition. However, in turbulance, a grain movement require that a grain lifting force should overcome to grain weight. Einstein neglected shear stress and utilized possibility of movement. On his experiments, some grain particle was coloured and observed in movable bed and consuquently it seem that there is intermittent movement and conversion between movable bed and moving grain. Brown developped Einstein's theory and obtained intensity of bed load discharge naming Einstein-Brown formula. It gives a good result on alluvial rivers.

1.6.6 Laursen (1958)

Laursen developed a statical equation is related between bed load discharge and flow conditions. It is given in the following;

$$\dot{C} = \sum_{i=1}^{n} i_b \left(\frac{D_{si}}{d}\right)^{7/6} \left(\frac{\tau_0}{\tau_C} - 1\right) f\left(\frac{U_*}{w_i}\right) \quad \textbf{(1.22)}$$

where,

$$\tau_0' = \frac{\rho V^2}{58}\left(\frac{D_{50}}{d}\right)^{1/3} \quad \textbf{(1.23)}$$

$$\tau_c = Y_c \rho g (S_g - 1) D_{si} \quad \textbf{(1.24)}$$

where, $\dot{C}$= the concentration of bed material discharge in % by weight,

n= the number of size fractions in the bed material,

i_b= the fraction, by weight, of bed material in a given size fraction,

D_{si}= the mean grain diameter, in ft, of the sediment in size fraction i,

d= the mean depth in ft,

τ_0'= Laursen's bed shear stress due to grain resistance,

τ_c= critical shear stress for particles of a size fraction,

f = denotes function of,

U_*= the shear velocity in ft/s,

w_i= the fall velocity, in ft/s, of sediment particles of diameter D_{si},

ρ= the density of water in slugs per ft^3,

V= the mean velocity in ft/s,

D_{50}= the particle size, in ft, at whict 50% of the bed material, by weight, is finer

Y_c= a coefficient relating critical tractive force to sediment size,

G= acceleration of gravity in ft/s^2, and

S_g= the specific gravity of sediment

The density ρ, entered into the original equation with Function 1.22, τ_0', and so the equation becomes dimensionally homogeneous. The equation is changed with inputting τ_0' into the original equation;

$$C = 10^4 \sum_{i=1}^{n} i_b \left(\frac{D_{si}}{d}\right)^{\frac{7}{6}} \left[\frac{V^2}{58 Y_c D_{si}(S_g - 1) g d} \left(\frac{D_{50}}{d}\right)^{\frac{1}{3}} - 1\right] f\left(\frac{U_*}{w_i}\right) \quad \textbf{(1.25)}$$

where, C= the concentration of bed material discharge, in parts per million by weight.

$f(\frac{U_*}{w_i})$ values is shown in the following;

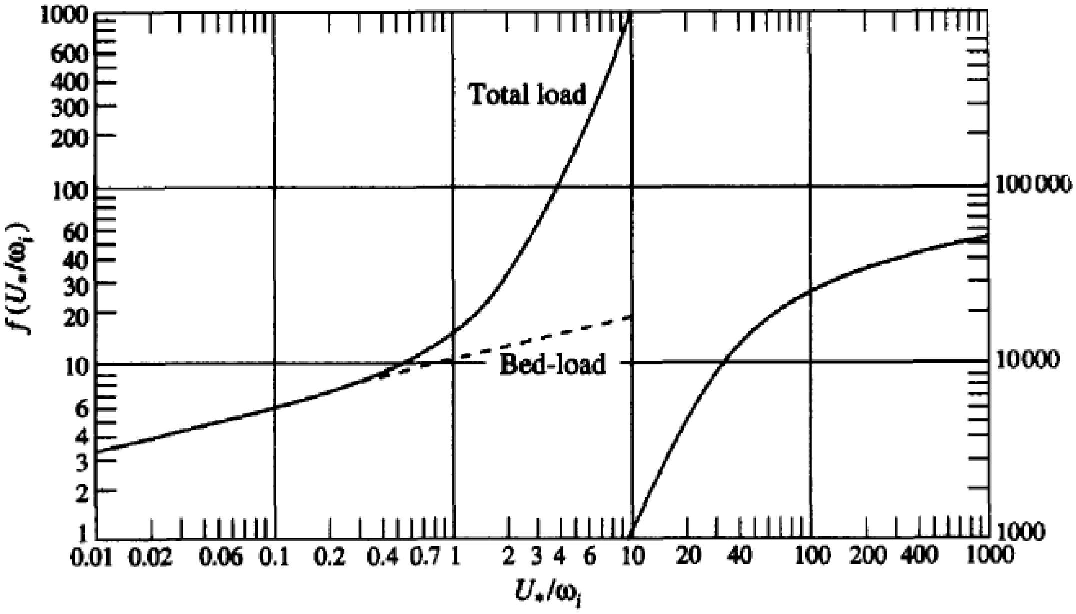

Figure 1.6: Function $f(\frac{U_*}{w_i})$ in Laursen's approach(Laursen, 1958; Yang, 1996)

1.6.7 Colby (1964)

A graphical method was suggested to capture the discharge of sand-size bed material, ranging from 0,1 to 0,8 mm, by Colby. g_s, presents the bed material discharge, in lb/s/ft of width at 15,6° Celsius(°C) water temperature (Colby's 1964).

$$g_s = A(V - V_c)^B 0.672 \quad \textbf{(1.26)}$$

where; V= the mean velocity in ft/s,

V_c= the critical velocity in ft/s,

D= the mean depth in ft,

d_{50}= the practical size, in mm, at which 50% of the bed material by weight is finer,

A, B= coefficients

Colby developed his approach to utilize Einstein's bedload function(1950). For solution, the mean flow velocity V, average depth D, median particle diameter d_{50}, water temperature T, and fine sediment concentration C_f is required. The graphical solutions are described and shown in the following;

Step 1: with the given V and d_{50}, determine the uncorrected sediment discharge q_{ti} for the two depths shown in Figure 1.. that are larger and smaller than the given depth D, respectively,

Step 2: interpolate the correct sediment discharge q_{ti} for the given depth D on a logarithmic scale of depth versus q_{ti}

Step 3: with the given depth D, median particle size d_{50}, temperature T, and fine sediment concentration C_f, determine the correction factors k_1, k_2 and k_3 from Figure 1.7

Step 4: the total sediment discharge (in ton/day/ft of channel width), corrected for the effect of water temperature, fine suspended sediment, and sediment size, is: (Yang, 2006)

$$q_i = [1 + (k_1 k_2 - 1)0.01k_3]q_{ti} \quad (1.27)$$

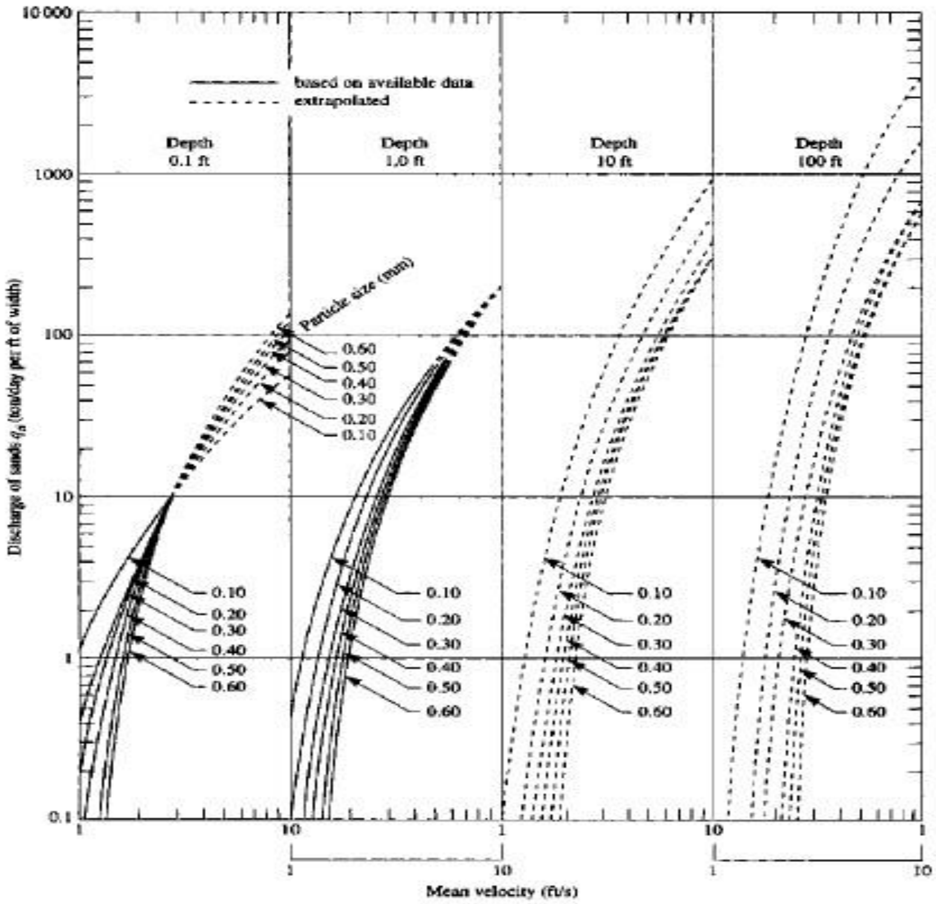

Figure 1.7: a) Relationship of discharge of sands to average velocity for six median sizes of bed sands, four depths of flow, and a water temperature of 60 °F (Colby, 1964; Yang, 1996)

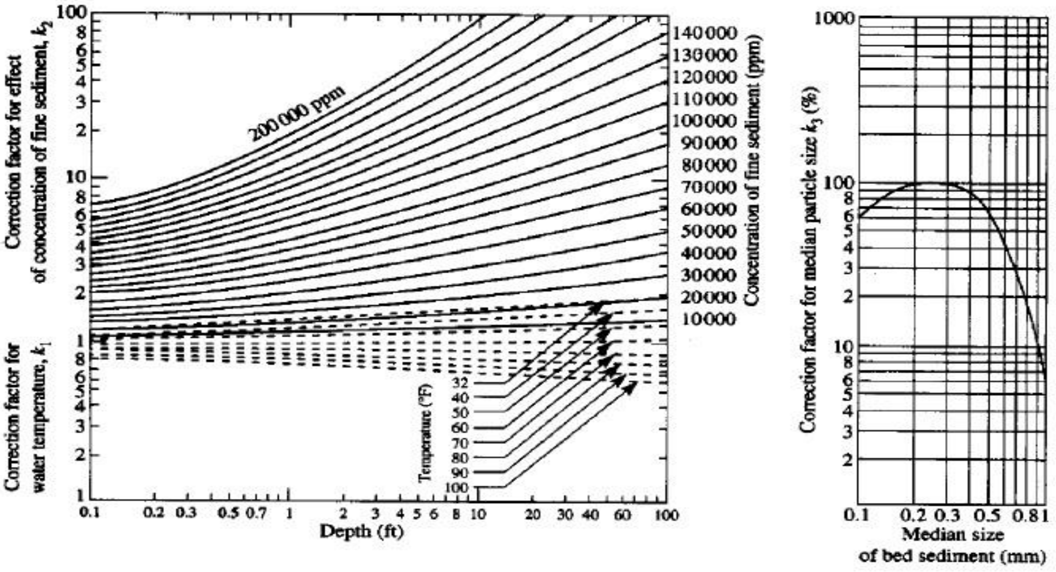

Figure 1.7: b) Approximate effect of water temperature and concentration of fine sediment on the relationship of discharge of sands to average velocity(Colby, 1964; Yang, 1996)

From Figure 1.7a, k_1=1 for T=60 ^oF, k_2= 1 where the effect of fine sediment can be neglected, and k_3=100 when the median particle size is ranging from 0,2 to 0,3 mm. Because of the range of data used in the determination of the rating curves presented in Figure 1.7a and 1.7b, Colby's approach should not be applied to rivers with median sediment diameter greater than 0,6 mm and depth greater than 3 m. (Yang, 2006)

1.6.8 Engelund-Hansen (1966)

Engelund and Hansen developed a semi-empirical formula. It was produced to predict stage-discharge relationships and sediment transport in alluvial rivers. The observed grain size is ranging from 0.19 to 0.93 mm (Scheer, 2002). Both suspension sediment and bed load were measured by researchers.

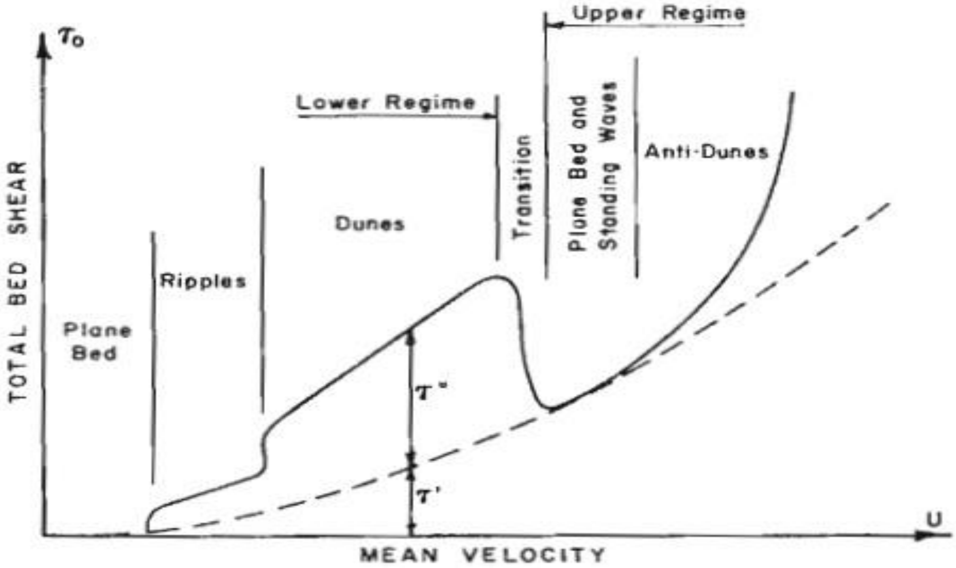

Figure 1.8: Relationship between total bed shear and mean velocity (Engelund-Hansen, 1967; National Engineering Handbook Section 3, 4-12)

As it seen, the dimensionless form of the τ_0, was divided into two parts. τ' is the first part that it is traction on the particle surface. The other part is τ'' corresponding to bed form drag.

Figure 1.8 in conjunction with Figure 1.9 shows the flow regime in which a semi-graphical solution.

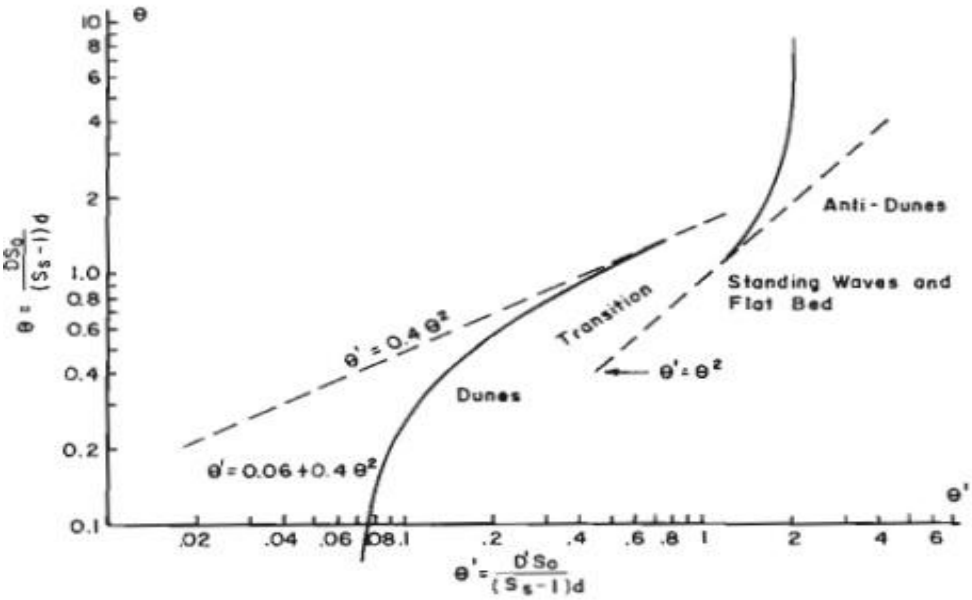

Figure 1.9 : Relationship between dimensionless forms of bed shear(From Engelund-Hansen (1967) and American Society of Civil Engineers (1975, p.135), National Engineering Handbook, Section 3, 4-13)

1.6.9 Toffeleti (1969)

Toffeleti developed an equation to compute bed material discharge. It is based on Einstein (1950) approach with three seperated zones:

1. Velocity distribution in the vertical is captured from an expression different from that used by Einstein;
2. Several of Einstein's correction factors are adjusted and combined;
3. The height of the zone of bedload transport is changed from Einstein's two grain diameters (Yang, 2006).

Total sediment load is computed by the formula. The observed grain size is ranging from 0,062 to 16 mm on experiments.

Du Boys, Schochlitsch, Meyer-Peter Müller, Einstein-Brown's formulas are generally useful to solve bed load problems.

1.7 Sediment Works in Turkey

Sediment data is usually used for dam's sizing and calculation for dead storage in Turkey. Observing sediment and finding erosion characteristic feature are helpful for engineering and also economy. Sediment works in Turkey has three part;

1. Land works
2. Lab study
3. Office study

1.7.1 Land Works

Lots of formula were improved to calculate sediments data. However, sediment works in land is the effective one even if it is expensive and hard.

Suspended sediment samples can be collected according to depth integration method which represents entire depth and profile of river. Before collecting sediments sample, measurement of discharge is applied. If discharge value is higher than long service flow value, 10 plummets (%5, %15, %25, %35, %45, %55, %65, %75, %85, %95 of total flow value); if not, 6 plummets (%8, %25, %42, %58, %75 ve %92) sediment sample are collected.

US.DH-48 is used on getting into river bed, and US.DH-49 is used on unslung situations like using lift or crane. Sediment samples are given to lab for analysing.

1.7.2 Lab Study

Sediment features of every stations are defined by the help of samples. The defined features are sediment concentration and sediment grain size distribution.

a) Calculation of Suspended Sediment Simples Concentration

Filtration method is applied. In this method, sediment sample, which is mixture of water and sediment, is filtered by filter paper. Oven drying is applied on wet sediment, it waits 2 hours at 105^{O} in oven. It gives net sediment concentration which is mixture of sand,clay and silt. After that, sediment concentration is captured by the following formula;

$$\text{Sediment Consentration (C),ppm} = \frac{Net\ Sediment(sand+clay+silt)weight\ x\ 10^6}{Sediment\ Simple\ (water+sediment)weight} \qquad \textbf{(1.28)}$$

PPM is the first letters of Part Per Million. Its unit is mg/l.

These ppm values are entered another formula and flow rate of suspended sediment is obtained;

$$Q_S = Q*C*0{,}0864 \qquad \textbf{(1.29)}$$

where Q_S: Flow rate of sediment in river (tone/day)
Q: Flow rate when Sediment simple is taken (m^3/s)
C: Sediment concentration

b) Calculation of Sediment Grain Size Distrubition

After capturing concentration of sediment, sand and mixture of clay and silt are separated by using sieve analysis. 0,0625 mm sieves are used for the analyse and consequently upper side of sieve is sand, below side is mixture of clay and silt.

The analyse gives us weight of sand and mixture of clay and silt. Average %sand and %mixture of clay and silt are acquired as well as the following formulas:

$$\text{Station average \% sand} = \frac{Total\ weight\ of\ Sand}{Total\ weight\ of\ net\ Sediment} * 100 \qquad \textbf{(1.30)}$$

$$\text{Station average \%(clay+silt)} = 100 - \text{Station average \% sand} \qquad \textbf{(1.31)}$$

1.7.3 Office Study

Suspended sediment sample is usually collected once per a month. Besides, discharge is measured every day and published as annual flow. Thus, daily suspended sediment can be calculated by using daily discharge.

Discharge (X) (tone/day), which is measured when sediment sample is collected, and discharge of sediment in river (Y), which is calculated before, have a relationship with high correlation coefficient.

This general equation is given in the following;

$$\log Y = a + b.\log X \text{ or} \quad \textbf{(1.32)}$$
$$Y = 10^a.X^b$$

a and b are described as a station coefficients. The optimal function is selected according to its correlation coefficient.

Sediment rating curve and its function are captured for every stations by using above functions. After that, daily sediment weight, its unit is tone/day, is acquired. These daily sediments are summed annually and total annual sediment weight is captured as tone/year. Every year total annual sediment weights, which is calculated during sediment observation period, are summed, and result is divided total year and so long service average suspended weight is captured as tone/year. The last result is divided sediment net rain fall area and long service average sediment yield of station is calculated as tone/year/km^2.

1.8 Literature Review

Sediment load was studied by many researchers. Fuzzy logic, fuzzy logic and wavelet analyses combination, sediment rating curve, artificial neural network, gene expression programing, Kalman filtering, triple diagram models, etc. were used for prediction of sediment load. Sen, Z.., Altunkaynak, A. and Ozger, M. (2004) were used perceptron Kalman filtering procedure to predict sediment concentration. Altunkaynak, A. (2011) was also used Geno-Kalman filtering to predict suspended sediment concentration. Altunkaynak, A. and Wang, K. (2010) used triple models for prediction of suspended solid concentration in Lake Okeechobee.

As it is mentioned before, fuzzy logic, wavelet methods and their combination are used for forecasting sediment load. These are very useful tools and used in many area. Many researchers have used these methods in predictive models.

One of them is TUBITAK project, was conducted between 2006-2009 at Kayseri Erciyes University, about modelling sediment load by fuzzy-neuro approach on a river. Kişi et. al. (2006) were used fuzzy logic approach to estimate suspended sediment concentration from streamflow. The result showed us the fuzzy model was able to produce much better results than rating-curve models. The abilities of neuro-fuzzy (NF) and neural network (NN) approaches to model the streamflow-suspended sediment relationship were investigated by Kişi (2005). It was said that the NF model gives better results than other methods.

Application ANN and wavelet conjunction model were used on another study (Rajaee et al., 2010). Result of this study showed us wavelet-artificial neural network (WANN) is better than artificial neural network (ANN), multilineer regression (MLR) and sediment rating curve (SRC) models in prediction. Wavelet-ANN method was used to predict suspended sediment load study and on this research, measured data were decompused into wavelet components by using discreet wavelet transform and the new wavelet series were used as input for the ANN model. This model provided a good fit to observed data for the testing period (Partal and Cigizlioglu, 2008). Moosavi et al. (2014), searched on wavelet-ANN and wavelet-ANFIS to determine which one gives better conclusions, and it was seen that wavelet-ANFIS model is better than wavelet-ANN. Homayouni and Amiri (2011) compared wavelet, fuzzy logic and ANN approach to predict stock price. According to researchers, stock market prediction is very difficult, because it depends on several unknown factors. They used Tehran stock market prices to predict and they proposed combination of wavelet, fuzzy logic and ANN approach. It gave accurate results than wavelet model, fuzzy logic model and ANN model respectively.

