UNCERTAINTY ANALYSIS OF A HYDRODYNAMIC SEDIMENT TRANSPORT MODEL: A CASE STUDY FROM THE GÖKSU RIVER

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Abstract: This paper describes a theoretical, hydrodynamic model and represents the critical parametric uncertainties associated within the model. The mathematical model structure has been constructed by using process-based equations including both mechanistic and empirical relationships regarding the bedload and suspended sediment transport rate. Model equations are used in bed elevation determination due to the accumulated sediment load within the channels. According to the model, simulations of sediment concentration profiles are in agreement with typical depth averaged sediment profile graphs. Simulation results suggest that total sediment concentration is higher near the river bed than closer to the surface and bedload concentration begins to increase linearly with increasing depth while suspended load tend to decrease. Sediment transporting capacity is found to be higher in stream links with higher velocity and slope values. Results also indicate that bed elevations can change considerably according to changing flow conditions. A Generalized Sensitivity Analysis procedure is applied to the model to determine the correlation between the system's components and the most significant parameters. Results of the analysis suggest that five out of seven parameters, including sediment density, porosity, river depth, channel slope and river flow, are significant at the 90% confidence level or greater. These parameters contain a low level of uncertainty, because they showed much less correlation with the other parameters.

Keywords: Sediment Transport; River; Bed Elevation; Generalized Sensitivity Analysis; Göksu River

1. INTRODUCTION

Transport of sediment through a catchment is primarily driven by the transport of water through the catchment. Any process-based model of sediment delivery, on any scale, must therefore be driven by a similar scale hydrologic model. In the case of hydrologic systems the driving input is rainfall and the resultant output is river discharge. Sediment delivery systems share this driving input of precipitation, and the output of system as bedload or suspended load, is inextricably linked to discharge. Given this relationship between the two physical systems, the issues faced in the modelling of sediment transport are essentially the same issues of catchment hydrologic modelling. Erosion and deposition of sediment exert a major influence over channel morphology, the quantity; nature and balance of the types of sediment are being important (Richards, 1982). Whilst natural erosion rates vary greatly with rock type and relief within one climatic region, they are also closely related to climatic controls (Schumm, 2005). Sediment transport is affected by the hydraulic and hydrodynamic characteristics of the stream including river morphology and flow. The mechanisms of sediment movement and the transporting capacity of varying flow conditions are discussed in various texts on fluvial geomorphology (e.g. Richards, 1982). Hydraulic factors that control the sediment transport capacity of a stream are most appropriate for alluvial rivers, which have beds and banks formed of river-deposited material that can be transported by high flows. River morphologic evolvement is a complicated process, which involves the interaction of flow through channel bends, interaction between flow and the bed, bank erosion and sediment transport. River dynamics are mainly determined by the ratio between the amount of sediment to be transported and the energy that is available for that transport, and, as a result, fluvial development occurs by erosion and deposition (Vandernberghe, 2002). The previous modelling studies focussed on various aspects of river system dynamics ranging from hydrological models such as rainfall-runoff modelling, to hydrodynamic models that account for