Fuzzy logic and wavelet combination method were usually researched with other methods like neuro, artificial neural network. Some of them are given in the following. Rajaee et al. (2010), investigated the prediction of suspended sediment load in a gaugin station in the USA by using neuro-fuzzy, conjuction of wavelet analysis and neuro-fuzzy as well as conventional sediment rating curve models. Result of this study showed that the wavelet analysis and neuro-fuzzy model are better than the fuzzy and sediment rating curve models. Shiri and Kisi (2012) studied estimation of daily suspended sediment load with wavelet conjunction models. Firstly, the convenient gene expression programing (GEP), neuro-fuzzy (NF) and artificial neural network (ANN) techniques were applied to estimate suspended loads by using recorded daily river discharge and sediment load data. The models were compared to each other with statistic criteria. The result showed that GEP model performed better than NF and ANN models. Secondly, the discrete wavelet conjuction models with convenient GEP, NF and ANN techniques were constructed and compared with one another. Finally the result showed that the wavelet-GEP model performed better than the wavelet-NF and wavelet-ANN models. Mirbogheri and friend’s study (2010) included four models; artificial neural networks (ANNs), neuro-fuzzy model (NF), conjuction of wavelet analysis and neuro-fuzzy (WNF) model and conventional sediment rating curve (SRC) method. This studies results showed that the NF model performed better than the ANN and SRC models. However the best model was approved the WNF model which was in satisfactory agreement with the measured data. Alikhani (2009), researched combination of neuro fuzzy and wavelet approaches in river engineering. In that study, three models were investigated and compared one another. These were neuro-fuzzy (NF), conjuction of wavelet analysis and neuro-fuzzy (WNF) and conventional sediment rating curve (SRC) models. The result of the study illustrated that the advantage of WNF model to NF approach in similation of suspended time series. A conjunction method (wavelet-neuro-fuzzy) for prediction of precipitation were used in Turkey. The daily precipitation data of three stations were used and the wavelet-neuro-fuzzy model provided good results. The observed daily precipitation values were decomposed some sub-series by using discrete wavelet transform and than suitable sub-series were used as inputs to the neuro-fuzzy models (Partal and Kişi, 2007). In China, two researchers studied on combination of wavelet and fuzzy combined with statistical correlation for runoff prediction of Yamadu station at Sinkiang province and they found the prediction accuracy of that model is satisfying (Yong and Zhi-Chun, 2011). The other study is from Texas by Ozger et. al. (2012). Wavelet-fuzzy logic (WFL) combination method, artificial neural network (ANN) model and wavelet-artificial neural network (WANN) model were compared. As a result of this study, WFL showed better results than other methods. Besides that, Ozger et. al. (2011) developed a WFL model for meteorological variables. The model was applied to ten climate divisions in Texas and its performance was compared with conventional fuzzy logic model. The results showed that the WFL model outperformed the FL model. Fire detectors run was researched by using fuzzy-wavelet combined method and the result of study indicates that it is greatly contributed to translate a new understanding of flames dynamics into algorithms that are capable of discriminating between a real fire and possible interferences, such as those caused by the sun's radiation (Thuillard, 2000). Combined fuzzy logic and wavelet was used on electric cable systems to find the exact location of a fault in a distribution cable (Moshtagh and Aggarwal, 2004). Reddy and Mohanta (2007) used wavelet-fuzzy combined approach for digital relaying of electricity things. Wavelet and fuzzy logic combination method was also used for behaviour of humans. In that study, researchers made an algorithm to diagnose the constitutional jaundice (Ali et al., 2009). Ngaopitakul (2012), used discrete wavelet transform and fuzzy logic combination for transmission systems in Thailand. The discrete wavelet transform was used to detect the high frequency components from the system's signals. The variations of first scale high frequency component that detects fault were used as an input for the fuzzy logic. FL was also compared with the comparison of the coefficients DWT technique. As a conclusion, the proposed method gave accuracy. Non-stationary time series was analyzed by fuzzy-wavelet method in England. In this study, discrete wavelet transform was used to preprocess a non-stationary time series, than non-random wavelet companents was fuzzied for forecasting. It showed that wavelet-fuzzy combination has better performing than pure fuzzy modeling (Popoola et al., 2004). Binh et al. (2012) researched prediction of the electrical loads by using the maximum overlap discrete wavelet transform (MODWT) and fuzzy logic. In the study, the fuzzy-rules were determined in order to carry out the forecasting for each individual wavelet sub-series and after that, the individual wavelet sub-series forecasts were recombined to give the final result. Khan et al. (2012) studied on wavelet fuzzy-neural network (WFNN) control strategy to examine the performance of full car active suspension system and it gave more accurate results than passive, semi-active and PID controller. Chiu et al. (2013) used combination of neuron network and fuzzy logic with wavelet packets to classify sleep stages. Combination of neuron network and fuzzy logic was used to recognize the sleep stages in each epoch. Average accuracy of the experiment was 93,79%. Hai and Chen (2012) used power quality evaluation approach based on wavelet packet decomposition and fuzzy logic. In this research, first, the power quality indices are redefined in the time frequency domain by using wavelet packet decomposition then a fuzzy evaluation model is used. The approach helped reduced the size of data processed which is required in modern power system applications. Saghafinia et al. (2012) used the adaptive continuous wavelet transform and fuzzy logic to detect the motor fault condition of a large size motor. The experiment result showed that the proposed method detect motor fault conditions accurately. Sasi et. al. (1997), utilized wavelet transform and fuzzy logic approach for handwritten character recognition and they proved that wavelet transform reduces cost over other transforms and fuzzy logic approach helps to get wide range of writing variation. Karatepe and Alcı (2005), compared fuzzy wavelet combination model and wavelet model. The study showed that fuzzy logic and wavelet model achieves high function approximation accuracy and fast convergence. Xiao and Sun (2003), proposed a framework of a traffic prediction model by using fuzzy-neural network and wavelet decomposition. The study provided a new procedure which is fast and easy to implement. The wavelet part provide fully comprehensive input to the next step of the prediction framework. The researchers have proved that combination models with wavelet techniques improve the accuracy of prediction models. In this study we used wavelet and fuzzy method provides some advantages over conventional approaches.

1.9 Study Area

The data obtained from two basins which are “Muteferrik Dogu Karadeniz Basin (Miscellaneous Eastern Blacksea Basin)” and “Coruh Basin”. The basins are located in the north-east part of Turkey, Eastern Blacksea Region. Table 1.2 shows measurement stations located in the basin. The study area is shown in Figure 1 and 2. Both basins are open basins, that basin’s streams have an access to sea.

Table 1.2: Location of Stations

Basin (DSI Number)	**Miscellaneous Eastern Blacksea Basin (22)**	**Coruh Basin (23)**
Station		
Bolamancayi-Orencik	+	
Degirmenderesi-Esiroglu	+	
Firtina Deresi-Topluca	+	
Fol Deresi-Bahadirli	+	
Iyidere-Simsirli	+	
Melet Cayi-Aricilar	+	
Termecayi-Gokceli	+	
Bertasuyu-Baglik		+
Coruh-Camlikaya		+
Coruh-Ispir		+
Oltusuyu-Asagikumlu		+
Oltusuyu-Coskunlar		+

Muteferrik Dogu Karadeniz Basin is located in North-East part of Turkey, between 40ᴼ15’- 41ᴼ34’ north latitudes and 36ᴼ43’- 41ᴼ45’ east longitudes. The basin has Blacksea in north, Kackar mountains on its eastwards, Yamanli, Soganli, Kemer, Igdir mountains on its southern, Carsamba plain on its westwards. The basin has big and high mountainside. Vegetation cover of the basin shows differences from inshore to hinterland regions. Inshore part of the basin is rainy and has a mild climate, so plant cover is exuberant. Hinterland part is less warmy and rainy so the plant cover is meadow moreover some parts are rock face. It is expected that large part of the sediment transported in streams is originated from mountanious area where the plantation is weaker and basin slopes are high. Land use of Muteferrik Dogu Karadeniz Basin is presented in Table 1.3 (OSİB, 2012; Tübitak MAM CBS, 2012)

Table 1.3: Land use of Muteferrik Dogu Karadeniz Basin

Land Use	**Area (ha)**	**Area (%)**
Forest and semi-natural area	1.500.072	66
Agricultural area	761.201	33
Artificial area	12.815	0,6
Surface water	10.351	0,5
TOTAL	2.284.439	100

Figure 1.10: Map of Miscellaneous Eastern Blacksea Basin

Coruh basin is located on North-East part of Turkey and South of Blacksea, adjacent to the border of Georgia. Coruh river starts west side of Bayburt and crosses over Georgia and flows into Blacksea. It has three main tributary naming as Tortum, Oltu and Berta. Middle part of Coruh river, below of Oltu stream and entire Berta stream's area are forest, the other part is generally meadow. According to Landsat photos which are taken in September 2001, Coruh basin land use is presented below;

Table 1.4: Land use of Coruh Basin

Land Use	**Area(ha)**	**Area(%)**
Forest	440.227	21,7
Semi-natural area	236.518	11,7
Agricultural area	280.839	13,9
Meadow area	935.221	46,2
Other	131.601	6,5
TOTAL	2.024.406	100

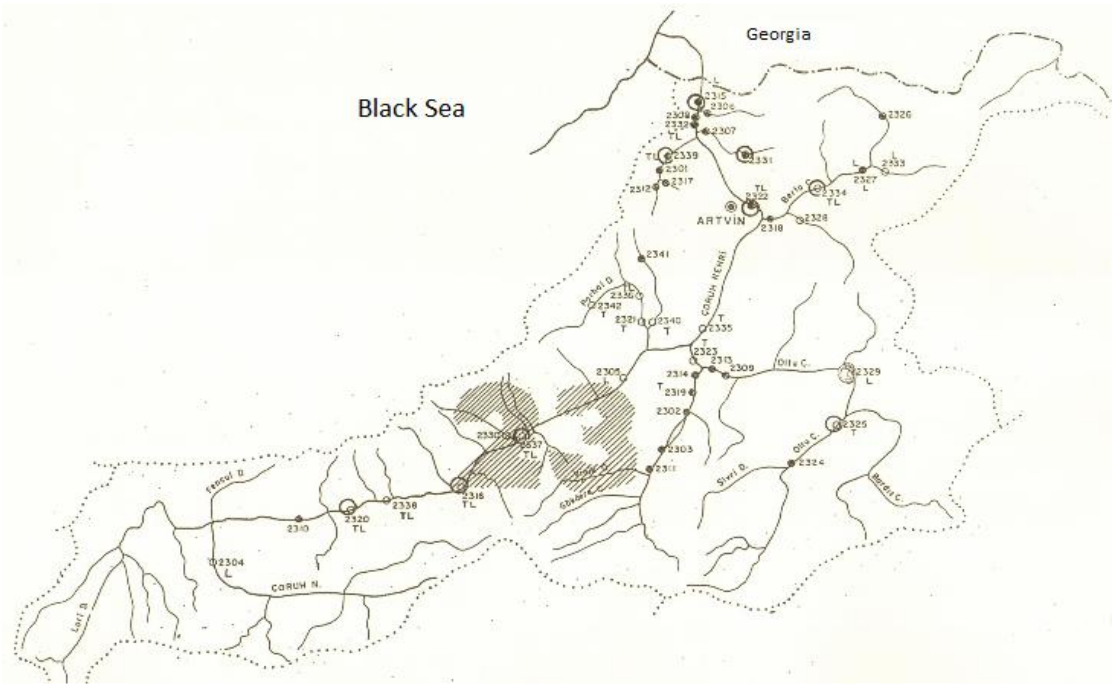

Figure 1.11: Map of Coruh Basin

1.10 Data

Data from October, 1999 to January, 2006 was used for the study and it was taken from DSI, General Directore of State Hydraulic Works. Data units are taken in two types, tone/year and parts per million (ppm).

Statical analyses are important for researchers. The statistical properties of the sediment discharge and flowrate are given in Table 1.5 and Table 1.6. We studied on average, standart deviation, coefficient of skewness and coefficient of variation. Sediment's unit was taken as tone/year and flow's unit was taken as m^3/s.

Table 1.5: Statical Analyses of Sediment discharges at Stations

Station Name	Station ID	Observation period (month.year)	Average (t/year)	St. Deviation	Coef. of Skewness	Coef. of Variation
İyidere-Şimşirli	2218	10.99-12.05	279,33	868,88	5,38	3,11
Folderesi-Bahadirli	2228	10.99-12.05	368,98	2882,15	8,63	7,81
Firtinaderesi-Topluca	2232	10.99-12.05	218,98	801,93	6,62	3,66
Meletcayi-Aricilar	2238	10.99-12.05	224,23	869,89	6,39	3,88
Termecayi-Gökceli	2245	10.99-12.05	29,07	104,70	7,18	3,60
Degirmendere-Esiroglu	2251	10.99-12.05	419,78	2052,51	6,38	4,89
Bolamancayi-Orencik	2259	10.99-12.05	2504,92	21547,62	9,00	8,60
Coruh nehri-Ispir	2316	10.99-12.05	1118,94	5128,19	7,92	4,58
Oltusuyu-Asagikumlu	2325	10.99-12.05	1822,11	7710,16	6,49	4,23
Oltusuyu-Coskunlar	2329	10.99-12.05	3944,17	11519,99	3,91	2,92
Bertasuyu-Baglik	2334	10.99-12.05	1899,04	8488,86	7,83	4,47
Coruh nehri-Camlikaya	2337	01.99-12.05	2633,26	7976,65	4,57	3,03

Table 1.6: Statical Analyses of Flowrate at Stations

Station Name	Station ID	Observation period (month.year)	Average (m^3/s)	St. Deviation (m^3/s)	Coef. of Skewness	Coef. of Variation
İyidere-Şimşirli	2218	10.99-12.05	26,48	21,83	1,72	0,82
Folderesi-Bahadirli	2228	10.99-12.05	4,11	7,19	5,30	1,75
Firtinaderesi-Topluca	2232	10.99-12.05	30,39	25,30	1,67	0,83
Meletcayi-Aricilar	2238	10.99-12.05	9,40	16,35	5,30	1,74
Termecayi-Gökceli	2245	10.99-12.05	6,27	7,86	2,28	1,26
Degirmendere-Esiroglu	2251	10.99-12.05	12,93	19,02	3,22	1,47
Bolamancayi-Orencik	2259	10.99-12.05	19,00	44,48	7,55	2,34
Coruh nehri-Ispir	2316	10.99-12.05	40,33	59,81	3,91	1,48
Oltusuyu-Asagikumlu	2325	10.99-12.05	6,55	8,00	2,53	1,22
Oltusuyu-Coskunlar	2329	10.99-12.05	16,57	20,75	2,20	1,25
Bertasuyu-Baglik	2334	10.99-12.05	26,80	30,98	2,44	1,16
Coruh nehri-Camlikaya	2337	01.99-12.05	62,96	80,16	2,52	1,27

We can obtain some information about study area from sediment-discharge time table.

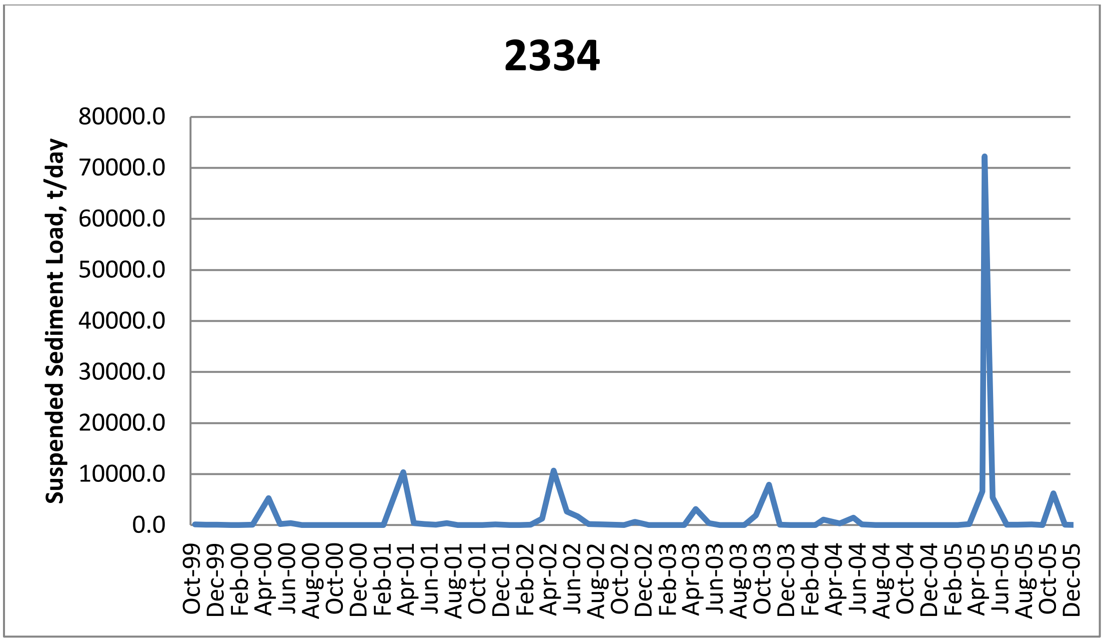

Figure 1.12: Suspended Sediment Load time series of Bertasuyu-Baglik Station in Coruh Basin

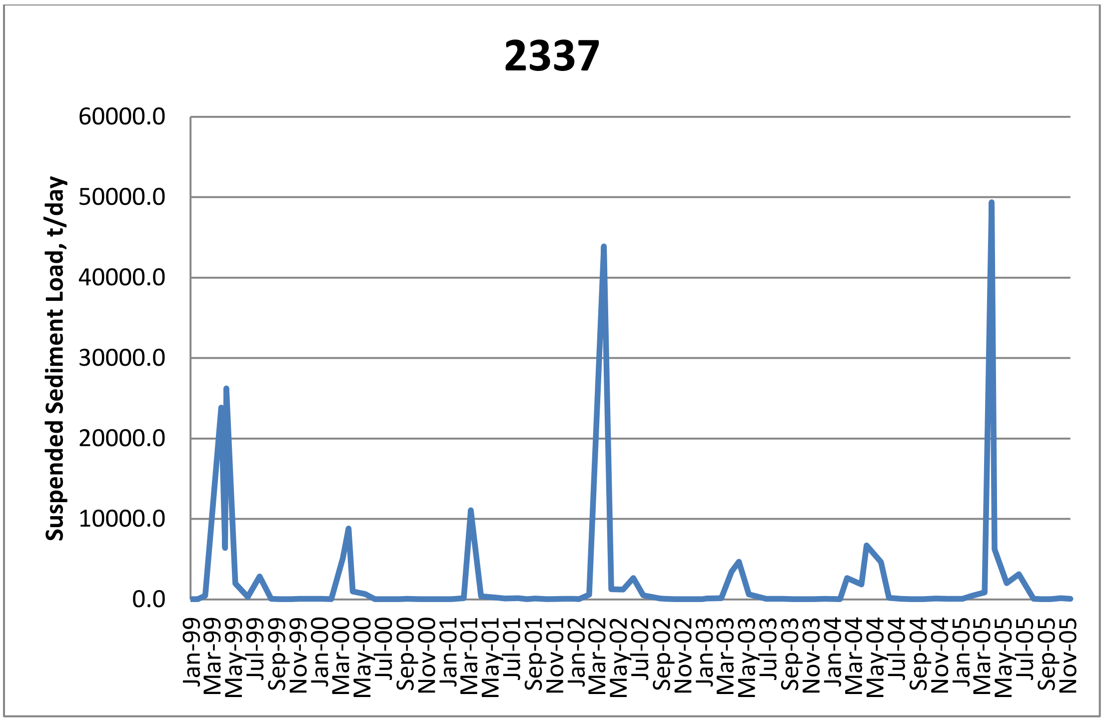

Figure 1.13: Suspended Sediment Load time series of Coruh River-Camlikaya Station in Coruh Basin

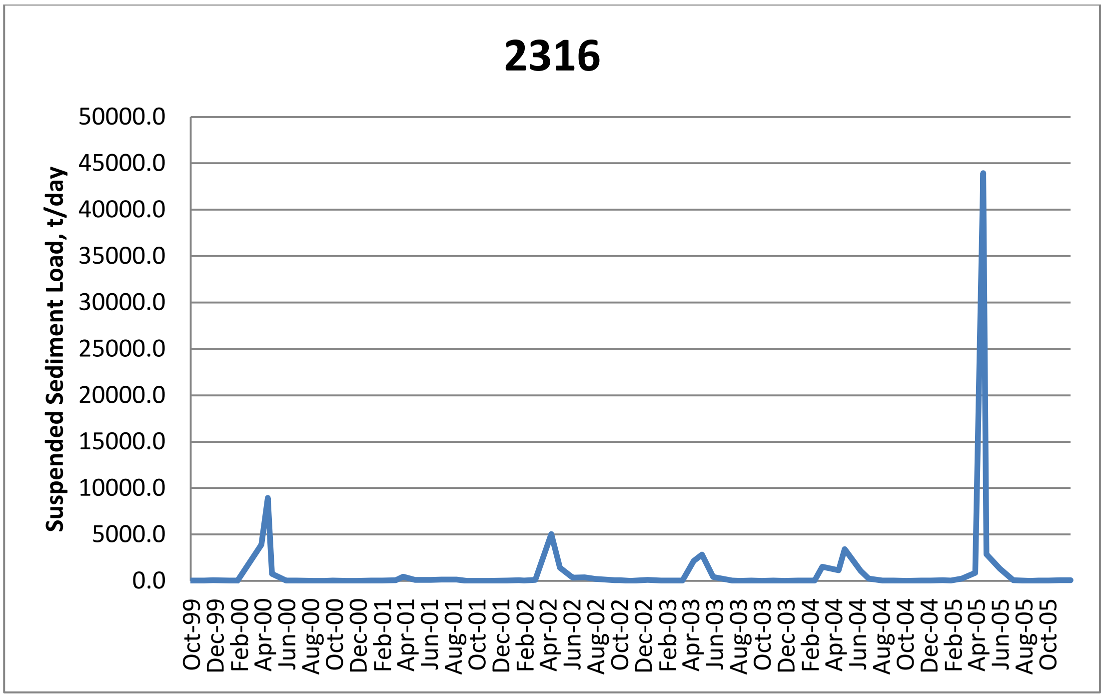

Figure 1.14: Suspended Sediment Load time series of Coruh River-Ispir Station in Coruh Basin

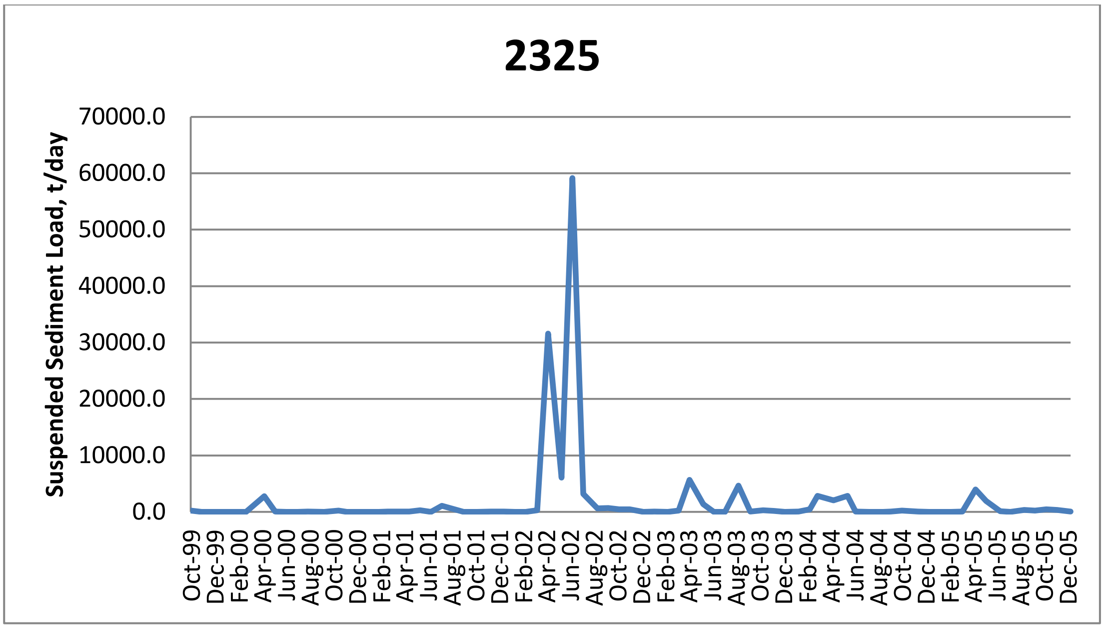

Figure 1.15: Suspended Sediment Load time series of Oltusuyu-Asagikumlu Station in Coruh Basin

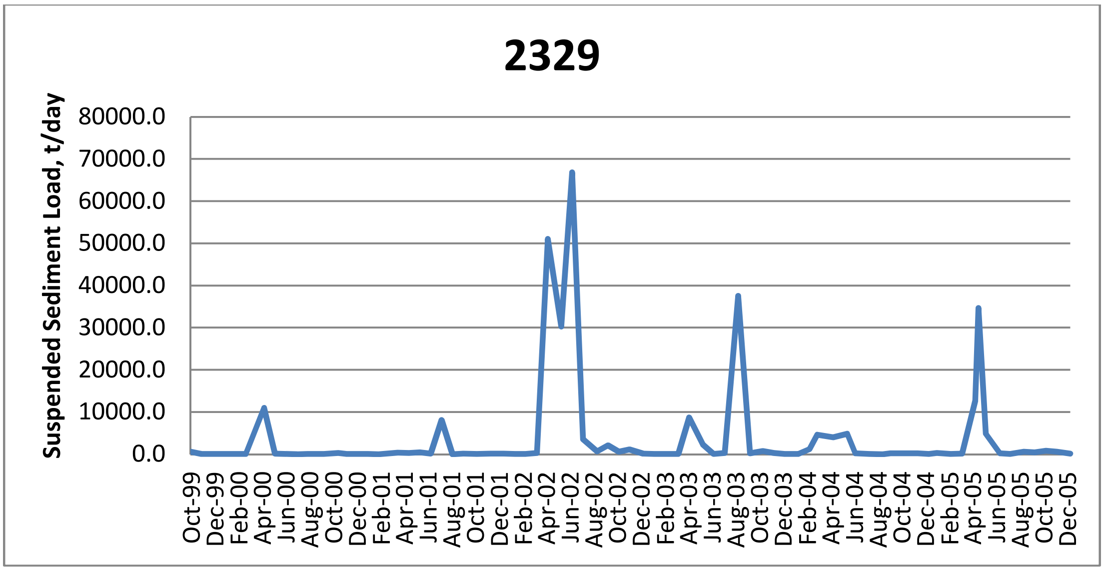

Figure 1.16: Suspended Sediment Load time series of Oltusuyu-Coskunlar Station in Coruh Basin

Figure 1.12-16 represent suspended sediment load time series of Coruh Basins stations.

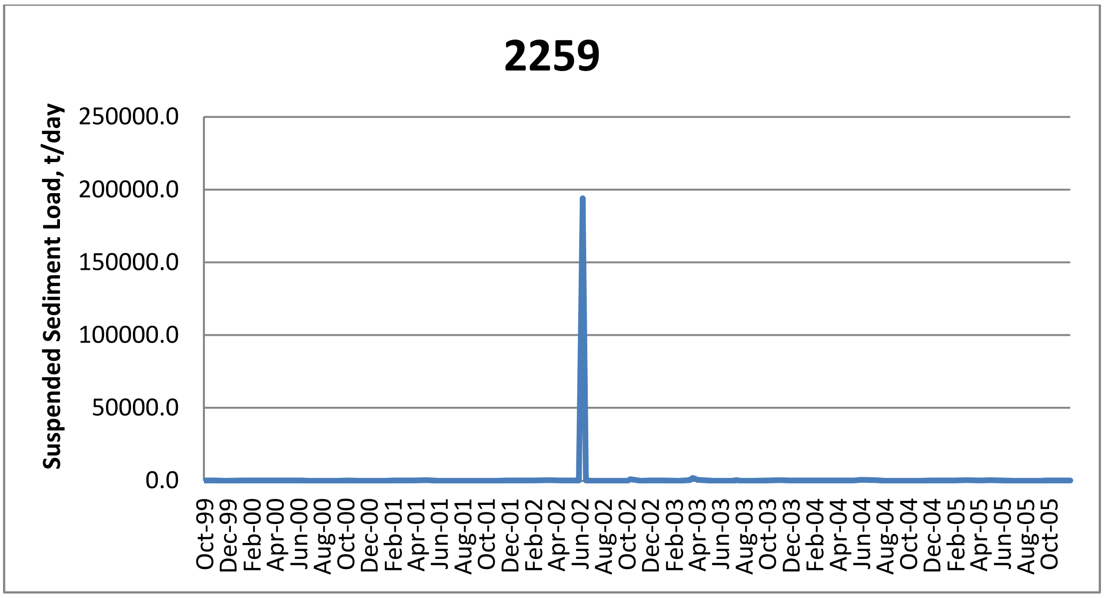

Figure 1.17: Suspended Sediment Load time series of Bolaman-Orencik Station in Miscellaneous Eastern Blacksea Basin

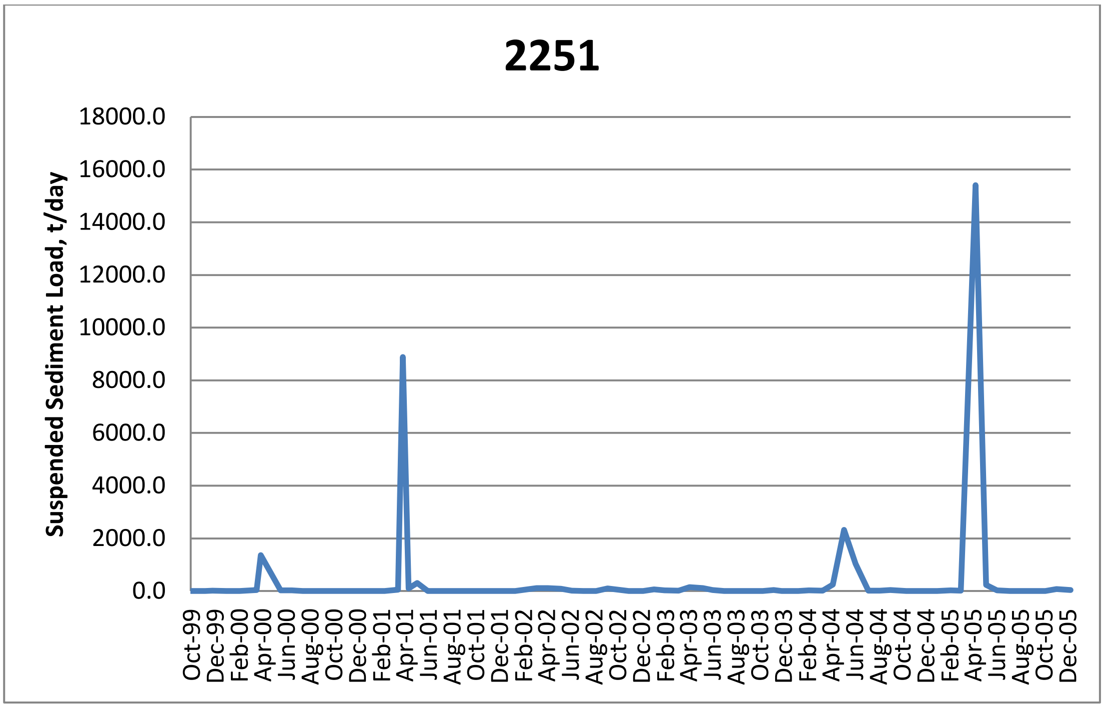

Figure 1.18: Suspended Sediment Load time series of Degirmenoglu-Esiroglu Station in Miscellaneous Eastern Blacksea Basin

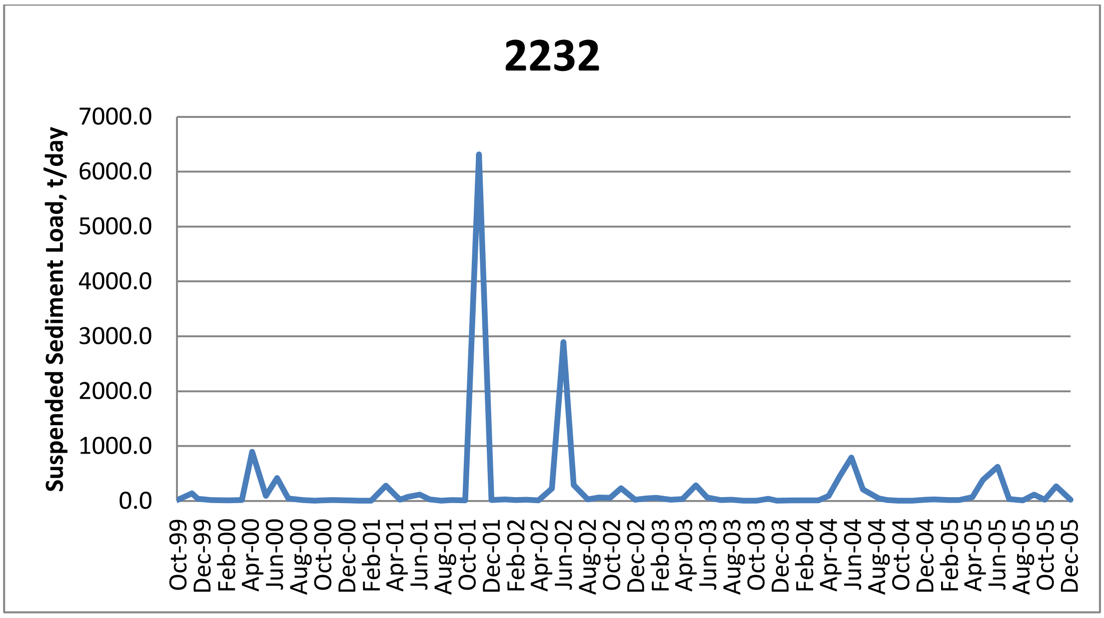

Figure 1.19: Suspended Sediment Load time series of Firtina stream-Topluca Station in Miscellaneous Eastern Blacksea Basin

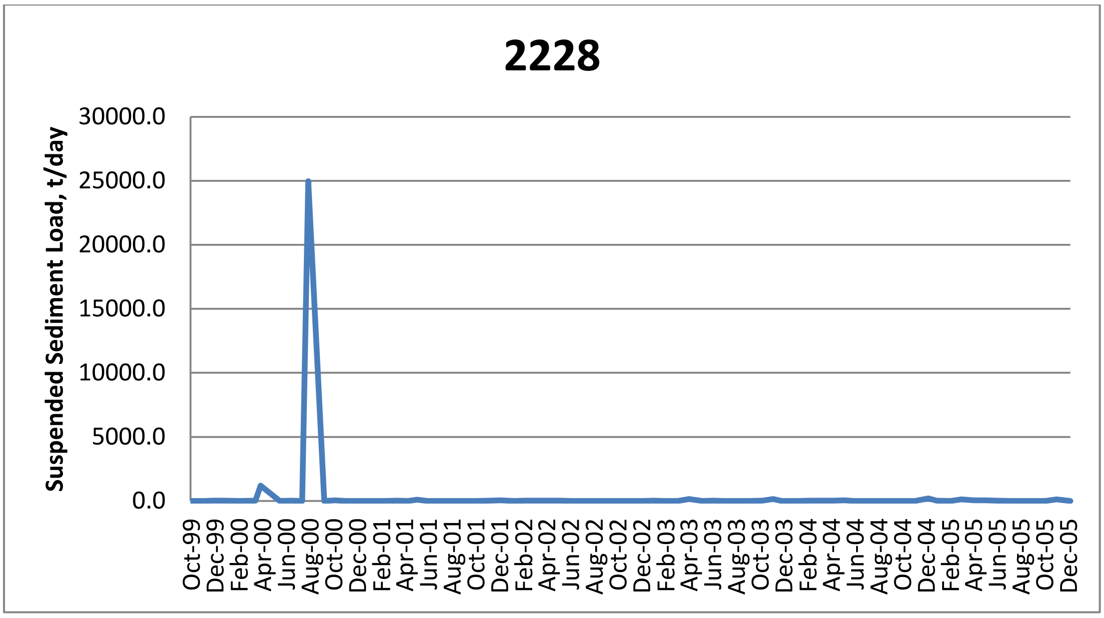

Figure 1.20: Suspended Sediment Load time series of Folderesi-Bahadirli Station in Miscellaneous Eastern Blacksea Basin

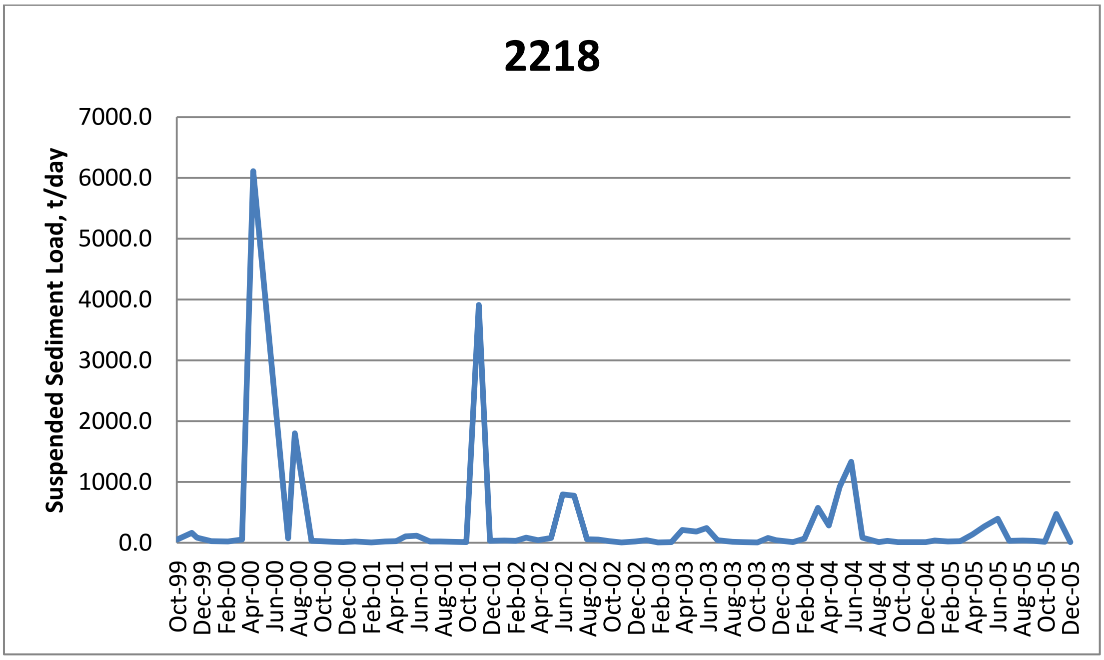

Figure 1.21: Suspended Sediment Load time series of Iyidere-Simsirli Station in Miscellaneous Eastern Blacksea Basin

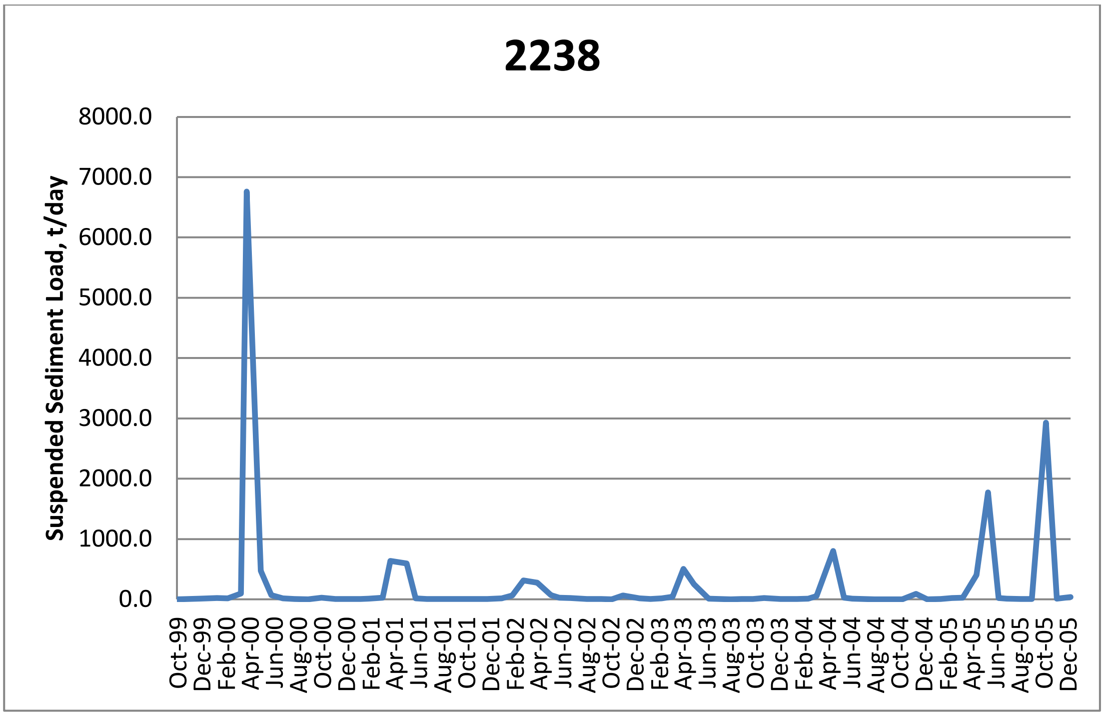

Figure 1.22: Suspended Sediment Load time series of Meletcayi-Aricilar Station in Miscellaneous Eastern Blacksea Basin

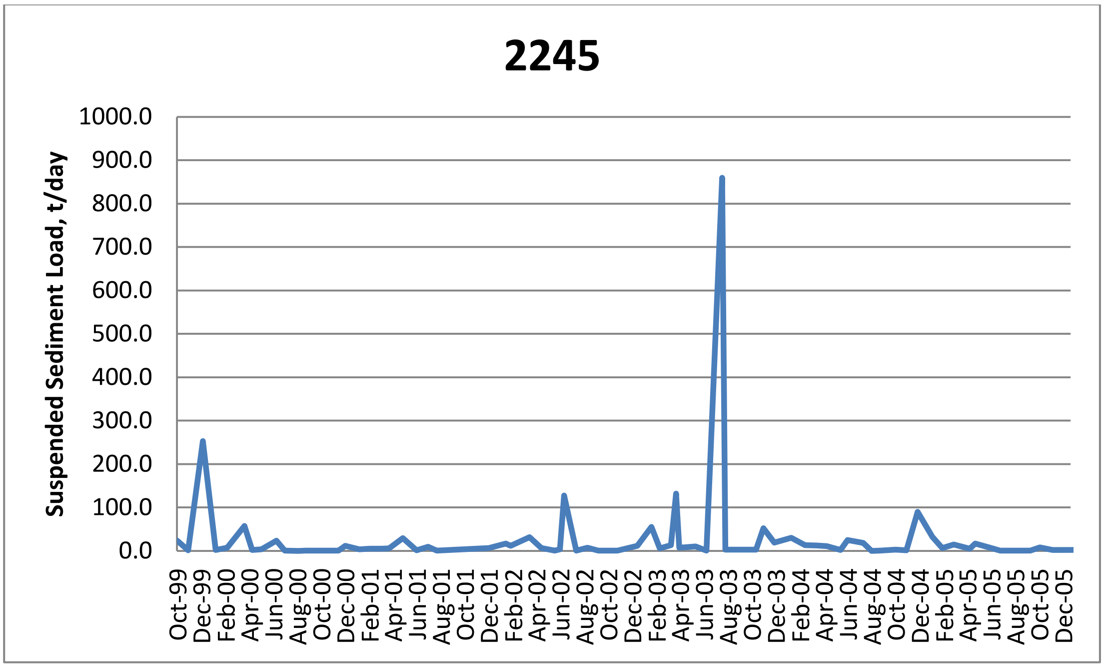

Figure 1.23- Suspended Sediment Load time series of Termecayi-Gokceli Station in Miscellaneous Eastern Blacksea Basin

Stations 2334, 2337, 2316, 2325 and 2329 located in Coruh Basin has high sediment values in April-May period as can be seen from the Figures 1.12-1.16, respectively. The flood in Coruh river overflowed originated from excessive precipitation and snowmelt on April 2005, caused overabundance sediment transportation in the river. According to newspapers, the discharge of river was the highest value last 37 years from that year[(1)]. As can be seen from the Coruh basin's figures, it effected the sediment discharge values too. In general, the high sediment values is seen in April-May period. It is possible that snowmelt is also other factor that caused high sediment discharge.

Stations 2259, 2251, 2232, 2228, 2218, 2238 and 2245 located in Miscellaneous Eastern Blacksea Basin has high sediment values in April-May and October-December period as can be seen from Figure 1.17-1.23, respectively. It can be said that the reason of high discharge value in April-May period is snowmelt, in October-December period is excessive precipitation.

[1] Akbaş, H., 27.04.2005. From http://www.hopam.com/icerikdetay.php?iid=1047 at 22.08.2013.

2 METHODS

2.1 Wavelet Analyses

2.1.1 Historical Overview

In 1807, Joseph Fourier, is a mathematician from France, developed a theorem which name is same as his name. This theorem represents a signal with a series of coefficients based on an analysis function. Besides, most of periodic function, also trigonometric function, can be dilated in endless series and integrals. It can be said that Fourier led other researchers to develop wavelet analyses approach. For the first time, Alfred Haar mentioned wavelets in an appendix of his PhD thesis in 1909. One of the property of the Haar wavelet was that it vanishes outside of finite interval. Unfortunately, Haar wavelet is not continuously differentiable which somewhat limits their applications (Graps, 1995). In the 1930s, Paul Levy, a physicist, found scale-varying that Haar basis function superior to Fourier basis functions. Scale varying basis function can be explained like this;

A basis function varies in scale by chopping up the same function or data space using different scale sizes. For example, we have a signal over the domain from 0 to 1. We can divide the signal with two step functions that range from 0 to 1/2 and 1/2 to 1. Then we can divide the original signal again by using four step functions from 0 to 1/4, 1/4 to 1/2, 1/2 to 3/4, and 3/4 to 1. And so on. Each set of representations code the original signal with a particular resolution or scale (Strang, 1992). In 1981, Alex Grossman and Jean Morlet, a physicist and an engineer, brought out wavelets based on physics. Not long after, Stephena Mallat and Yves Meyer developed a multiresolution anaysis with using wavelets in 1986. After decade, around 1998, Inglis Daubechies developed that theory and established her own family of wavelets. This work has led to wavelet applications until today.

2.1.2 Fourier Analyses

2.1.2.1 Fourier Theorem

The cornerstone of Fourier's theorem consists of a superposition of sines and cosines. According to the theorem, signals can be analyzed easier with representation a serial.

$$f(x) = a_0 + \sum_{k=1}^{\infty}(a_k \cos kx + b_k \sin kx) \tag{2.1}$$

f(x) represents superposition of sinus and cosinus.

Coefficients of Fourier (a_0, a_k and b_k) are defined as the following equations:

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(x)dx \tag{2.2}$$

$$a_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\cos(kx)\,dx \tag{2.3}$$

$$b_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\sin(kx)\,dx \tag{2.4}$$

Signals can be shown with complex exponential form and its function;

$$x(t) = \sum_{k=-\infty}^{\infty} c_k\, e^{jk\omega t} \tag{2.5}$$

We can see complex Fourier coefficient in that function and it is defined as following equation;

$$c_k = \frac{1}{T_0}\int_{T_0} x(t)\, e^{-j\omega t}\, dt \tag{2.6}$$

Both notation of Fourier series with complex numbers and trigonometric have same features except amplitude. Notation of amplitude in trigonometric is twice value of complex numbers.

2.1.2.2 Fourier Transform

Fourier's approach was an evolution for mathematicians. After that, researchers utilazed Fourier theorem to analyse a signal in the time domain for its frequency content. Fourier transform decomposes a signal into complex exponential function of different frequencies. This transform is shown with f(w) in this equation;

$$f(\omega) = \int f(t).\, e^{-j\omega t}\, dt \tag{2.7}$$

$$e^{-j\omega t} = \cos(\omega t) + j\sin(\omega t) \tag{2.8}$$

Frequency features of signals are captured easily by using fourier transform. On the other hand, we can not acquire when frequency occurs in the signal. This is one of major disadvantage of fourier transforms. If the disadvantages of Fourier transform is listed, it can be seen that;

- It cannot provide simultaneous time and frequency localization.
- It is not useful for analyzing time-variant, non-stationary signals.
- It is not appropriate for representing discontinuities or sharp corners.

Fourier transform can be classified into 3 parts.

a. Discrete Fourier Transform

Discrete Fourier transforms based on estimating Fourier transform function from a significant area of signal. The selected area is supposed to represent of a signal. Discrete Fourier Transfrom is not applicable in practice. However, it is necessity for Fourier transform on field of computers, etc where does not keep endless knowledge.

b. Fast Fourier Transform

Fast Fourier transform is developed by Cooley and Tukey in 1965. It is similar to discrete Fourier transform and it is very useful algorithm to calculate discrete Fourier transform. Calculating of discrete Fourier transform consumes lots of time for large signals (large N). Fast Fourier transform does not take noisy number of intervals N, but only the intervals $N=2^m$. The reduction in the number of intervals makes the fast Fourier transform be faster. That’s why this is called fast Fourier transform.

c. Short-time Fourier Transform

Fourier transform defines all components of a signal. The stationary signal’s frequency components are same in all time. That’s why it is unnecessary to take time information of stationary signals (Pillis and Radunsnkaya, 2003; Fidan, 2006)

However, all signals are not non-stationary. That type of signals are called dynamic signals. For dynamic signals, not only frequency components but also time intervals of frequency are important. Short-time Fourier transform was developed to obtain answer for that situations, by Dennis Gabor in 1946. The approach is captured missing time information, by using windowing technique like discrete Fourier transforms, in significant time intervals (Valens, 1999).

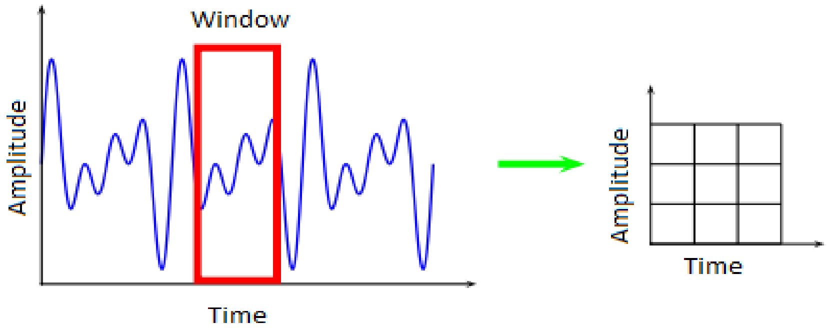

Figure 2.1: Short-time Fourier Transform (Fidan, 2006)

$$\text{STFT}_{x}^{W}(t', w) = \int_t [x(t).W(t-t')].e^{-j\omega t}\,dt \qquad \textbf{(2.9)}$$

In this function; x(t), W, w, t' represent a signal, windowing function, frequency parameter and time parameter respectively.