various transport mechanisms such as sediment transport or models of river morphodynamics. Most of the existing models focus on simulating a single aspect of the fluvial system such as runoff, sediment transport, or river morphologic development. Mathematical modelling of rainfall-runoff processes has a long history (Beven & Kirkby, 1979; Iberal, 1990; Beven et al., 1995). There are also several models that couple hydrology and sediment transport (Thodsen et al., 2007; Kettner & Syvitski, 2008), sediment transport and river morphology (Lancaster & Bras, 2002) or hydrology and river morphology (Bogaart & van Balen, 2000; Bogaart et al., 2003). River meandering and braiding are the two important processes involved in morphologic evolvement of channels, and predictive modelling of the development of channel patterns and their associated landforms has been a challenging task. Majority of models dealing with river morphodynamics are mathematical, since mathematical models are successful in representing river systems' processes and behaviour, such as meander development or bed elevation (Bogaart & van Balen, 2000; Lancaster & Bras, 2002; Bogaart et al., 2003). Of these numerical models, some of them adopt process-based approaches (Dietrich et al., 1999; Bogaart & van Balen, 2000; Bogaart et al., 2003; Wainwright, 2006; Jarrit & Lawrence, 2007; Thodsen et al., 2007), some are theoretical, based on the linearization of the St. Venant flow equations (Ikeda et al., 1981; Blondeaux & Seminara, 1985; Sun et al., 1996), or some models may also use nonlinear integrodifferential equations to solve the problem of planimetric growth of river meanders (Seminara et al., 2001). Brasington & Richards (2007) have provided a review of key physically-based geomorphological models. Some of the models of river morphology are based on topographic steering, which has more in common with cellular approaches to channel braiding and landscape evolution modelling than to rigorous, physics-based analyses of river meandering (Lancaster & Bras, 2002). Last decades have witnessed a significant progress on the development of cellular models that simulate the processes within river channels and their geomorphic evolution (Lancaster & Bras, 2002; Coulthard & Van De Wiel, 2006; Wainwright, 2006). The proliferation of the cellular models can be partly attributed to the relative simplicity of cellular models and their ability to address some of the shortcomings of other numerical models (Coulthard et al., 2007). Different methodologies adopted in fluvial landscape modelling ranging from empirical to fully mechanistic ones are discussed and reviewed in Peckham (2003). The conceptual framework of modelling fluvial hydraulics and sediment transport has largely relied on experimental flume studies and computational fluid dynamics (CFD) (Brasington & Richards, 2007). Recent advances in modelling techniques such as remote sensing and the use of Digital Elevation Models (DEM) have led to the development of novel spatial and cellular algorithms, efficient discretization methods and an increasing reliance on high quality topographic data. In fluvial geomorphology, cellular models use simplified or 'relaxed' versions of the complex flow equations used in CFD models (Coulthard et al., 2007). On the other hand, the causes and impacts of river meandering have captivated river scientists for years and during the last few decades there have been significant improvements in our understanding of the processes that lead to river meandering and braiding. Over the last decade, several 'reduced complexity' cellular models have been developed. Pioneering work of Murray & Paola (1994) has been followed by the application of cellular algorithms to fluvial environments including meandering rivers (Lancaster & Bras, 2002), braiding rivers (Coulthard & Van De Wiel, 2006) and river catchments and reaches (Coulthard et al., 2007). The basic principles of modelling fluvial geomorphology are based on the simple rules and simplifications of the governing physics (e.g. the interactions between the routing of water and sediment). In fluvial systems modelling, there is a tendency to model only certain aspects of processes such as meandering streams, braiding streams, or bed elevation changes. However, a limited number of studies take into account the effect of stochastic methods, such as Monte Carlo analysis to model sediment transport.

The physically-based, mathematical approach adopted in sediment transport modelling focuses on representing the physical processes involved in the interaction between flow and channel bed and the banks by a set of algebraic and differential equations. The strength of mathematical models is their ability in producing plenty of different scenarios for the possible changes in environmental systems, which makes them reliable tools in interpreting the mechanisms that govern morphological changes occurring within river systems. Mathematical models can be solved with a computer programme under specified input and parameter conditions in order to assess the behaviour of the model under various conditions. However, the difficulty in matching physical theory and the practical estimation of model parameter values is well-recognized in hydrology (Brasington & Richards, 2007).

In this paper, a theoretical modelling methodology is adopted to simulate the bed elevation change of fluvial systems and a stochastic method is applied to determine the uncertainties associated within the model parameters. The theoretical model is developed by using pocess-based equations including both mechanisticf and semi-empirical relationships. Finally, randomness was injected through probability distribution functions, and a Generalized Sensitivity Analysis procedure was carried out to identify the parametric correlations and uncertainities within the model. To be able to run simulations under varying stream conditions, the mathematical model is implemented by developing a computer simulation programme.

2. METHODOLOGY

The methodology behind the model here is to develop a physically-based, mathematical hydrodynamic model of sediment transport first and then to add randomness via Monte Carlo simulations to determine the significant parameters and parametric correlations.

2.1. Study Area

Göksu River is located in the Eastern Mediterrenean region of Turkey (Fig. 1) and contains large relatively unspoiled forested mountains and alpine meadows. Coastal areas constitute an important section of the Turkish riviera with intensive tourism. The coastal plains contain major greenhouse facilities and fruittree plantations with industrial complexes developed around the city of Mersin (Akbulut et al., 1992).

The headwaters of the river are located southwest of the town of Hadım of Konya province, in the Central Mediterranean part of Turkey. The two main branches are the Hadım and Ermenek

Creek, which join in Suçatı, located near the town of Mut of Mersin province. From here onwards the river is called Göksu. The river is 260 km long and empties into the Mediterranean Sea 16 km southeast of Silifke. The Göksu River's catchment area is 10.100 km^2 and anual water yield is 3.63 billion m^3. With its 260 km long river and 10,069 km^2 area, Göksu River is one of the most important catchments of Turkey. Göksu River is selected as the case study and the model is applied to the downstream catchment of the river.

Göksu Delta is accepted as a special protection area with its rich flora and fauna species living in the Delta. Göksu Catchment has both agricultural and urban settlement areas with settlements concentrated around the Göksu River, which affects the urban development sustainability in a bad way (Akiner & Akiner, 2010).

There is a real pollution potential in the Delta due to the uncontrolled agriculture and unplanned constructions, which threatens the survival of living species. The average daily concentration of suspended load is 363 ppm over a period of 45 years. Moreover, low lying deltas such as Göksu are also vulnerable to the impacts of sea level rise, salt water intrusion as well as other impacts of climate change (Özyurt & Ergin, 2009).

On the catchment area, a GIS analysis was conducted by employing spatial analysis tools of ARC GIS 9.3. A satellite image of the area is available in order to identify basic land cover and topographical features. Basically from this satellite image, a raw map of the area was created, which highlights masses of water and larger towns and cities. Topographical features are projected on the raw map in order to show basic topographical figures. After the topographical features are understood via step projection, gradual projection is applied to the raw map. Gradual representation is needed for better calculation and formulation.

Figure 1. Map of the study area showing the locations of stations where data are obtained.
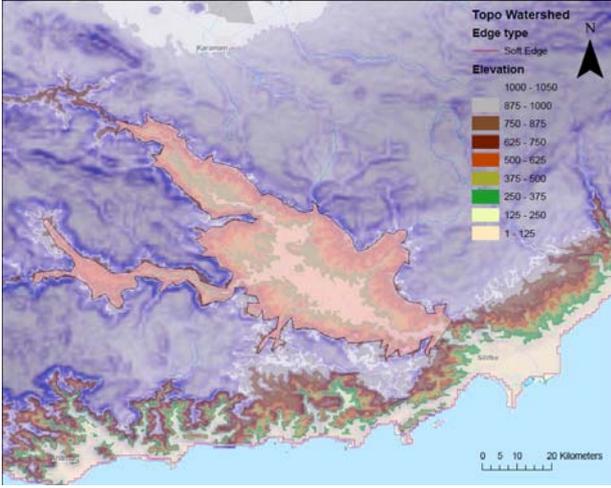(Source: 33º 48′ 55″ E and 36º 24′ 11″ N. Google Earth. January 07, 2013)

Figure 2. Map of the catchment area of interest.

Slope data is calculated from the topographical layer and a new layer of slope is produced. This layer later projected on the raw map in order to highlight the higher slope and lower slope areas. Topographical map and slope map are projected together with different color scales in order to highlight plains and plateaus. Plateaus are visible in the map with light blue and dark grey color and plains are light colored both in blue and gray scale, Göksu Basin becomes visible. Topography which is lower than the edge of the basin (altitude<1200m) is colored in order to obtain and present a better visualization. Area of interest is selected as a polygon from the highlighted map; this is the catchment which feeds the Göksu River (Fig. 2).

2.2. Modelling Sediment Transport

The most important processes regarding sediment transport and storage are degradation and aggradation, which are actually the change of river bed over time. This erosion/sedimentation rate is directly governed by the spatial divergence of sediment transport, as can be seen from the one-dimensional sediment continuity equation (Eq. 1). Rearranging Eq. 1 and considering that the sediment produces a layer of thickness dy with a porosity λ, yields Eq. 2:

$$\frac{\partial z}{\partial t} = \nabla q_{s_v} + I + T = \frac{\partial q_{s_v}}{\partial x} + I + T \quad (1)$$

$$dydx = -\frac{1}{1-\lambda} dq_{s_v} dt \quad (2)$$

where q_{sv} is the volumetric unit sediment transport rate, I is unit external sediment input, and T is vertical movement due to tectonics. In this model I

and T are ignored for simplicity. Initiation of particle motion begins when the shear stress exerted on the individual sediment particles is large enough to initiate motion. This makes shear stress one of the most significant physical properties in the model. Sediment load includes bed, suspended and wash load (Richards, 1982). A well recognized relation for bedload transport can be provided in the form of Eq. 3. Suspended sediment, on the other hand, is non-uniformly distributed with depth and across the channel, especially where secondary currents are well developed (Richards, 1982), it depends on the product of sediment concentration and velocity profiles as indicated in Eq. 4:

$$q_b^* = 8\left(\tau^* - \tau_c^*\right)^{1.5} \quad (3)$$

$$q_s = \int_0^H c_s(z)u(z)dz \quad (4)$$

$$q_t = q_b + q_s \quad (5)$$

where q_b^* is the Einstein number, and τ^* and τ_c^* are the boundary and critical shear stress, respectively. The velocity profile equations incorporate a measure of bed shear stress (Eq. 6) in the shear velocity term, which serves as a scaling parameter for kinematic velocity profiles in turbulent boundary layers. By using the definition of shear velocity (Eq. 7), Eq. 6 is rearranged to yield Eq. 8:

$$\tau_0 = \kappa^2 y^2 \rho_w \left(\frac{du}{dy}\right)^2 \quad (6)$$

$$u_* = \sqrt{\frac{\tau_0}{\rho_w}} \quad (7)$$

$$\frac{du}{dy} = \frac{u_*}{\kappa y} \quad (8)$$

Integration of Eq. 8 gives the logarithmic velocity distribution (Eq. 9), where $y= d - z$. It is also crucial to determine the vertical location of suspended particles (Eq.10), since the water velocity acting on these particles is obtained from logarithmic velocity profile.