By using short-time Fourier transform, it is possible to acquire calculation of different transform values in time intervals in addition to time information. Both time and frequency information can be obtained from the signal. The performance of short-time Fourier transform analysis depends on the chosen window. For instance, a rectangular window, a triangular window and Hamming type can be taken. If antecedent signal is periodic and short or both starting and ending amplitudes are same, rectangular window function should be selected. If the signal is not periodic, triangular window function should be selected.

Besides shape of window, the lenght, is another important features. A long window gives a good frequency resolutions but an worthless time resolution. A short window gives better time resolution. However, different frequencies are not identified well. It is not possible to capture both a good time resolution and a good frequency resolution according to Heisenberg inequality (Rioul and Vetterli, 1991).

2.1.3 Fourier Transform to Wavelet Transform

As mentioned earlier, we cannot obtain accurate resolution for frequency and time together according to Heisenberg inequality. To obtain accurate results, an approach, it is called as multiresolution analsis, was developed. Analyzing a signal at different frequencies with different resolutions became possible. According to the approach, low frequency continues for the all duration of the signal, whereas high frequency appears time to time with short increases.

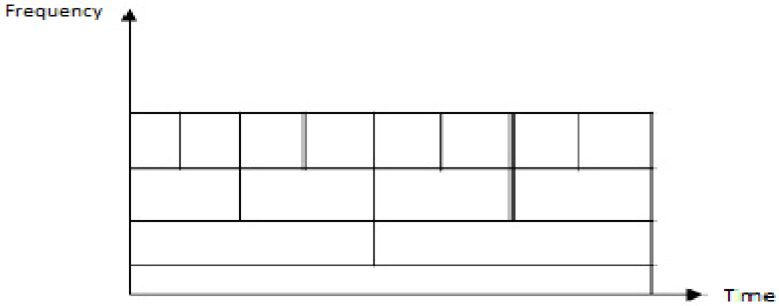

Figure 2.2: Multiresolution time-frequency plane (Merry, 2005)

The wavelet analysis, or wavelet transform, is the last and best way for practical applications. It provides to acquire simultaneous time and frequency localization. The analysis decomposes a signal into shifted and scaled versions of the wavelet function, ψ(t). The analyzing wavelet function ψ(t), is also called as the mother wavelet.

2.1.4 Wavelets

The mean of wavelet is small wave and its shape tends to be asymetric and irregular unlike sine waves. It is schematically displayed in Figure 3.

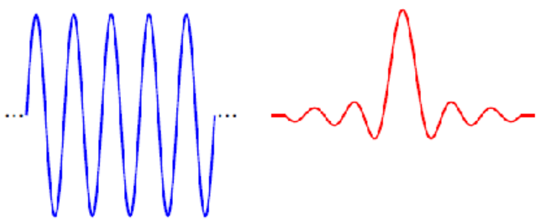

Figure 2.3: A Sine Wave and Wavelet

Wavelet analysis provides to consider a signal in time and scale plane. The time part represents beginning of wavelet formation and the scale part gives information about regularity. Both sinus wave's and wavelet's scale factors are schematically displayed in Figure 2.4.

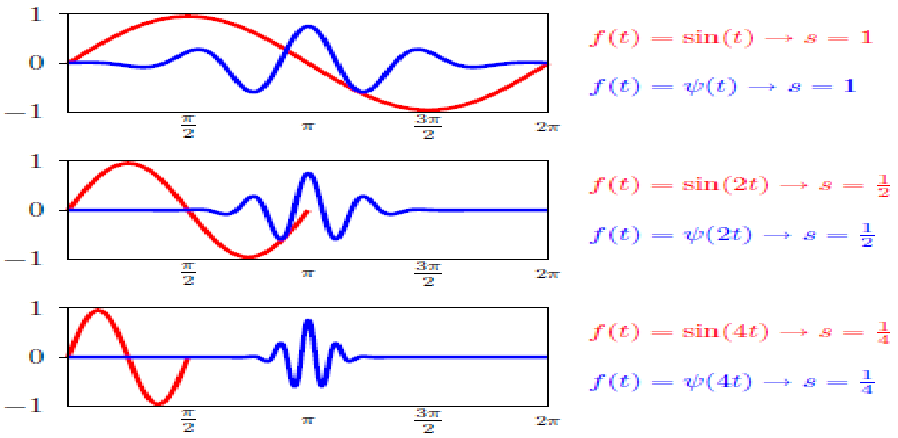

Figure 2.4: Sinus wave and Wavelet's scale factors (Abbak, 2007)

A function shranks proportionately along horizantal. Scaling factor is symbolised with s. In short, if "s" decreases, the wavelet shranks proportionately.

We mentioned about the analyzing wavelet function, ψ(t). It is classified as a wavelet if the following functions are satisfied;

$$\int_{-\infty}^{\infty} \psi(x)dx = 0 \qquad \textbf{(2.10)}$$

$$\int_{-\infty}^{\infty} \psi^2(x)dx = 1 \qquad \textbf{(2.11)}$$

All ψ(t), must be net value function at first, functions are classified as a wavelet if that functions are satisfied (Percival and Walden, 2002; Abbak, 2007).

Wavelet analyses can be investigated in two sections;

2.1.4.1 Continuous Wavelet Transform

The continuous wavelet transform is defined as in the following;

$$CWT(T,s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-T}{s}\right) dt \qquad \textbf{(2.12)}$$

The transformed signal CWT(T,s) is a function of the translation parameter T, specifies the location of the wavelet in time, and the scale parameter s. The mother wavelet is represented with f(t). The elements in CWT(T,s) are called wavelet coefficients, each wavelet coefficient is associated to a frequency and a point in the time domain. As a conclusion of CWT, a lot of wavelet parameters, C, are captured.

Continuous wavelet transforms algorithm is obtained in 5 steps;

1. Take a wavelet and compare with origin point of original signal,
2. Calculate the correlation parameter C between the wavelet and the signal; the greater the parameter the greater the similarity,

3. Scroll rigth the wavelet a bit, then repeat 1st and 2nd steps until entire of signal is completed,

4. Scale the wavelet, then repeat 1st, 2nd and 3rd steps,

5. Repeat 1st and 4th steps for all scaling (Abbak, 2007).

After these steps, different parameters from different parts of the signal is captured. The parameters is the outcome of the regression results.

2.1.4.2 Discrete Wavelet Transform

If wavelet analysis is applied for entire scaling, a huge data space is captured but it takes long time for translating and besides analysing (Rioul and Vetterli, 1991; Fidan, 2006). That’s why researchers regarded particular scaling and study within. Discrete wavelet transform is used to reduce that calculations. Translation and binary power of scale are two important points for discrete wavelet transform and there is a relationship (Erdogmus and Pekcakar, 2009). This procedure is called as dyadic. Mathematically, both continuous and discrete wavelet transforms are similar.

Discrete wavelet transform is used with filters. This is developed by Mallat in 1988. Discrete wavelet transform is faster than continuous wavelet transform with that filter algorithm (Graps, 1995; Fidan, 2006). “Low Pass Filter” is a filter for low frequency and “High Pass Filter” is a filter for high frequency.

2.1.5 Wavelet Forms

Wavelet forms are described in the following;

- Haar Wavelet Transform
- Daubechies Wavelet Transform
- Coiffet Wavelet Transform
- Meyet Wavelet Transform
- Morlet Wavelet Transform
- Mexican Hat Wavelet Transform

2.1.5.1 Haar Wavelet Transform

It is developed by Alfred Haar in 1909 and it is the first knowladge wavelet and the easiest one. Haar wavelet is a step function in a distinct area which is displayed on Figure 2.5.

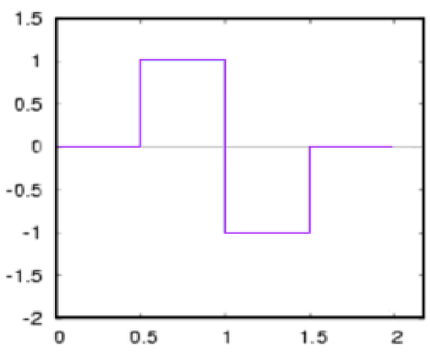

Figure 2.5: The waveform of Haar Wavelet

This symetric function is also called as square wave. Haar wavelet corresponds both continuous and discrete wavelet transform. Haar wavelet is not constant and it is the major disadvantage of Haar wavelet. It is calculated as the following;

$$f(x) \Rightarrow \begin{matrix} 1 & 0 \leq x < {}^{1}/_{2} \\ -1 & {}^{1}/_{2} \leq x < 1 \\ 0 & other \end{matrix} \qquad \textbf{(2.13)}$$

2.1.5.2 Deubechies Wavelet Transform

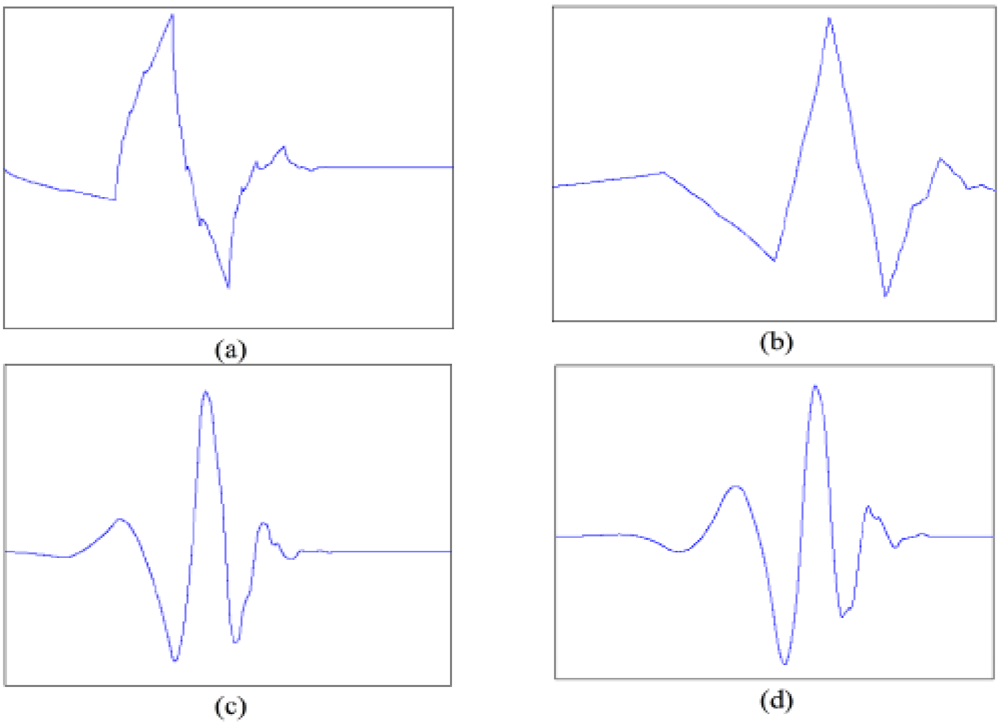

Figure 2.6: a) The waveform of Daubechies D-4 main wavelet
b) The waveform of Daubechies D-6 main wavelet
c) The waveform of Daubechies D-8 main wavelet
d) The waveform of Daubechies D-10 main wavelet

Deubechies wavelet transforms have various sorts between D-2 and D-20 and it steps double. Numbers of function denotes how many parameter does the wavelet have. Daubechies wavelets were established to include more damping moment. For instance, Daubechies D-2, it is also called as Haar wavelet, has only a damping moment. D-4 wavelet has two damping moments. Damping moment informs the signal if is polynomial or not. For instance, D-4 wavelet is implemented to quadratic polynom. D-6 wavelet is implemented equation of third degree polynom, or constant, lineer and quadratic polynom.

Deubechies wavelets are not symetric. It does not have functions. It is observed in both continuous and discrete wavelet transforms.

2.1.5.3 Coiflet Wavelet Transform

The transform was founded by Ingrid Daubechies same as Daubechies wavelet transform. The difference is that the Coiflet wavelets are more symmetric than the Daubechies wavelets. It is observed both continuous and discrete wavelet transforms and also it does not have function.

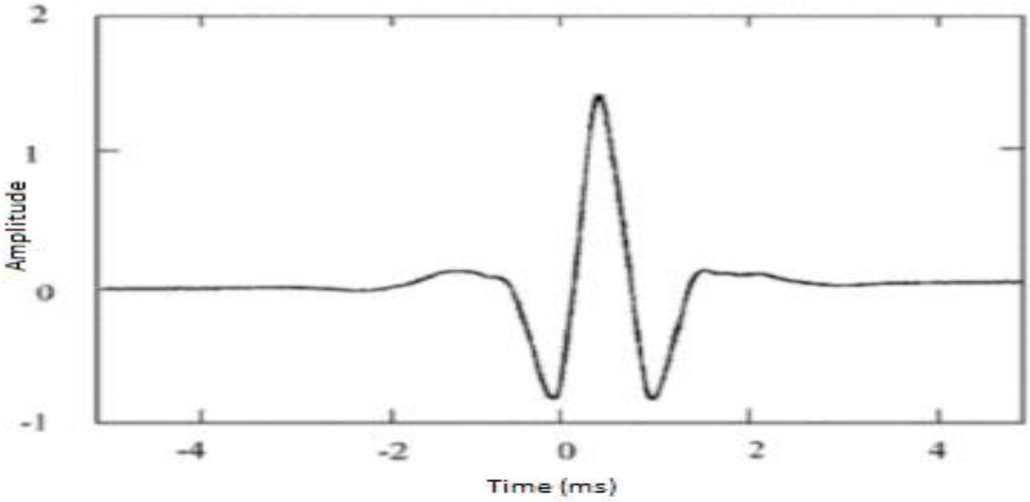

Figure 2.7: The waveform of Coiflet Wavelet

2.1.5.4 Meyer Wavelet Transform

Meyer wavelet transform is symmetric. It is suitable for both continuous and discrete transforms and it does not have function like Deubechies and Coiflet wavelet transforms.

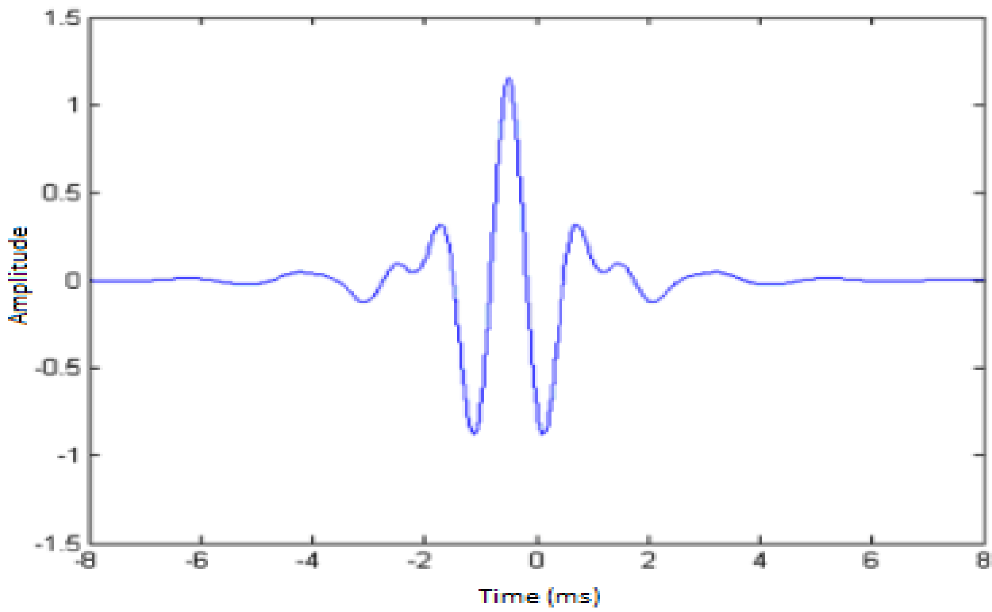

Figure 2.8: The waveform of Meyer wavelet

2.1.5.5 Morlet Wavelet Transform

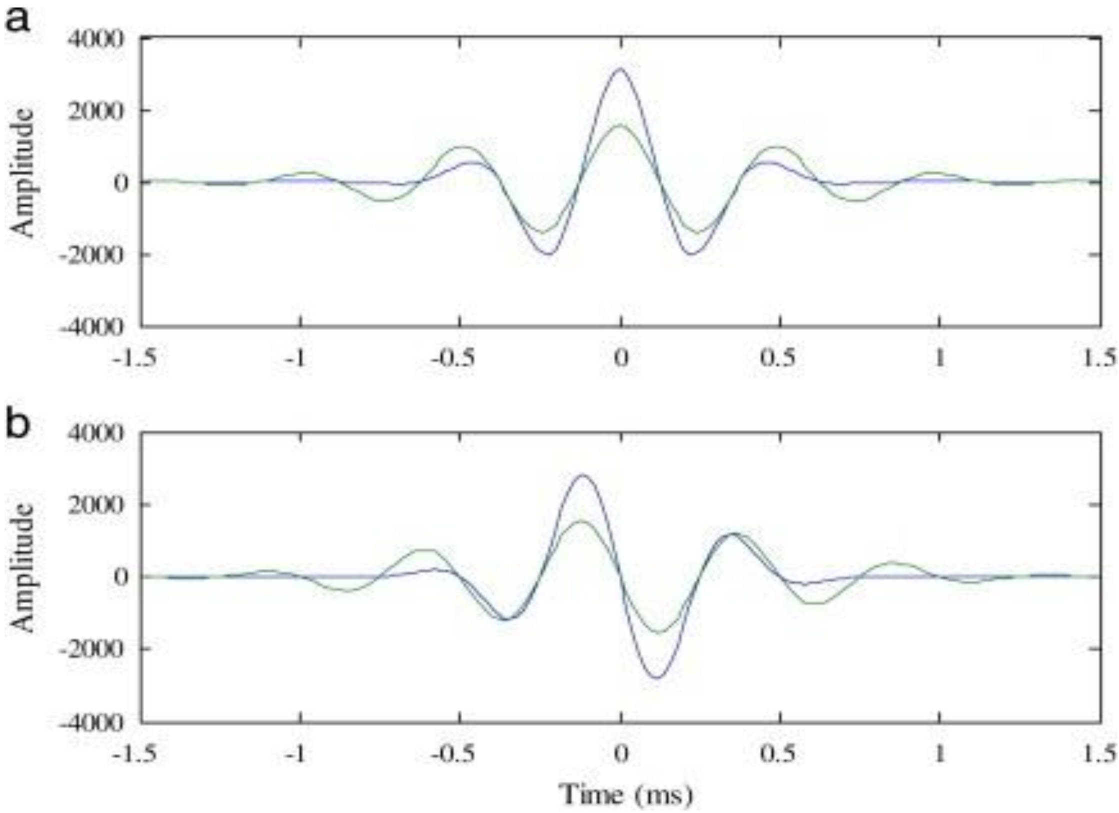

Figure 2.9: The waveform of Morlet wavelet a) Real part
b) Imaginary part

Morlet wavelet;

$$g(\omega) = e^{-2\pi(v-v_0)^2} \quad \textbf{(2.14)}$$

It has two parts, naming as real and imaginary part, and besides it is complex function. The parts are defined as the following functions;

$$g_r(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \cos(2\pi v_0 x) \quad \textbf{(2.15)}$$

$$g_i(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \sin(2\pi v_0 x) \quad \textbf{(2.16)}$$

v_0: constant and condition of conformity is defined as $v_0 > 0,8$.

Morlet wavelet is symmetric. It does not have scale function thats why it is **not** used in a discrete wavelet transform.

2.1.5.6 Mexican Hat Wavelet Transform

Mexican hat wavelet transform is a symmetric function. Besides that, it is the negative normalized second derivative of a Gaussian function. The wavelets are used for a continuous wavelet transform, **not** used for discrete wavelet transform. The function is defined with;

$$\psi(t) = (\frac{2}{\sqrt{3}}\pi^{-1/4})(1-x^2)e^{-x^2/2} \tag{2.17}$$

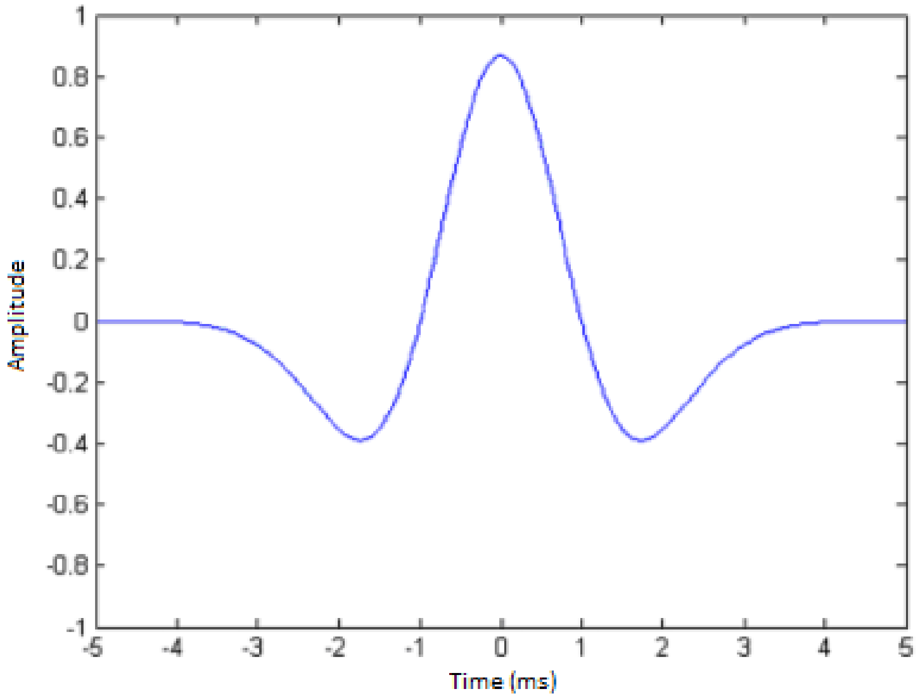

Figure 2.10: The waveform of Mexican Hat wavelet

2.2 Fuzzy Logic

In general, fuzzy logic is explained with approximate reasoning. Its sources have uncertainty features unlike exact and definite. Lotfi A.zadeh is the inventor of the reasoning and he developed the theorem in 1965. After that, fuzzy logic has grown in importance. Mamdani and Assilian made the approach significant by using it on their studies in 1975. As known, statistic and probability theory are based on accuracy but it is an uncertain world. That's why, we should study on uncertainties, in other words fuzzy logic. Fuzzy logic has been applied to variety of fields like engineering, medicine, psychology, etc.

Fuzzy logic bases on sets and subsets. In classical approach, it can be called as Aristo's approach, the object is either in the set or not. Mathematically, in terms of membership, when the object is an element of the set, the value is accepted as “1”, when it is not an element of the set the value is accepted as “0”. Fuzzy sets are extension of the classical notion set. The difference between classical and fuzzy logic approaches are listed the following sentences:

- In classical approach, a proposal is either true or false. In fuzzy logic systems, proposal maybe true or false. Also, it can have intermediate truth value.
- Classical approach allow only two quantifiers, “all” and “none”. Fuzzy logic allow that quantifiers plus it allow more quantifiers like “most”, “many”, “few”, “several”, etc.
- In fuzzy logic systems, every logical unit could become fuzzied whereas it is not possible in classical approach.
- In classical approach, there is only two degrees, 1 or 0, in or out. In fuzzy logic systems, every object has a degree between 0 and 1.

Fuzzy logic solves problems anywhere ranging from 0 to 1. It is called as membership degree. If it is closer to 1, it means the higher membership degree. It is also reversible. If it is closer to 0, it means the lower membership degree. Besides that, following sentences must be confirmed for sense of fuzzy words;

1) At least, one of the element in fuzzy set must be equal to 1, the biggest membership.

2) Fuzzy sets should be monoton. That means an element’s left and right sides values should be close the value of the element.

After this sentences, another difference between classical approach and fuzzy logic is appeared. Classical approaches have only one membership function besides that fuzzy logic systems have different membership functions as long as providing above sentences. All membership functions have to be normal, constant and convex. The most used membership functions are schematically displayed on Figure 2.11.

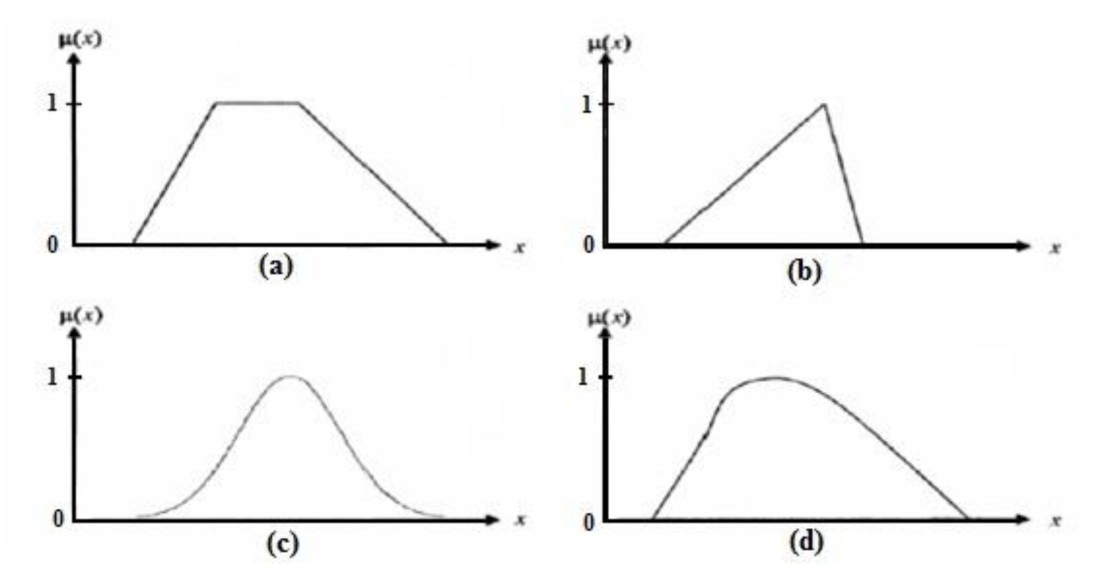

Figure 2.11: Membership functions a) Trapezium Type b) Triangular Type c) Gauss Membership Function d) Bell Type

The other notion of fuzzy logic is linguistic variables. Linguistic variables get linguistic datas with words or sentences. For instance, it is assumed that taking "age" is a linguistic variable so the linguistic data could be "old, very old, young, too young, etc." and the data receives value ranging from 0 to 1. It is displayed in Figure 2.12.

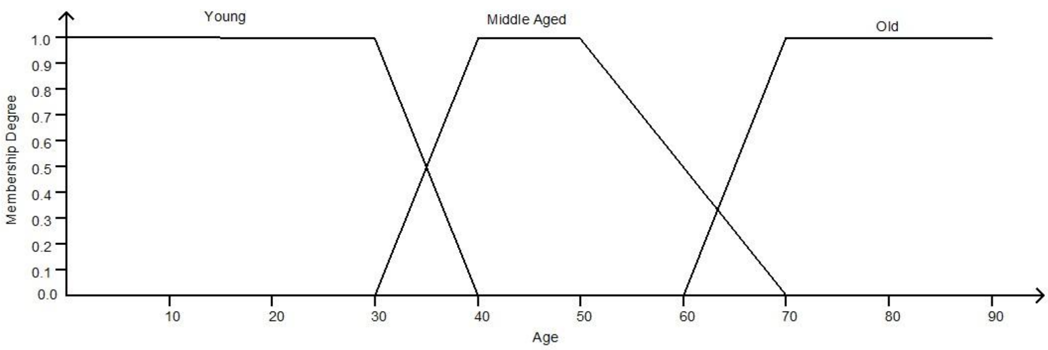

Figure 2.12: Fuzzy membership function of "Age"

For making easier and practical applications, it can be figured with triangular type. It is shown in Figure 2.13.

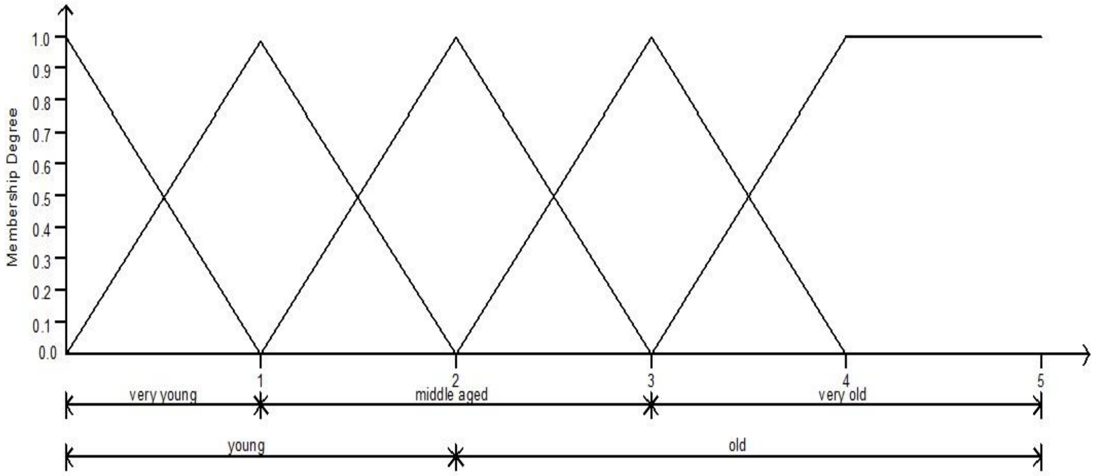

Figure 2.13: Triangular type of membership function of "Age"

"IF....THEN...." statements are used in fuzzy logic models and it is known as rules. The "IF" parts of the rules refer to adjectives and an area of input variables are described. A particular input value belongs to a certain degree, it is represented by the degree of membership function. The "THEN" parts of rules refer to the value of the output variable. To acquire the output of the controller, the degree of membership of the "IF" parts of all rules are averaged and weighted by degrees of membership (Uzunoglu et al., 2009; Wang, 1997; Leondes, 1998). The rules are very important. Each rule can be thought of a subsystem and it has one to many membership functions associated with it. The rule acts only when the inputs are applied to them (Gnanassegarane, 2009).

The base of controller fuzzy logic system is occured in 4 parts. These are unit of fuzzification interface, knowledge base, decision logic and defuzzification interface. It is schematically displayed in Figure 2.14.

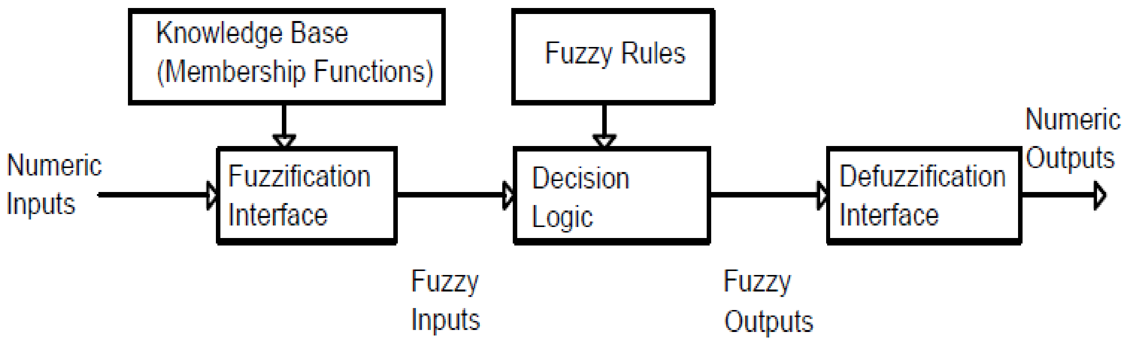

Figure 2.14: The Base of Controller Fuzzy Logic System

The fuzzification interface receives the current values of the input variables and eventually convert them into linguistic terms or fuzzy sets. The knowledge base contains information about domains of the variables and the fuzzy sets associated with the linguistic control rules. In addition, a rule base in form of linguistic control rules is stored in the knowledge base. The decision logic determines the information about the control variables with the help of the measured input values and the knowledge base. The aim of the defuzzification interface is creating a crisp control value out of the information about the control variable of the decision logic by using suitable transformations (Nauck and Klawonn, 1992; Iancu, 2012).
In the following, two important methods of fuzzy logic, Mamdani and Tagaki-Sugeno, are described and compared.

2.2.1 Mamdani's Fuzzy Systems

Mamdani Fuzzy Controller is the first controller system and most commonly seen on fuzzy methodology. It was developped by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by syntesizing a set of linguistic control rules obtained from experienced human operators. It is based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes. Representative Mamdani fuzzy rules is given in the following;

Type-1: IF x is A_1 OR y is B_1 THEN z is C_1 **(2.18)**

Type-2: IF x is A_2 AND y is B_2 THEN z is C_2 **(2.19)**

Type-3: IF x is A_3 THEN z is C_3 **(2.20)**

In these rules, x and y are input variables and z is an output variable. A_1, A_2, A_3, B_1, B_2 are called as the input fuzzy sets and C_1, C_2, C_3 are called as the output fuzzy set. The first part of rules, for example "IF x is A_1 OR y is B_1" is called as the rule antecedent and the second part, "z is C_1", is called as the rule consequent. A simple but representative Mamdani Fuzzy Systems is schematically displayed in Figure 2.15.

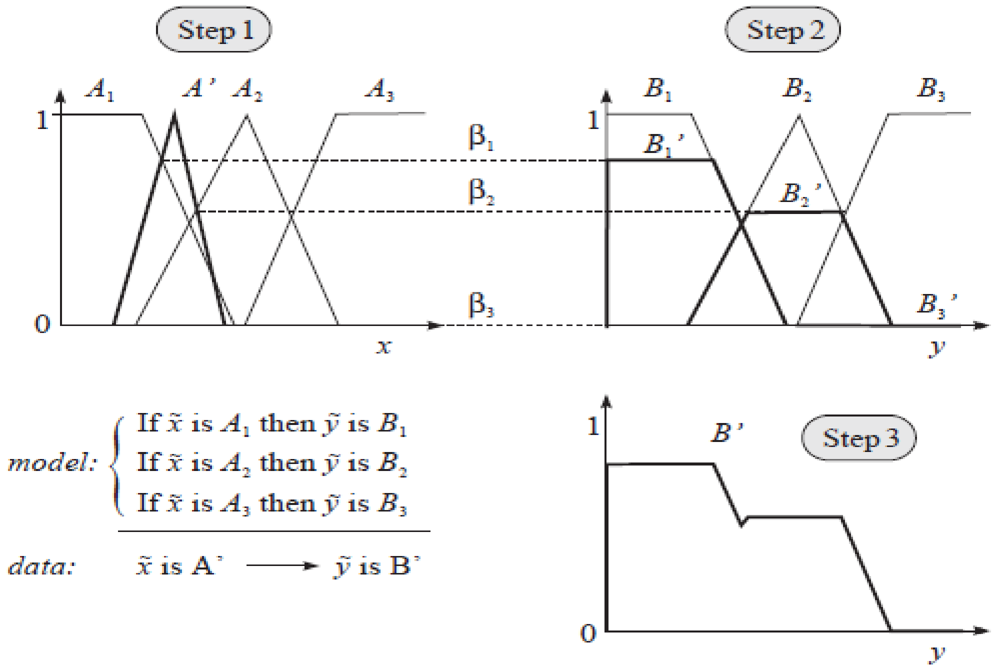

Figure 2.15: An Example of Mamdani Fuzzy Systems (Babuska, 1996)

2.2.2 Takagi-Sugeno's Fuzzy Systems

It was developed in 1985 and it is very similar approach with Mamdani Fuzzy Systems. The rule antecedent is same with Mamdani. Unlike Mamdani fuzzy systems, Takagi-Sugeno fuzzy systems use functions of input variables as the rule consequent and these are either linear or constant. A typical rule of Sugeno is shown in the following function;

IF x is A_1 OR y is B_1 THEN z is $f_i(x,y)$ i=1,2,...,K **(2.21)**

$f_i(x,y)$ is a real function of any type.

In the following section, advantages of Mamdani and Takagi-Sugeno Fuzzy Systems are compared;

Between Mamdani's and Takagi-Sugeno's fuzzy systems, they have differences. Mamdani's fuzzy systems use the technique of defuzzification of a fuzzy output. On the other hand, Takagi-Sugeno's uses weighted average. The other differences is about membership functions. Mamdani's has output membership functions whereas Sugeno's has not. Advantages of these types are given in the following;

Advantages of the Mamdani's Fuzzy Systems

- It is commonly accepted.
- It is intuitive.
- It is well suited to human input.

Advantages of the Takagi-Sugeno's Fuzzy Systems

- It is computationally efficient.
- It works well with linear techniques.
- It works well with optimization and adaptive techniques.
- It is well suited to mathematical analysis.
- It has guaranteed continuity of the output surface.[2]

2.3 The Combination of Wavelet and Fuzzy Logic Methods

Wavelet-Fuzzy Logic method (WFL) is proposed in this study. The method is based on multiresolution analysis. It is well known that a signal has different statistical properties such as trend, periodicity, sudden jumps etc. It is very difficult to make a time series analysis by including all statistical properties. So far, researchers have tend to divide concerned time series into homogeneous sub-series and setup predictive models for those sub-series. A signal is decomposed into bands. In general terms, wavelet transform is employed to decompose the signal and each band of the signal is fuzzied by fuzzy logic approach. Firstly, average wavelet spectra is used for decomposing the signal. Average wavelet spectra is scaled. After, bands are selected. It is important to seperate the signal because homogeneous series is obtained to predict more accurate results. Each bands are fuzzied individually. Input of function is called as predictors and output of function is called as predictand. Each predictand is fuzzied by its predictor. Shortly, fuzzy logic model is used to establish the relationship between each band of predictand and predictor. Finally, each band is reconstructed and estimated time series is achieved by using inverse continuous transform.

According to Ozger (2010), three steps must be provided for the succesful application of wavelet-fuzzy logic method;

1- The significant spectral bands are selected from average wavelet spectra,
2- Resulting spectral bands from previous step can be modeled by using fuzzy logic approach. To achieve the estimating problem each band is considered individually.
3- Finally, each modeled band is reconstructed to obtain the estimated time series. Inverse continuous wavelet transform is employed for reconstruction.

[2] MatLAB, Fuzzy Logic Toolbox, Fuzzy Inference System Modeling. From http://www.mathworks.com/help/fuzzy/comparison-of-sugeno-and-mamdani-systems.html

2.4 Sediment Rating Curve (SRC)

Curve showing the relation between sediment concentration and discharge of a stream at a station. If digitized, it is a rating table.[3]

Sediment rating curve is a classical approach to predict sediment load by using streamflow discharge. Sediment yield (or concentration) and stream discharge have a good relationship. Plenty of rating curve methods were developed but the most commonly used sediment rating curve functions are power functions (e.g. Walling, 1978; Jansson, 1997; Boukhrissa, 2013);

$$C = aQ^b \tag{2.22}$$

$$Q_s = aQ^b \tag{2.23}$$

where; a and b are regression coefficients,

Q: stream discharge

C: sediment concentration

Q_s: Sediment yield

[3] Dictionary of General Directorate of State Hydraulic Works of Turkey (DSI)

3 METHODOLOGY

3.1 Data Used

As mentioned before, the data from October, 1999 to January, 2006 was used for the study and it was taken from DSI. Since suspended load time series includes various values and its data range is very large, a preprocessing technique could be applied. In this study, the original time series log transformed and the transformed time series was used in the analysis. Later a computer programming script written in MATLAB was employed. This script is able to compute wavelet spectra and plot average wavelet spectra which shows the variation of spectral energy with months. A sample average wavelet spectra is given in Figure 3.1 for Baglik station. As can be seen from this figure, average spectral energy changes with time. On the other hand low frequency (high periods) gives some information about long-term periodicities. Other stations data series are decomposed into their sub-bands similarly. 5 bands were used for all stations. Increasing number of bands does not contribute model accuracy but makes the model more complex. Decreasing number of bands leads to non-homogeneous series and converges original time series.

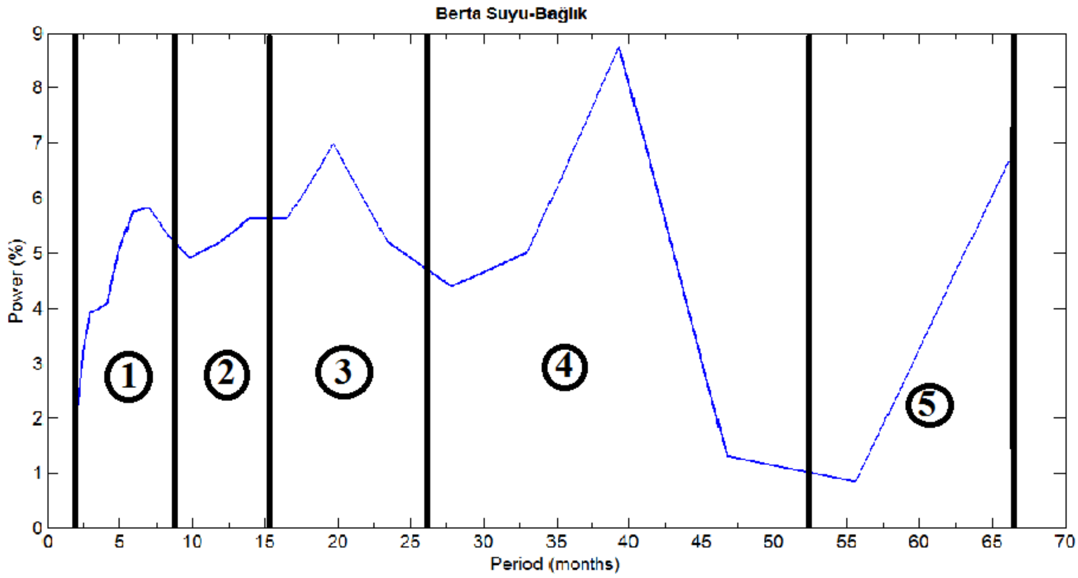

Figure 3.1: Average wavelet spectra and selected bands

Figure 3.2 shows the seperated 5 sub-bands and original time series. Higher frequency bands as in Band-1 and 2 holds noisy data of the series. Lower frequency bands as in Band-4 and 5 shows long term variations and periodicities.

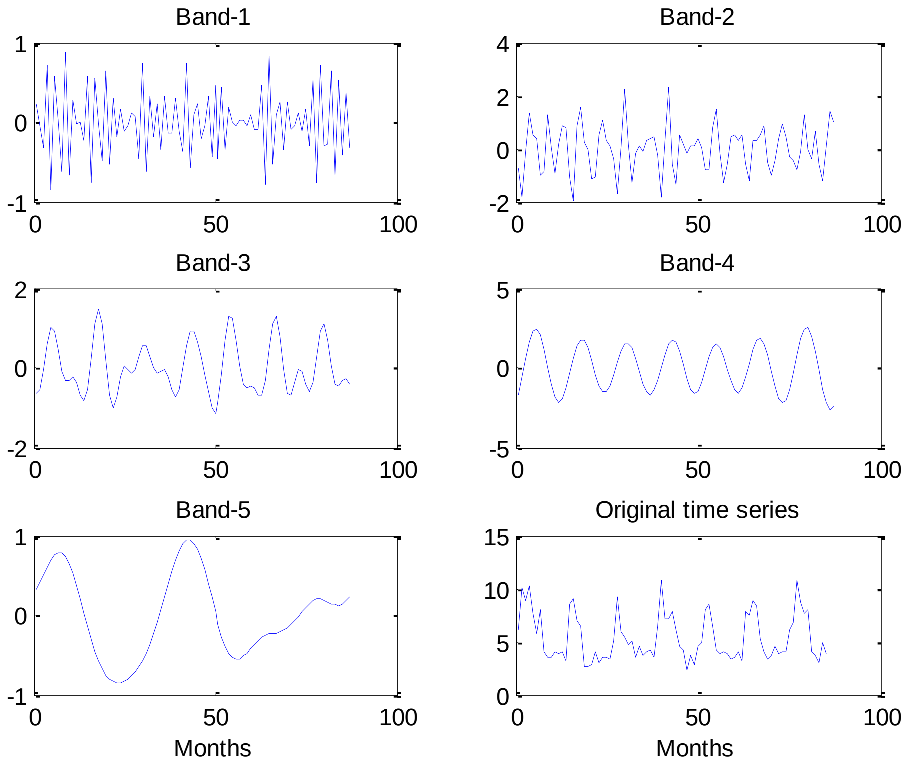

Figure 3.2: Significant spectral bands of observed sediment load for Çamlıkaya station

It is also possible to generate similar figures for other stations.

Prior to modeling, the data is divided into 2 parts which are training and testing parts. In the training part, model parameters were calibrated and two thirds of data was used for it. After training part, we obtained impartial results by using rest of data. Prediction is starting at $t=t_1$ for future time $t=t_2$, wave data registered earlier than $t=t_1$ should be used. This is mandatory for an independent prediction. We can predict t_i by using t_{i-1} and t_{i-2}.

3.2 The Combination of Wavelet and Fuzzy Logic Method

WFL is studied in previous part. The aim of the wavelet-fuzzy logic combination model is to forecast 1-month ahead suspended sediment load from previous sediment loads.

Logarithmic transformation is applied for the data to ease the comparision and interpretation. A signal is constituted by using time series data. The signal is decomposed in different scale from 1 to 21 by the help of wavelet analysis. Significant bands are selected by the help of average wavelet spectra. The selected significant bands are presented in Table 3.1. First row of station's shows bandwidth. Below the bandwidth, corresponding months are given respectively.

Table 3.1: Selected bands and corresponding months

Station NO	Band-1	Band-2	Band-3	Band-4	Band-5
2334	0-1	1-3	3-5	5-9	9-21
	0-2	2-3	3-4	4-8	8-66
2259	0-1	1-3	3-6	6-11	11-21
	0-2	2-3	3-5	5-12	12-66
2337	0-2	2-3	3-6	6-10	10-21
	0-2	2-3	3-5	5-10	10-66
2251	0-2	2-4	4-8	8-12	12-21
	0-2	2-4	4-7	7-14	14-66
2232	0-2	2-4	4-6	6-10	10-21
	0-2	2-4	4-5	5-10	10-66
2228	0-2	2-3	3-6	6-10	10-21
	0-2	2-3	3-5	5-10	10-66
2218	0-2	2-4	4-6	6-11	11-21
	0-2	2-4	4-5	5-12	12-66
2238	0-2	2-4	4-7	7-10	10-21
	0-2	2-4	4-6	6-10	10-66
2325	0-2	2-4	4-7	7-19	19-21
	0-2	2-4	4-6	6-47	47-66
2329	0-2	2-4	4-7	7-18	18-21
	0-2	2-4	4-6	6-39	39-66
2245	0-2	2-3	3-6	6-18	18-21
	0-2	2-3	3-5	5-39	39-66
2316	0-2	2-4	4-8	8-14	14-21
	0-2	2-4	4-7	7-20	20-66

Each band is modelled by fuzzy logic separately. Gauss or triangular fuzzy membership functions are selected. The most appropriate membership function type is chosen by the help of trial-and-error. Proposed model has 2 subsets, which is called "low" and "high", and 2 inputs. It is schematically displayed in Figure 3.3.

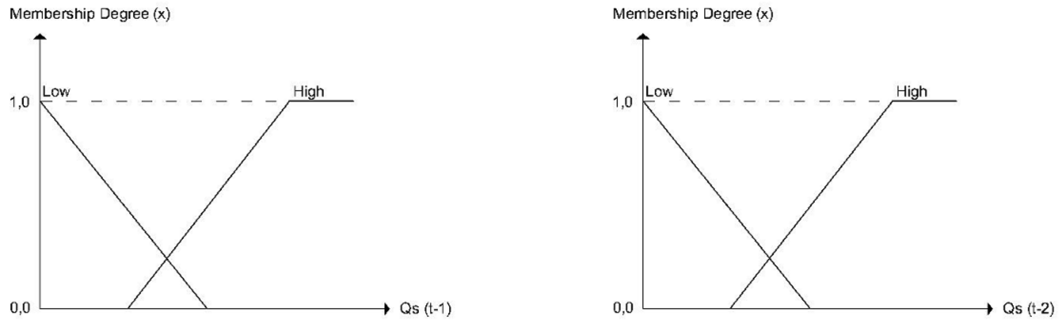

Figure 3.3: Representation of Fuzzy Logic part of the model

There are 4 fuzzy rules used for this study which are obtained from 2 different fuzzy sets as "Low-Low", "Low-High", "High-Low", "High-High" respectively.

$$y_1 = a_{1,low}Q_s(t-1) + b_{1,low}Q_s(t-2) + c_1 \quad \textbf{(3.1)}$$

$$y_2 = a_{2,low}Q_s(t-1) + b_{2,high}Q_s(t-2) + c_2 \quad \textbf{(3.2)}$$

$$y_3 = a_{3,high}Q_s(t-1) + b_{3,low}Q_s(t-2) + c_3 \quad \textbf{(3.3)}$$

$$y_4 = a_{4,high}Q_s(t-1) + b_{4,high}Q_s(t-2) + c_4 \quad \textbf{(3.4)}$$

Result is obtained by using weighted average.

$$\dot{y} = \frac{w_1y_1 + w_2y_2 + w_3y_3 + w_4y_4}{\sum w}$$

The processing continue until all bands modelled individually. Finally, each band is reconstructed by the help of inverse continuous wavelet transform to obtain predicted time series.

Wavelet analyses has two types, called discrete wavelet transform and continous wavelet transform. Generally, discrete wavelet transform is selected because it reduces calculations and removes "noisy" data so it is faster than continuous wavelet transform. On the other hand, since only dyadic scales are taken into consideration there can be a loss of information between scales. There is no loss of information for continuous wavelet transform so in this study, it is selected. Besides that, several form of wavelet is available as it is given in section 2.1.5. Mexican Hat wavelet form was selected for the analysis.

3.3 Error Criterias

Sediment prediction is very important process to determine reservoir storage volume, water use disorder functions, etc. Prediction error and time is directly proportional in sediment prediction. Statistical methods can be used to evaluate long time sediment predictions.

Miscellaneous Eastern Blacksea Basin and Coruh Basin are studied in this study. Prediction sediment is shown by $F_{i(model)}$, and observed sediment is shown by $F_{i(real)}$. Due to the prediction error, these two parameters never be equal to each other. Prediction error can be described by the sum of systematic error which is formed by a specific reason and random error. Predicted error is described by the following functions;

$$R^2 = \frac{F_0 - F}{F_0} \quad \textbf{(3.1)}$$

$$F_0 = \sum_{i=1}^{n} |F_{i(real)} - F_{i(mean)}| \quad \textbf{(3.2)}$$

$$F = \sum_{i=1}^{n} |F_{i(real)} - F_{i(model)}| \quad \textbf{(3.3)}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} (F_{i(real)} - F_{i(model)}) \quad \textbf{(3.4)}$$

where n: observed sediment weight data

F_{mean}: monthly average sediment weight of observed value

R^2: Coefficient of determination

MAE: Mean Absolute Error

Accuracy of the model can be evaluated by its R^2 which should be closer to 1, MAE which should be closer to 0 and coefficient of correlation which range from -1 to 1. Coefficient correlation is determined by Pearson correlation coefficient (r) or simple correlation coefficient and its value varies between -1 and 1. If r is closer to 1 or -1, it can be said that there is statistically significant relationship between variables. Positive values indicate there a positive relationship (direct) between variables, while negative values indicate there is a negative relationship between variables. If r is closer to 0, it means there is no relationship between the analyzed variables. R:±0,5 means there is an average relationship.

There is another defination naming as a speficity degree. In order to explain the changes of independent variable in terms of dependent variable changes, specificity degree is used. Square of Pearson correlation coefficient (r) is equal to specificity degree and it ranges from 0 to 1. It is shown by R^2. If the specificity degree is equal to 1, it means the explanation of occurance is 100%. If it is equal to 0, it means there is no explanation.

4 RESULTS

4.1 Sediment Rating Curve (SRC)

Sediment rating curve is a classical approach and it is generally shown with power function. Sediment rating curves presented schematically in Appendix-A. The parameters of sediment curve are included in Table 4.3.

Table 4.1: Result of Sediment Rating Curves $Qs=aQ^b$

Station Number	**a**	**b**	**R^2**
2334	2,76	0,38	0,79
2259	1,58	0,52	0,83
2337	3,32	0,44	0,83
2316	2,11	0,51	0,86
2251	1,88	0,45	0,82
2232	5,39	0,39	0,74
2228	0,76	0,50	0,77
2218	4,84	0,37	0,79
2238	0,98	0,52	0,80
2325	0,76	0,36	0,71
2329	1,53	0,34	0,66
2245	0,99	0,66	0,79

4.2 Scatter Diagrams

Scatter diagrams show the agreement between observed and predicted values. The 45° line in the diagram indicated the perfect model. As the scatter around this line increases, model accuracy decreases. In this section, wavelet-fuzzy logic combination method and stand-alone fuzzy logic model prediction scatter diagrams for all station are shown (Appendix-B). As it was described above, firstly we trained our model, then we obtained predictand results by using test part. In these diagrams, x axis shows observed data, y axis shows prediction results.

4.3 Comparison between Fuzzy Logic and Wavelet-Fuzzy Logic Method

This study proposed a technique using combination of fuzzy logic and wavelet methods in order to predict sediment load in two basins namely “Muteferrik Dogu Karadeniz Basin (Miscellaneous Eastern Blacksea Basin)” and “Coruh Basin”. The proposed method used wavelet method to seperate time series into its subseries. Then, the significant spectral bands were selected. While selecting less number of bands cause loss of information, excessive number of bands cannot represent the specific information accurately. According to Ozger (2010), 3-6 bands can represent the original time series sufficiently. In this study, 5 bands are used to represent the specific information for all stations. After that, fuzzy logic was used to establish a connection between predictors and the predictand band. In final step, predicted bands were reconstructed to obtain the final series.

Two different methods were conducted in this study which are fuzzy logic and wavelet fuzzy logic methods. In the first model, only fuzzy logic was used to predict sediment load, in the second model, the combination of wavelet method and fuzzy logic was used. The results are given Table 4.1 and Table 4.2 as fuzzy logic method and combination of wavelet-fuzzy logic method respectively.

Table 4.2: Stand-Alone Fuzzy Logic Results

Station Number	FL_Train Data R^2	FL_Test Data R^2	FL_Train Abs Error	FL_Test Abs Error
2334	0,243	0,249	3212,5	3910,6
2259	0,132	0,150	4545,3	4125,2
2337	0,384	0,455	2258,2	2572,4
2316	0,424	0,430	1268,2	1752,2
2251	0,206	0,191	758,9	829,6
2232	0,088	0,205	756,5	625,2
2228	0,054	-0,046	658,8	825,5
2218	0,133	0,192	578,9	725,1
2238	0,466	-0,211	459,8	700,2
2325	0,274	0,090	2869,6	2536,9
2329	0,210	0,179	4987,3	4334,5
2245	0,047	0,026	240,6	120,5

Table 4.3: Combination of Wavelet and Fuzzy Logic Method Results

Station Number	FL_Train Data R^2	FL_Test Data R^2	FL_Train Abs Error	FL_Test Abs Error
2334	0,978	0,974	428,9	635,4
2259	0,955	0,965	797,7	620,5
2337	0,979	0,978	536,8	683,9
2316	0,972	0,975	158,9	385,2
2251	0,971	0,981	425,3	387,0
2232	0,963	0,983	256,9	172,5
2228	0,959	0,987	125,8	213,2
2218	0,966	0,988	236,9	185,2
2238	0,986	0,936	96,3	162,5
2325	0,943	0,974	1536,6	925,8
2329	0,949	0,980	369,8	204,1
2245	0,945	0,970	25,9	11,2

As mentioned before, firstly, two thirds of data was trained and first column of table shows its correlation coefficient. The second column discribes the correlation coefficient of test data which is the last one third of the data. Absolute error of train data and test data coefficient are shown in third and fourth column, respectively.

5 DISCUSSIONS

The study discusses the main issuses regarding sediment load and provides a general introduction of the wavelet-fuzzy logic combination method. WFL is a relatively new method which has some attractive characteristics. Signals can be evaluated for their features in the frequency domain by applying wavelet analysis. In this study, the suspended sediment load time series was predicted by employing wavelet and fuzzy logic approaches.

Sediment rating curve, fuzzy logic and wavelet-fuzzy logic combination methods were compared to predict suspended sediment load. These method's theory and notions were described in the previous sections. The aim of this study is to indicate the effectiveness of the Wavelet-Fuzzy Logic (WFL) in forecasting suspended sediment load. The WFL provided more accurate results than the stand-alone Fuzzy Logic (FL) and Sediment Rating Curve (SRC) as can be seen from Table 5.1.

Table 5.1: R^2 and Mean Absolute error results of SRC, FL and WFL

Station Number	R^2			Mean absolute error		
	SRC	FL	WFL	SRC	FL	WFL
2334	0,79	0,249	0,974	1890,5	3910,6	635,4
2259	0,83	0,150	0,965	2499,2	4125,2	620,5
2337	0,83	0,455	0,978	2615,7	2572,4	683,9
2316	0,86	0,430	0,975	1107,3	1752,2	385,2
2251	0,82	0,191	0,981	414,8	829,6	387,0
2232	0,74	0,205	0,983	202,5	625,2	172,5
2228	0,77	-0,046	0,987	367,7	825,5	213,2
2218	0,79	0,192	0,988	265,4	725,1	185,2
2238	0,80	-0,211	0,936	221,6	700,2	162,5
2325	0,71	0,090	0,974	1820,8	2536,9	925,8
2329	0,66	0,179	0,980	3940,7	4334,5	204,1
2245	0,79	0,026	0,970	26,3	120,5	11,2

Sediment concentration and stream flow rate data is need to set up SRC models using power function. As it can be seen from Table 5.1, SRC can not give satisfactory results to predict suspended sediment load in Coruh and Miscellaneous Eastern Basins. The correlation coefficient value was found in the range of 0,66 to 0,86 and its mean absolute error value was calculated between 26,3 and 3940,7 t/day. When correlation coefficient's result is properly analyzed, it is seen that if sediment concentration and stream flow rate values variation follows a power function, SRC method gives more accurate results. For example, the correlation coefficient of Ispir station is 0,86 because there are mostly produced corresponding change in the sediment concentration and stream flow. Besides that, there are no significant changes except April 2005. On that date, there were flood and it is biggest discharge of last 37 years. Unlike Ispir station, at Coskunlar station, 10,5 m^3/s flow value and 37521 tone/day sediment concentration value were measured on August 2003. The next measured values on September 2003, was 11,2 m^3/s and 178,9 tone/day. There are numerous example like this. These kind of inconsistences in data series lead to SRC give weaker results in Coskunlar station compared to Ispir station. As a conclusion, SRC is not reliable method to predict sediment load, because it does not give accurate results in a condition of unusual situation like flood, extra-ordinary streamflow value or non linear change of independent variable of model.

In stand-alone fuzzy logic method, the signal was modelled directly by using fuzzy membership function which are gauss or triangular type. Membership function type was selected by trial-and-error. Takagi-Sugeno fuzzy system was employed in this study and "high" and "low" were selected as subsets. These two subsets generated 4 fuzzy rules. Output parameters was optimized by utilizing training data. It is seen from Table 5.1 that fuzzy logic gave the weakest results. The highest value of correlation coefficient results was found to be 0,45 in station 2337.

In Wavelet-Fuzzy logic combination model, fuzzy logic part of model includes same steps as in fuzzy logic model. Fuzzy rule base is created to predict each sub-bands. The proposed model takes the advantage of band seperation. Wavelet transformation seperate the signal into its bands. Homogeneous series was obtained by the help of bands and it makes the modeling easier. In this study, the signal decomposes into 5 bands. 5 bands were predicted by Takagi-Sugeno fuzzy model and the outputs were summed up to obtain predicted results. It is clearly seen that WFL reduced the model errors substantially. Also, as it is seen from Table 5.1, correlation coefficient of the WFL model was found between 0,936 and 0,988. Besides that, WFL method was successful to predict peak values. The scatter diagrams for all stations are presented in Appendix B.

6 CONCLUSIONS

In this study, wavelet approach and fuzzy logic combination model was compared to stand-alone fuzzy logic method and sediment rating curve. Fuzzy logic and wavelet-fuzzy logic methods are employed to predict one month ahead sediment load from two previous ones. SRC method uses current discharge to predict current sediment load. Although SRC method uses current discharge value to predict sediment load, it has limited capacity in prediction compared to wavelet and fuzzy logic method. Correlation coefficient of SRC method was found in the range of 0,66 to 0,86 and mean absolute error was found between 26,3 and 3940,7 t/day. Stand-alone FL has the lowest results in statistically. Its correlation coefficient was 0,45 at most and mean absolute error was found in the range of 120,5 to 4334,5 t/day. On the other hand, WFL has the highest accuracy among the other methods. Its correlation coefficient ranges from 0,936 to 0,988 and mean absolute error was found in the range of 11,2 to 925,8 t/day.

Wavelet transform was used to decompose sediment time series into its bands. Since average wavelet spectra is used to decide the selection of bands, it can be seen as a key tool for the proposed approach. The resultant bands were modelled by fuzzy logic approach. It is shown that modelling with decomposed sediment time series helps to improve the model accurucies.

As a conclusion, the results show significant advantages of WFL for sediment load prediction. It has advantages of high approximation accuracy. It is clearly seen that WFL can be applied to the prediction of suspended sediment load. The proposed WFL model can be used in hydraulic engineering applications easily.

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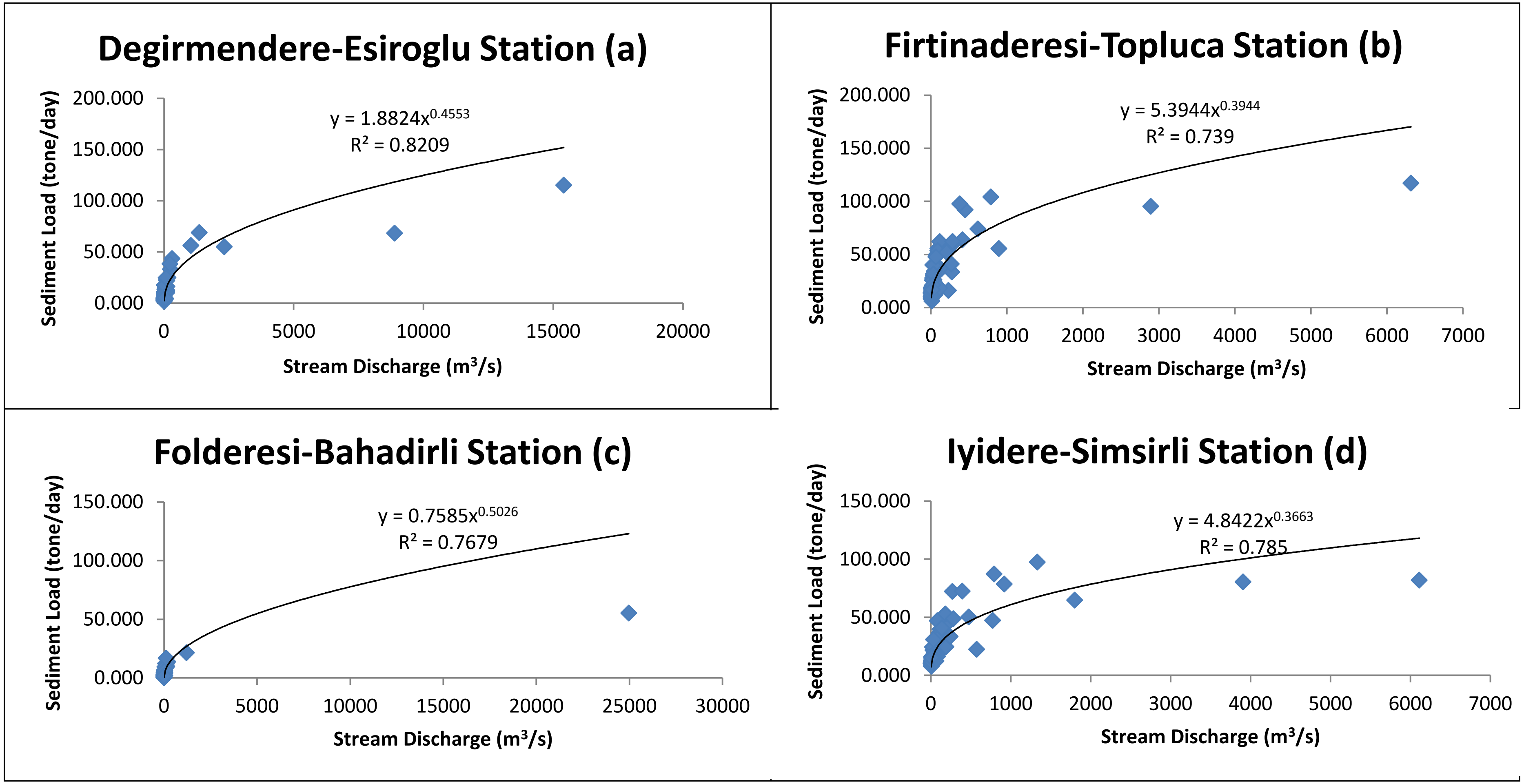
APPENDICES

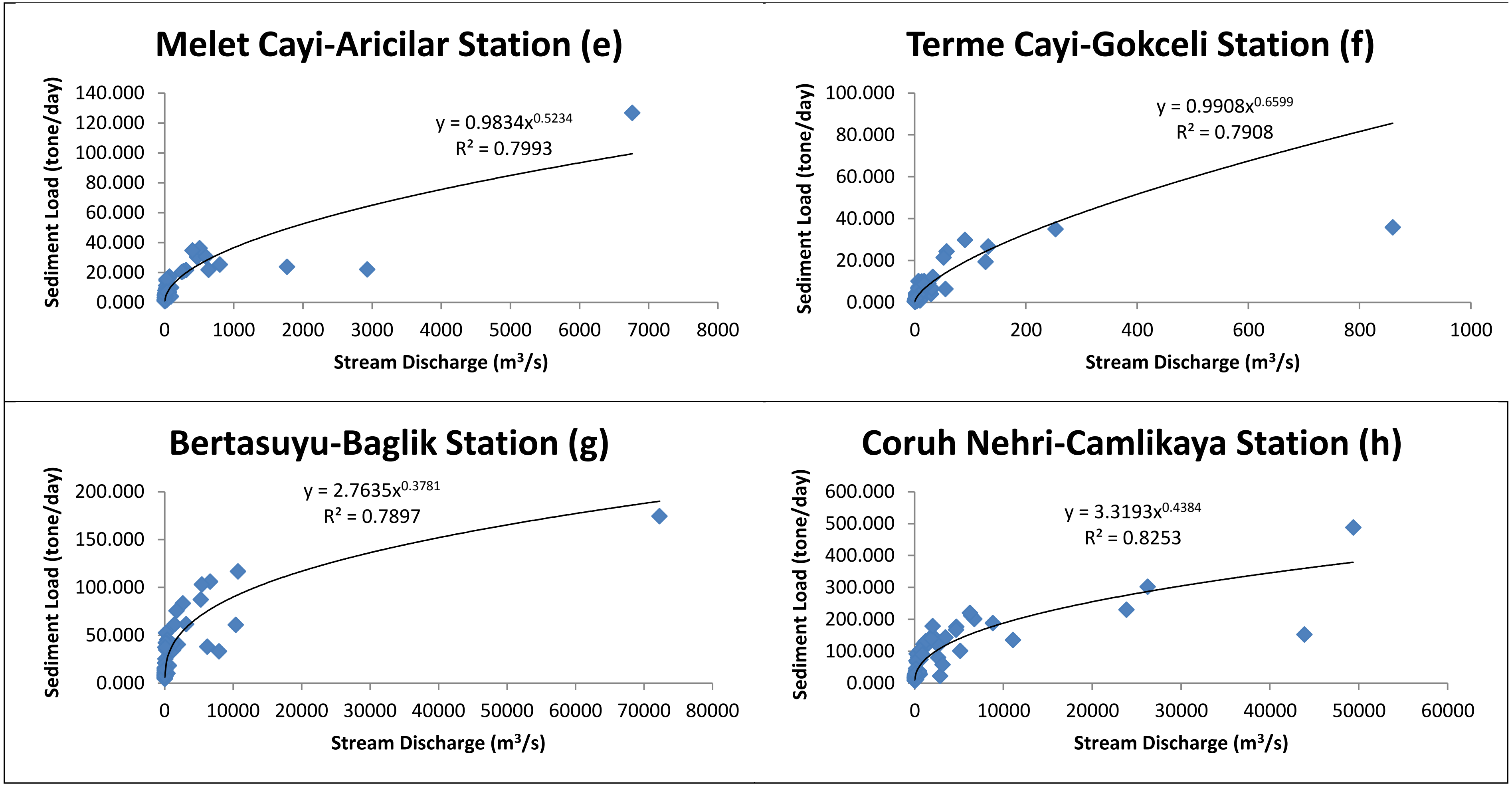
APPENDIX A: Sediment Rating Curve Figures

APPENDIX B: Scatter diagrams

APPENDIX A



Degirmendere-Esiroglu Station (a)
y = 1.8824x^0.4553
R² = 0.8209
Sediment Load (tone/day)
Stream Discharge (m³/s)
Firtinaderesi-Topluca Station (b)
y = 5.3944x^0.3944
R² = 0.739
Sediment Load (tone/day)
Stream Discharge (m³/s)
Folderesi-Bahadirli Station (c)
y = 0.7585x^0.5026
R² = 0.7679
Sediment Load (tone/day)
Stream Discharge (m³/s)
Iyidere-Simsirli Station (d)
y = 4.8422x^0.3663
R² = 0.785
Sediment Load (tone/day)
Stream Discharge (m³/s)


Melet Cayi-Aricilar Station (e)
y = 0.9834x^0.5234
R² = 0.7993
Sediment Load (tone/day)
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0.000
0
1000
2000
3000
4000
5000
6000
7000
8000
Stream Discharge (m³/s)
Terme Cayi-Gokceli Station (f)
y = 0.9908x^0.6599
R² = 0.7908
Sediment Load (tone/day)
100.000
80.000
60.000
40.000
20.000
0.000
0
200
400
600
800
1000
Stream Discharge (m³/s)
Bertasuyu-Baglik Station (g)
y = 2.7635x^0.3781
R² = 0.7897
Sediment Load (tone/day)
200.000
150.000
100.000
50.000
0.000
0
10000
20000
30000
40000
50000
60000
70000
80000
Stream Discharge (m³/s)
Coruh Nehri-Camlikaya Station (h)
y = 3.3193x^0.4384
R² = 0.8253
Sediment Load (tone/day)
600.000
500.000
400.000
300.000
200.000
100.000
0.000
0
10000
20000
30000
40000
50000
60000
Stream Discharge (m³/s)

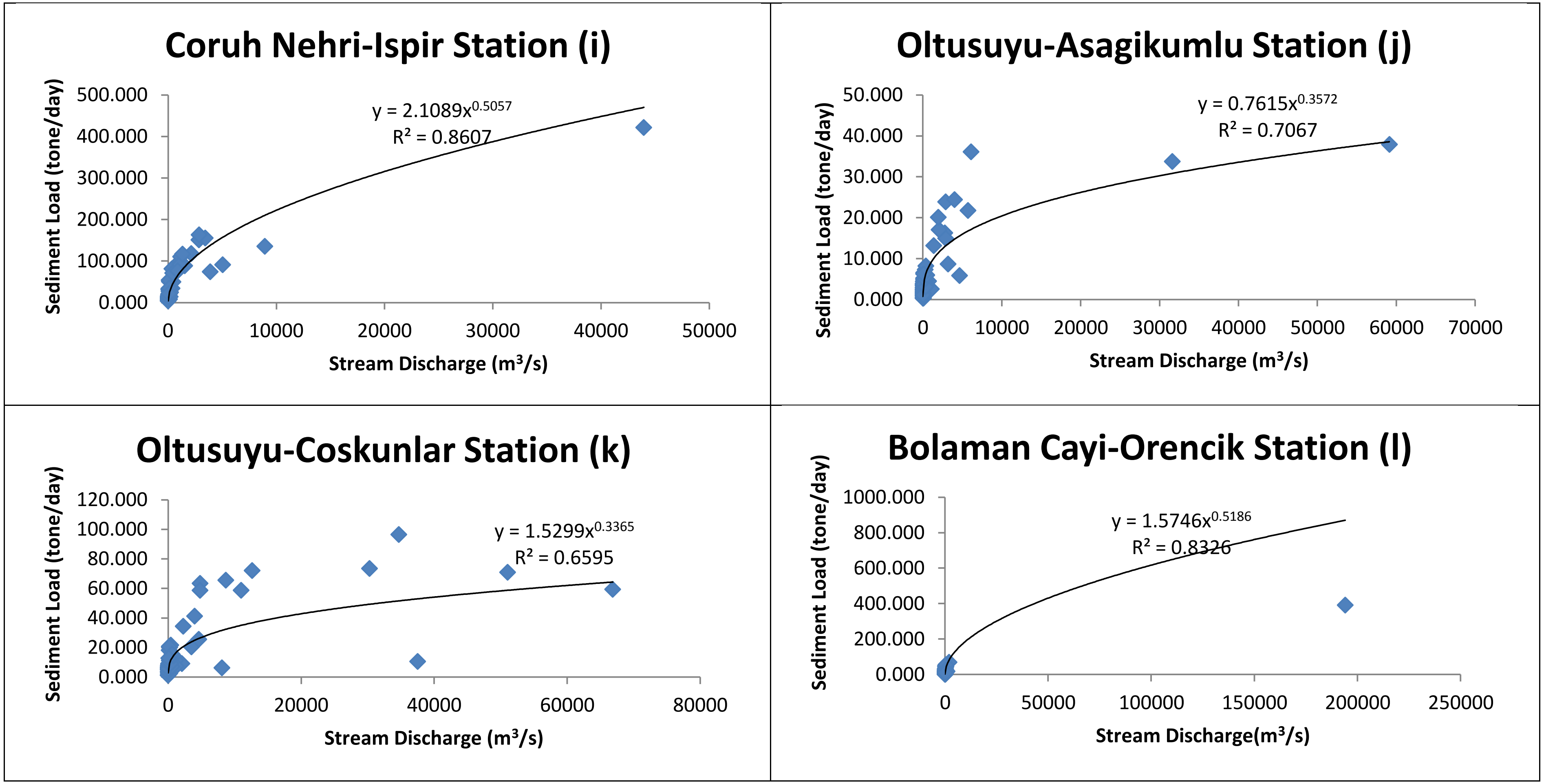


Figure A.1: SRC figure of stations: (a) Degirmendere-Esiroglu, (b) Firtinaderesi-Topluca, (c) Folderesi-Bahadirli, (d) İyidere-Simsirli, (e) Meletcayi-Aricilar, (f) Terme Cayi-Gokceli, (g) Bertasuyu-Baglik, (h) Coruh Nehri-Camlikaya, (i) Coruh Nehri-Ispir, (j) Oltusuyu-Asagikumlu, (k) Oltusuyu-Coskunlar, (l) Bolaman Cayi-Orencik

APPENDIX B

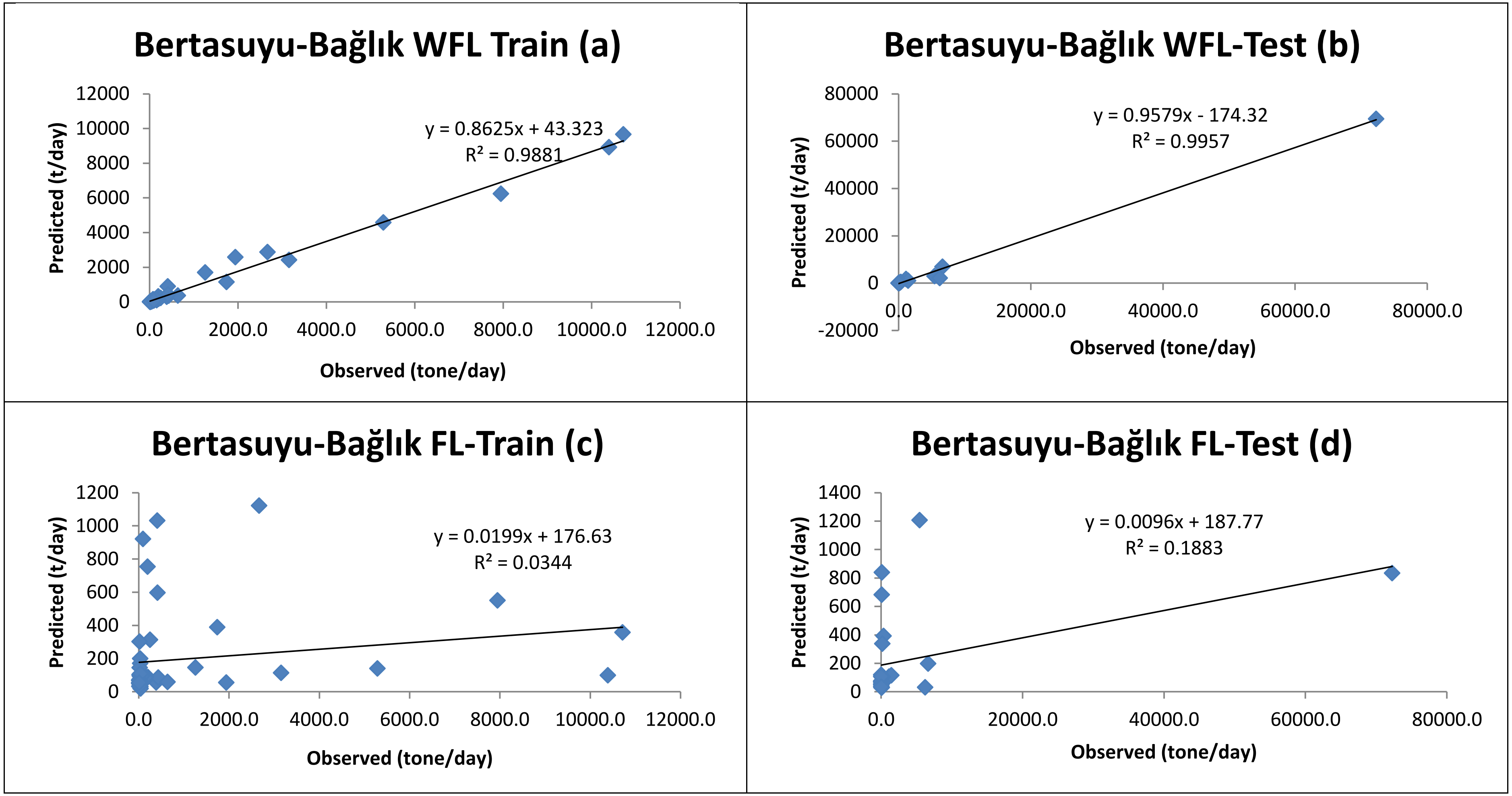


Figure B.1: Bertasuyu-Baglik station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

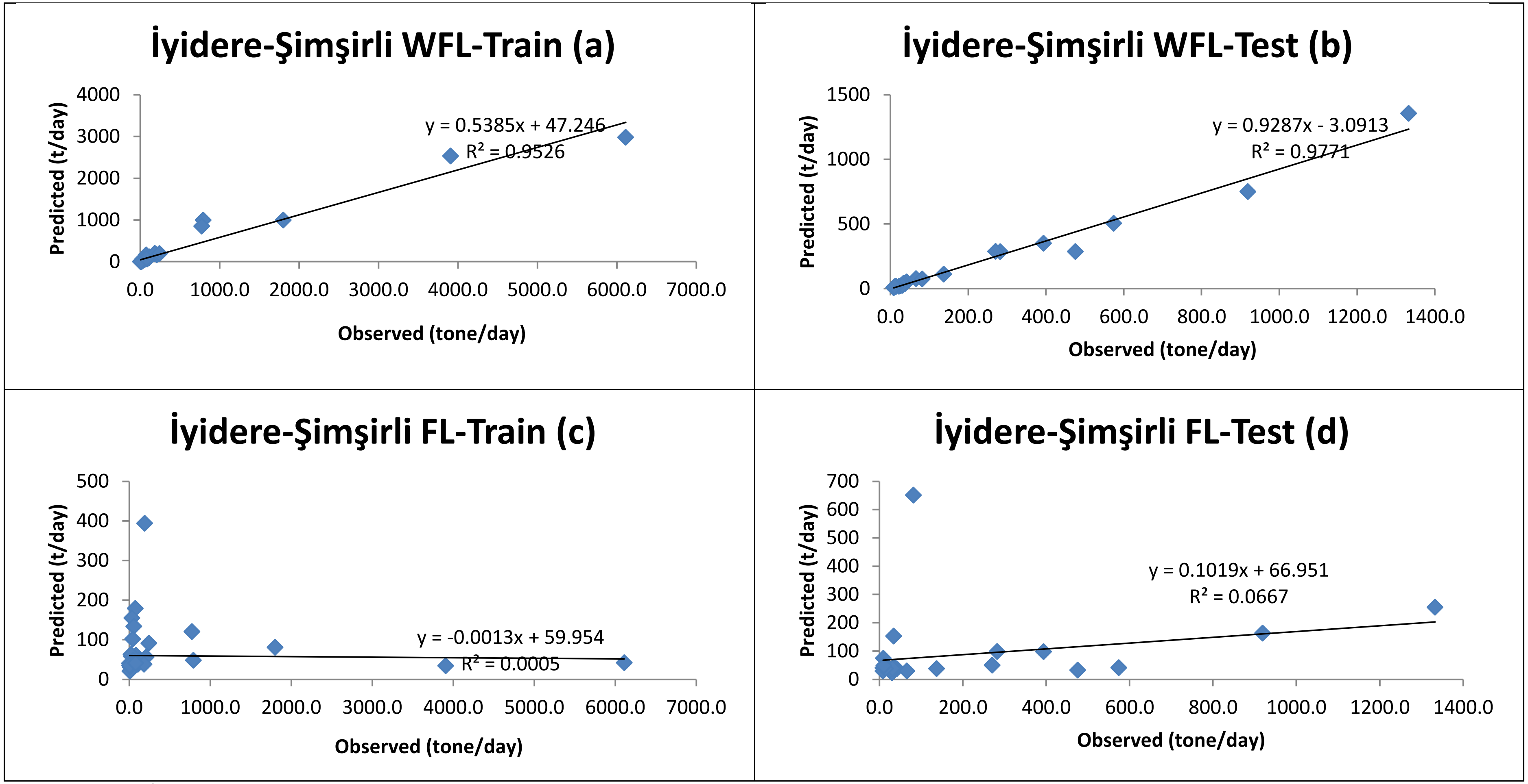


Figure B.2: İyidere-Şimşirli station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

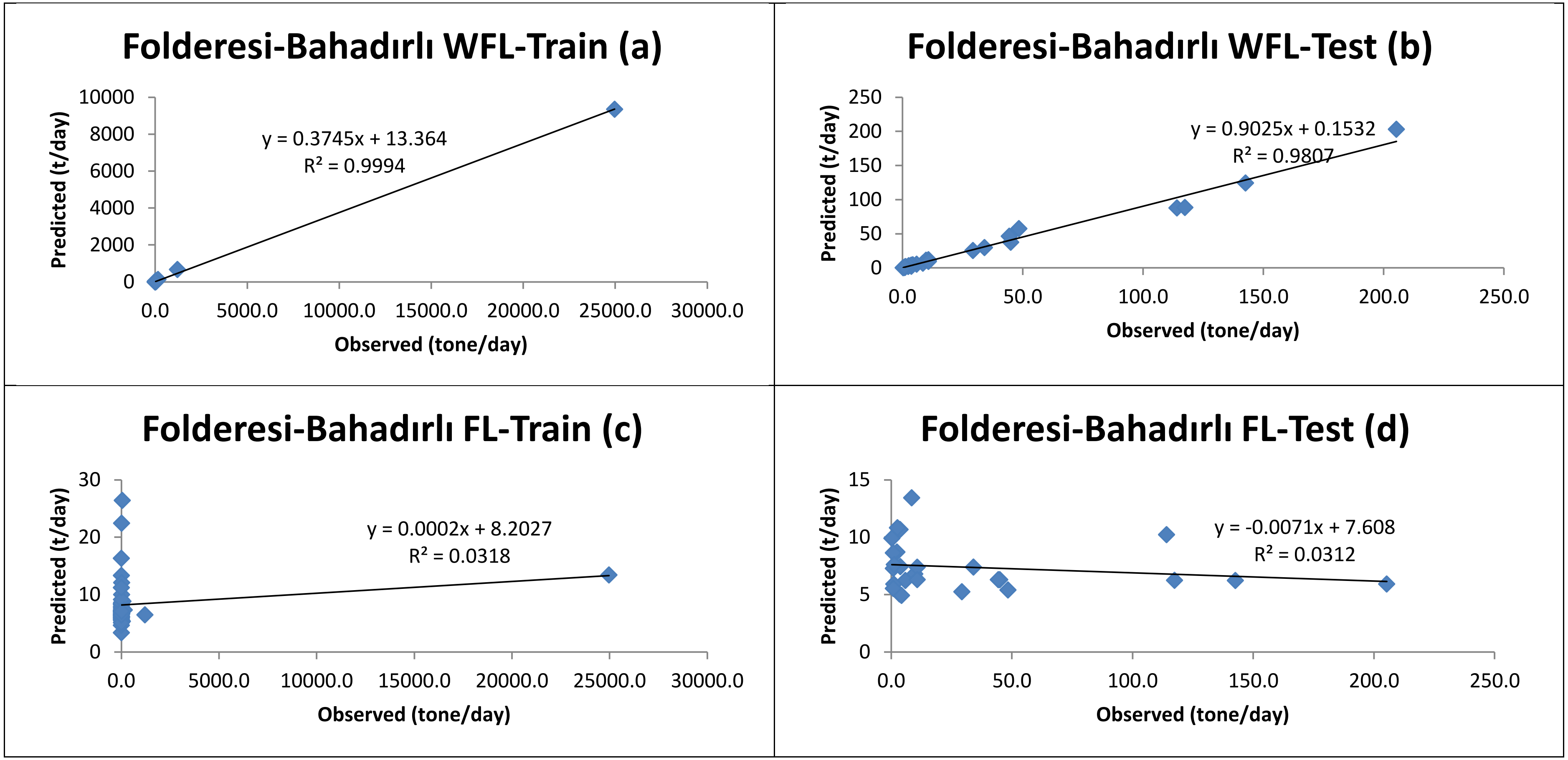


Figure B.3: Folderesi-Bahadırli station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

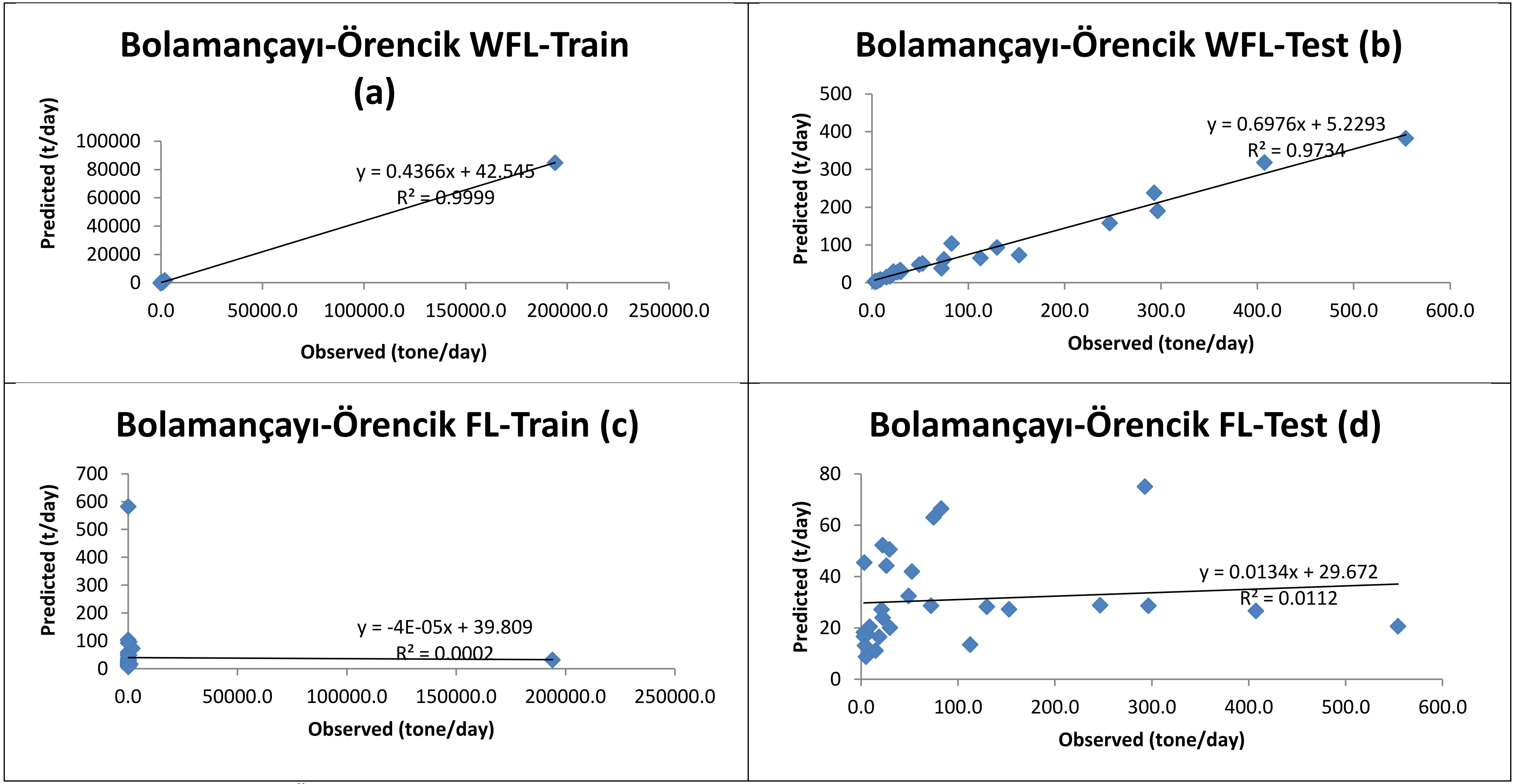


Figure B.4: Bolamançayı-Örencik station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

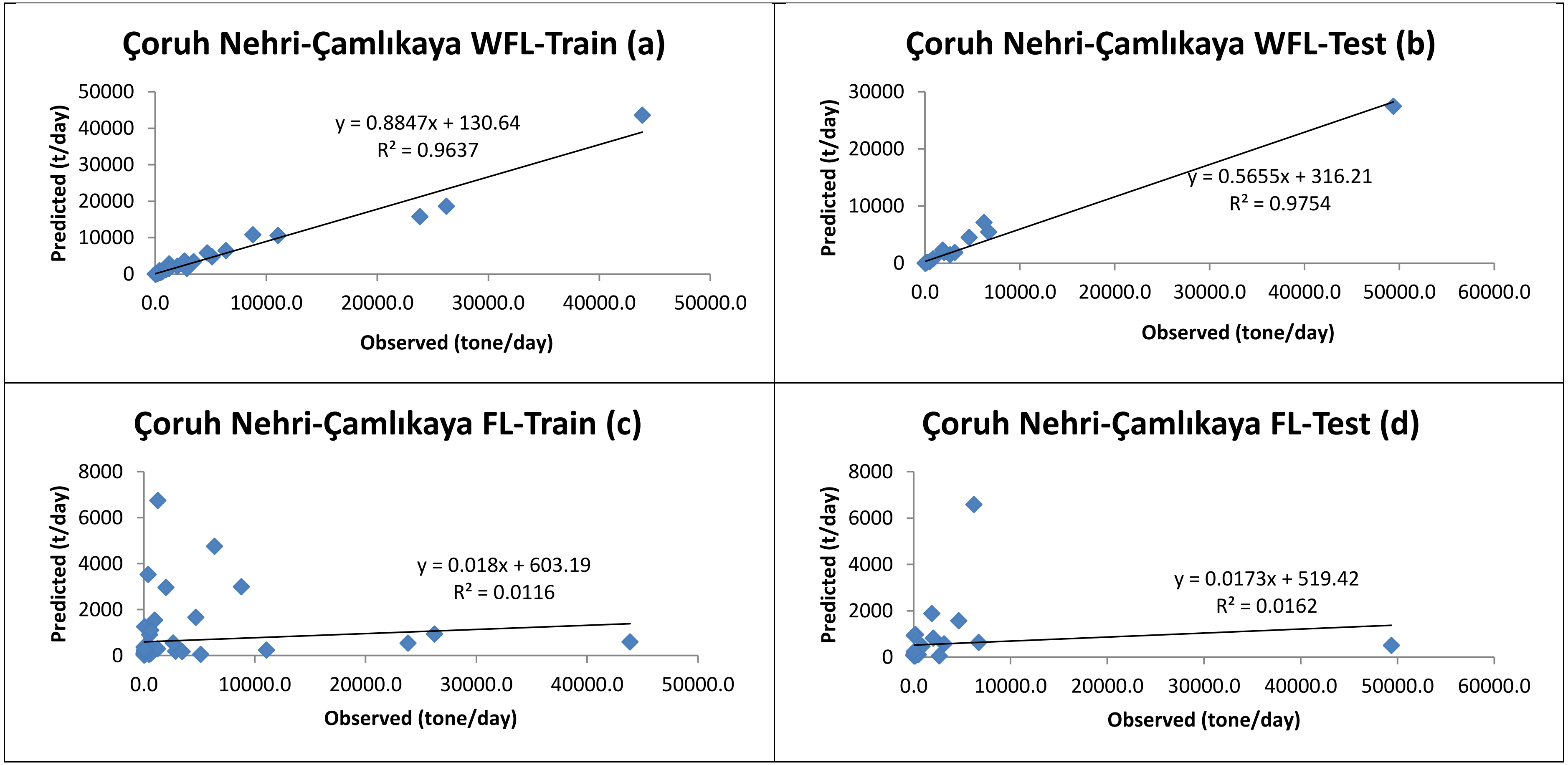


Figure B.5: Çoruh Nehri-Çamlıkaya station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

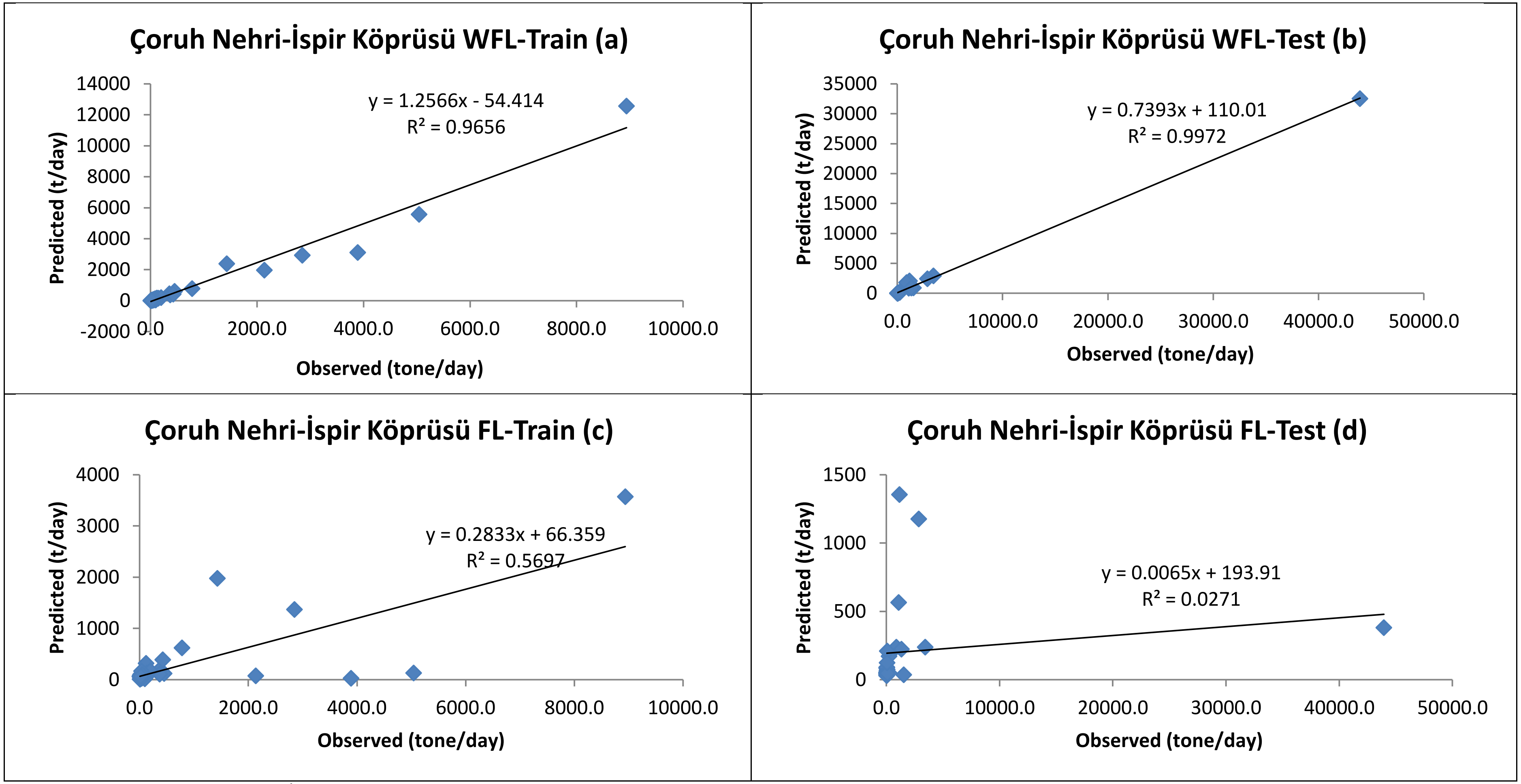


Figure B.6: Çoruh Nehri-İspir Köprüsü station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

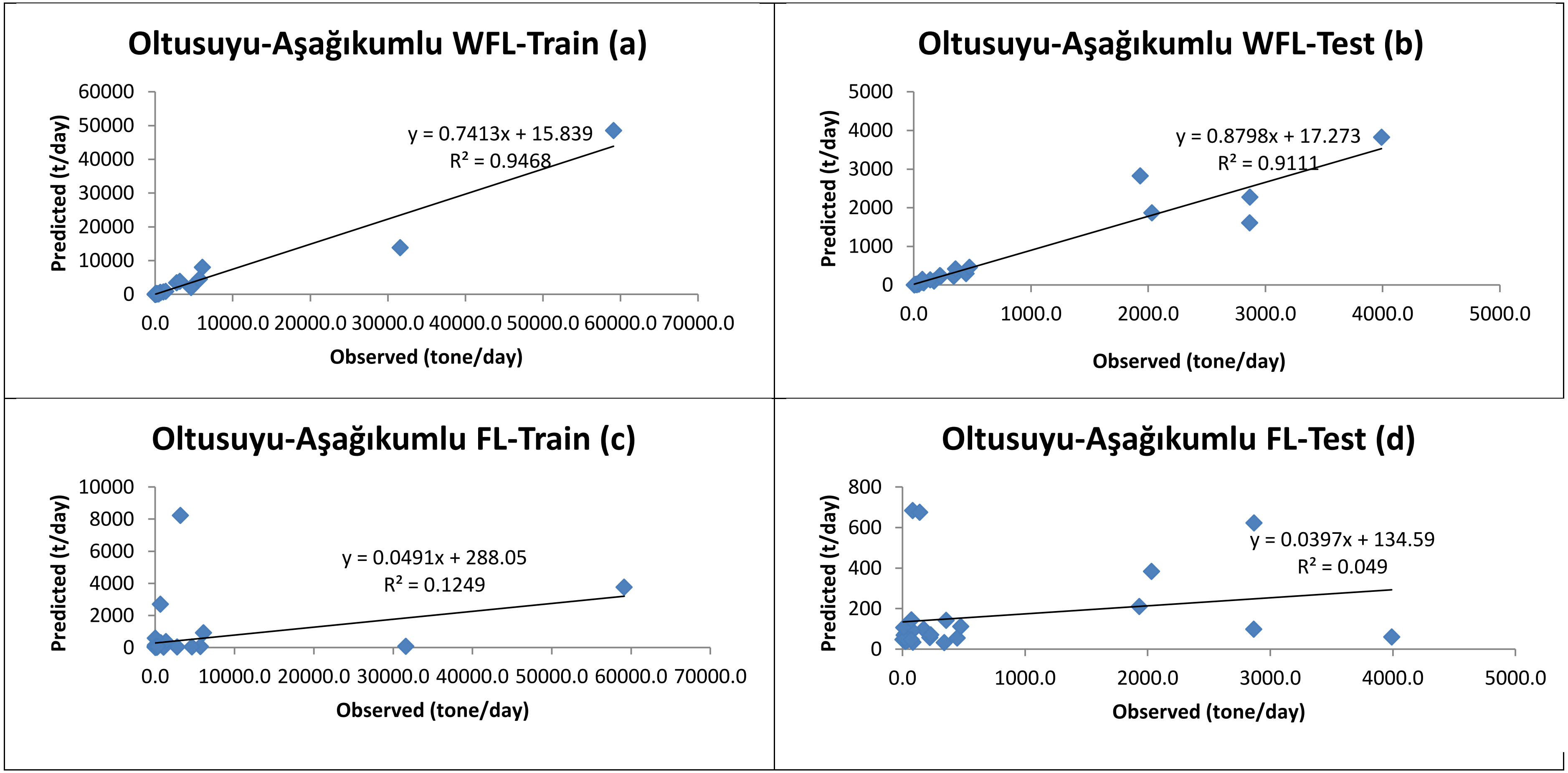


Figure B.7: Oltusuyu-Aşağıkumlu station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

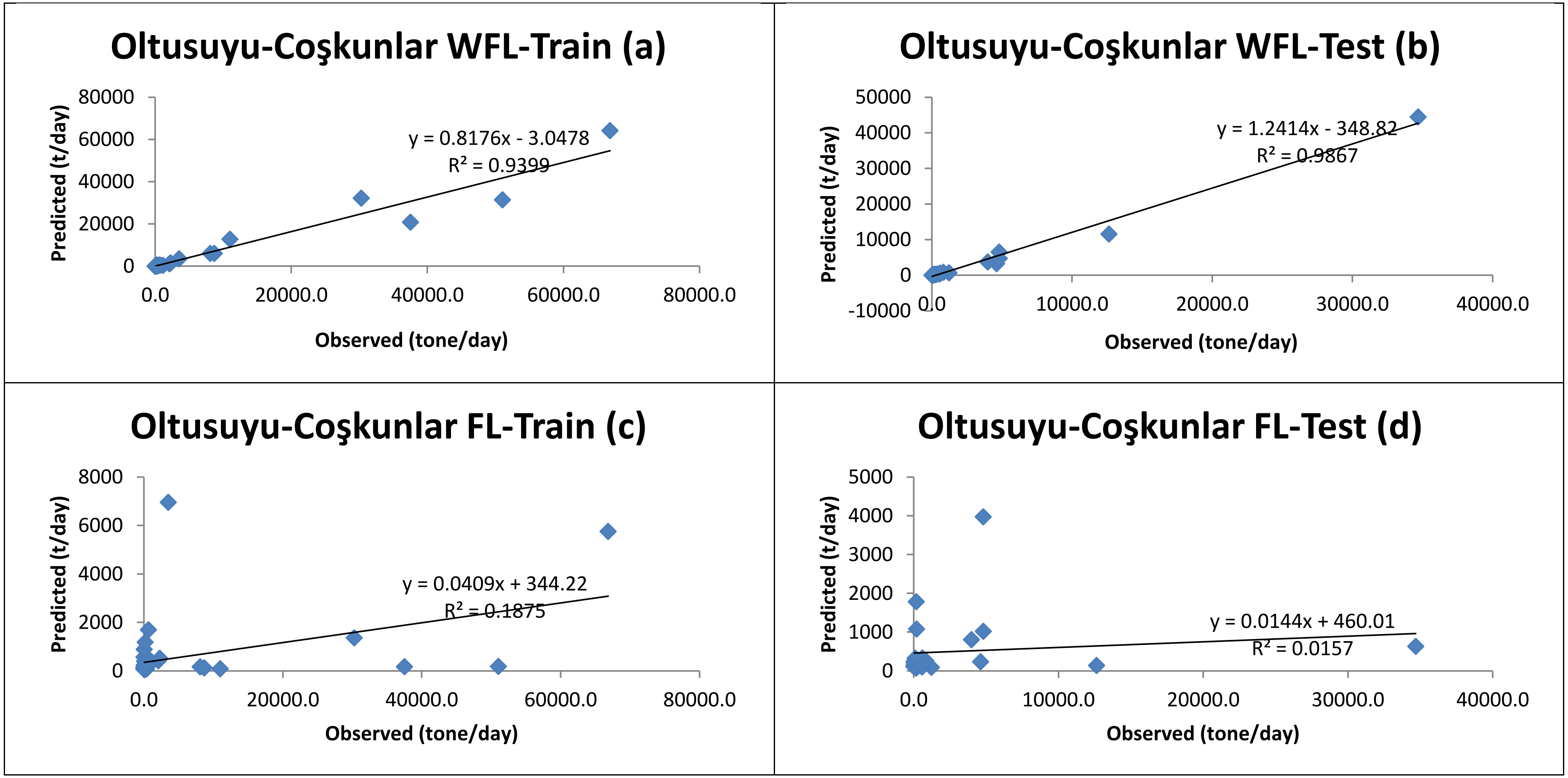


Figure B.8: Oltusuyu-Coşkunlar station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

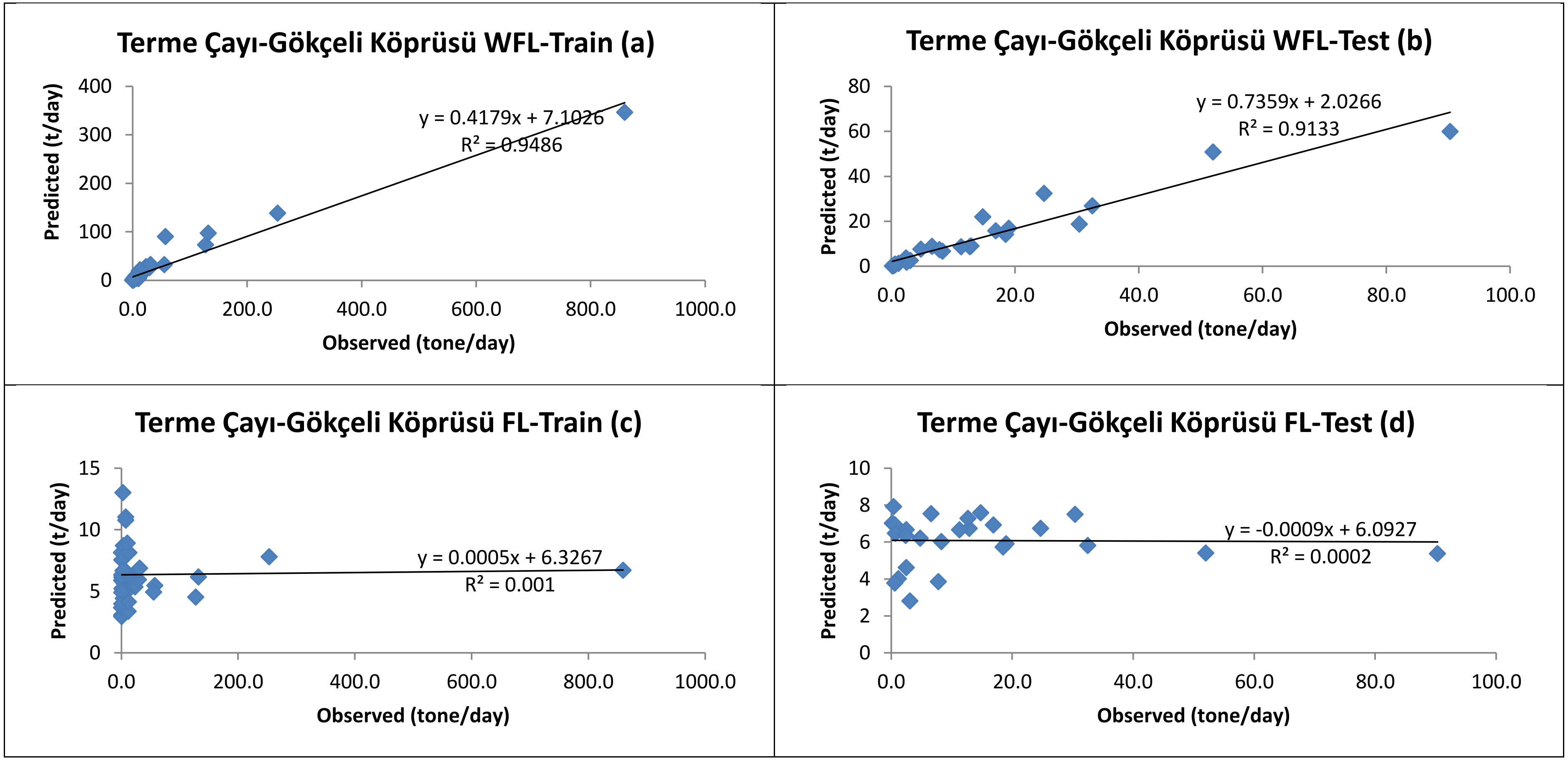


Figure B.9: Terme Çayı-Gökçeli Köprüsü station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

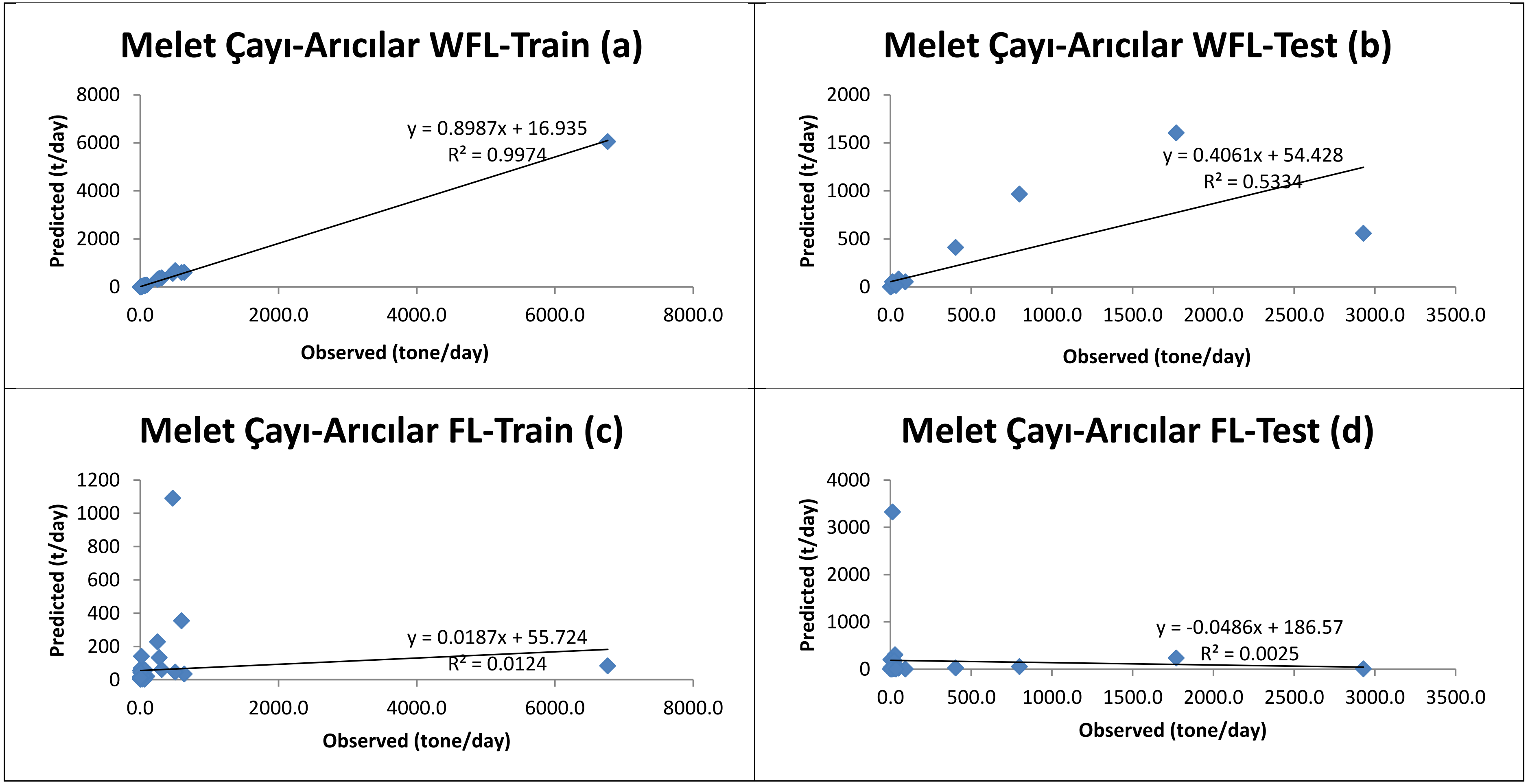


Figure B.10: Melet Çayı-Arıcılar station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

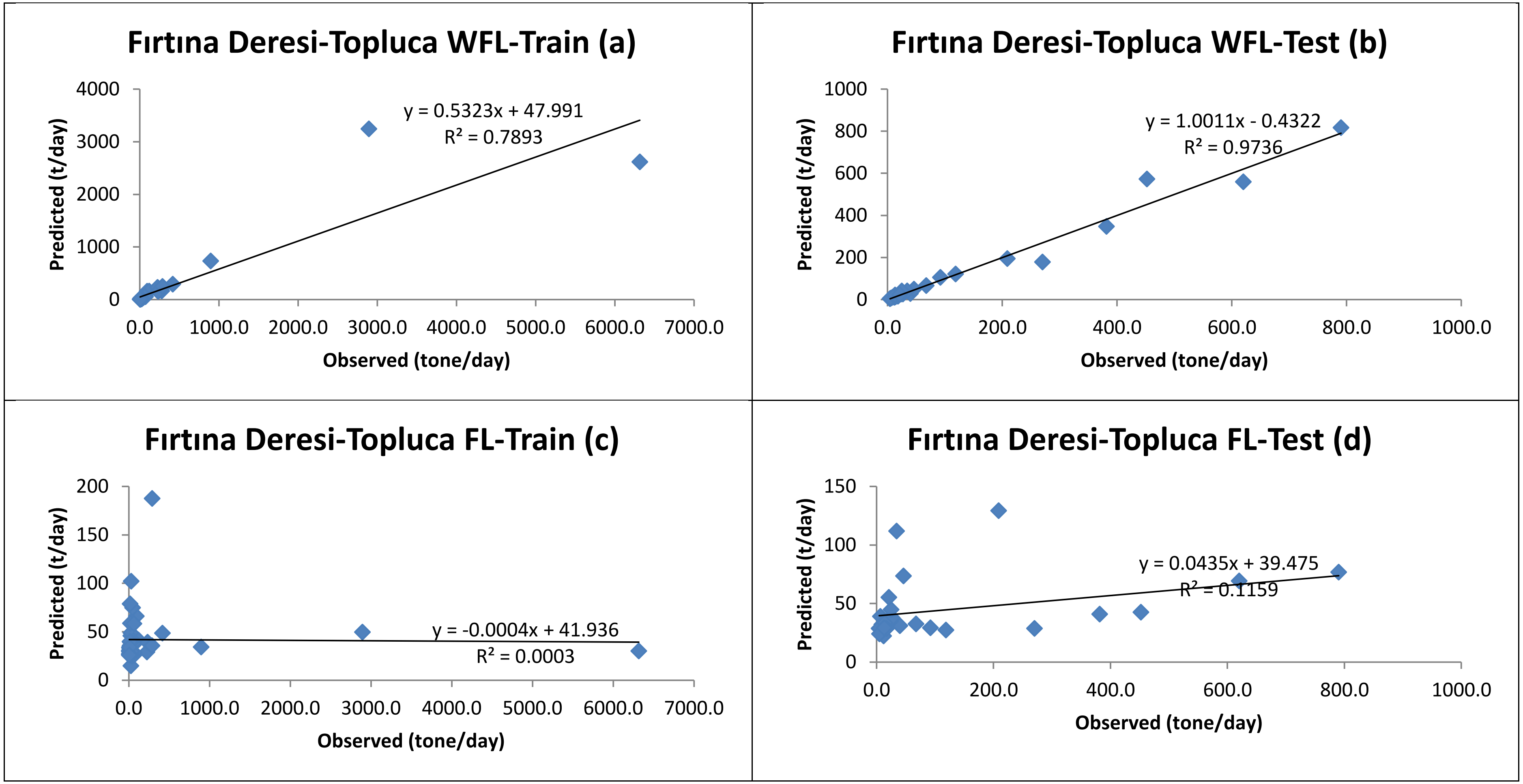


Figure B.11: Fırtına Deresi-Topluca station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

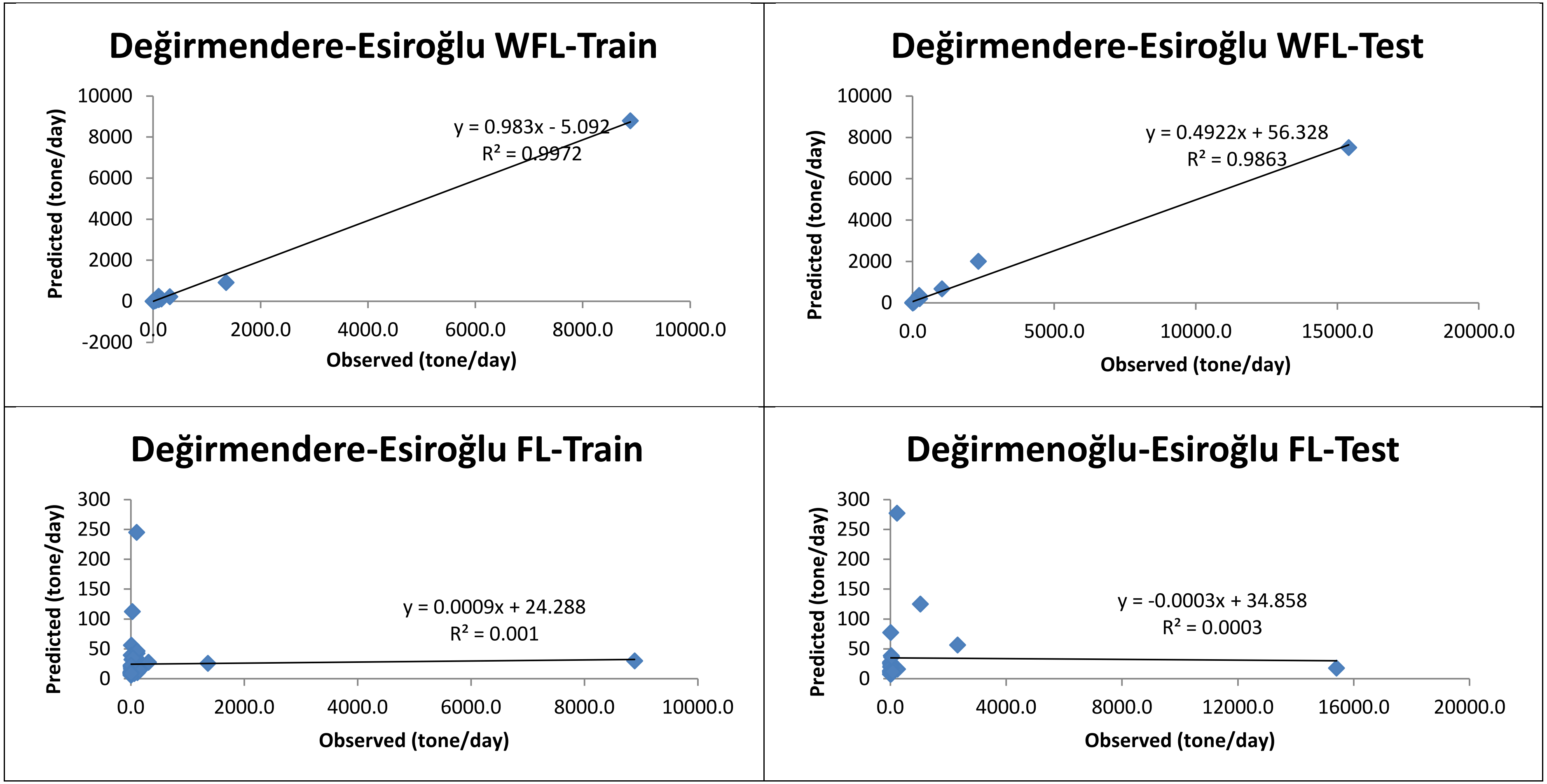


Figure B.12: Değirmendere-Esiroğlu station's scatter diagram of: (a) WFL-Train, (b) WFL-Test, (c) FL-Train, (d) FL-Test

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List of Publications and Patents: Sediment Load Prediction by Fuzzy Logic-Wavelet Combination Method, 2013, *Istanbul International Solid Waste, Water and Wastewater Congress 2013*. May 22-24, 2013, Istanbul, Turkey

PUBLICATIONS/PRESENTATIONS ON THE THESIS

- Ozger, M. and **Kabataş, M. B.**, 2013, Sediment Load Prediction by Fuzzy Logic-Wavelet Combination Method, 2013, *Istanbul International Solid Waste, Water and Wastewater Congress 2013*. May 22-24, 2013, Istanbul, Turkey
- Ozger, M. and **Kabataş, M. B.**, 2014, Sediment Load Prediction by Fuzzy Logic-Wavelet Combination Method, *Journal of Hydrology* submitted.