Thus, for each time step Δt, the new vertical location is determined by using Eq. 11:

$$\frac{u(z)}{u_*} = \frac{1}{\kappa} \ln\left(\frac{d-z}{z_0}\right) \quad (9)$$

$$v = \frac{2(\rho_s - \rho_w)g(D/2)^2}{9\mu} \quad (10)$$

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$$y_{t+1} = y_t + (v \times \Delta t) \qquad (11)$$

In accordance with the model algorithms presented above, a computer program was utilized for the implementation of the model. Figure 3 provides the flowchart of the computer simulation programme.

2.3. Data Requirements

The data was obtained from Turkish General Directorate of Electrical Power Resources Survey and Development Administration (EIE), and included daily flow and monthly sediment concentration. Data required for the simulation model are given in table 1.

2.4. Generalized Sensitivity Analysis of the Model

It is not always possible to fully utilize a model because of the lack of data. A technique called Generalized Sensitivity Analysis (GSA) was developed by Spear & Hornberger (1980) for the preliminary analysis of an environmental system and to identify the critical uncertainties of a model for the direction and planning of future research.

This technique also reveals the parameters or processes that have little influence on the simulated outputs of the model. The idea of the method is to utilize a simulation model together with a classification algorithm. This allows for any particular matrix of the determinants to be labelled as either representative or not representative of the observed behaviour. The underlying principle is to incorporate uncertainty in the model by specifying the parameters via probability distribution functions and then to perform Monte Carlo simulations choosing parameter values from the specified distributions. The result of each simulation is then classified as being either a behaviour or non-behaviour. Once the parameter space is divided by the behavioural mapping, analysis then focuses on the determination of which parameters are most important in distinguishing between behaviour and non-behaviour.

Accordingly, in this study, the value of each parameter was changed from -90% to +90% of its original calibration value. After a simulation is completed, the process is repeated 1000 times. After 1000 runs, the model will have produced m parameter vectors, which led to behaviour, and n ($=1000-m$), which did not. After an initial set of 1000 simulations, the CDFs for each of the parameters were examined. These parameter vectors were then used in performing the Kolmogorov-Smirnov (K-S) two sample test, which uses the maximum vertical deviation between the two cumulative distribution curves as the statistic $d_{m,n}$.

2.4.1. Göksu River's Defining Behaviour

The following qualitative behaviour was discerned from the discharge and sediment concentration data of the Göksu River provided in figure 4:
  i.   there are generally two peaks regarding both river flow and sediment concentration that can be observed within a year,
  ii.   in each year , at least one of the two peaks of sediment concentration, which is above 700 ppm, also corresponds to a peak in flow,
  iii.   if there is not a sediment peak that exceeds 700 ppm, the second peak itself corresponds to the peak value in flow.

3. RESULTS

3.1. Results of the Sediment Transport Model

To carry out a qualitative validation, a region from Göksu River's downstream (Fig. 5) was selected to be used for the application of the model. The stream is divided into 4 parts due to topographical (cross-sectional area, slope), hydrodynamic (flow) and quality (sediment concentration) variations, and the model was run for specific purposes to test whether it 'simulates as intended'.

Distribution of sediment concentrations are usually expressed as vertical profiles. The interpretations of these profiles are usually complex and involve some major problems due to the degree of ambiguity and subjectivity in the interpretations. Figure 6a illustrates the simulation of the sediment concentration profile in a selected link (Link 1), and is in agreement with typical depth averaged profile graphs. As figure 6a indicates, vertical sediment profile is remarkably smooth and continous with decreasing sediment concentration values approaching the water surface; and, therefore amenable to a simple mathematical representation. It is clear from the graph that the sediment concentration increases downwards in the water column. There is a slight convex and concave trend in the upper and lower parts of the graph, respectively, meaning that the concentration profile is not rectilinear (Yang et al., 2004). On average, the total sediment concentration is about 2.3 times greater near the bed than closer to the surface. A similar relationship between depth and sediment flux is also represented in figure 6b.
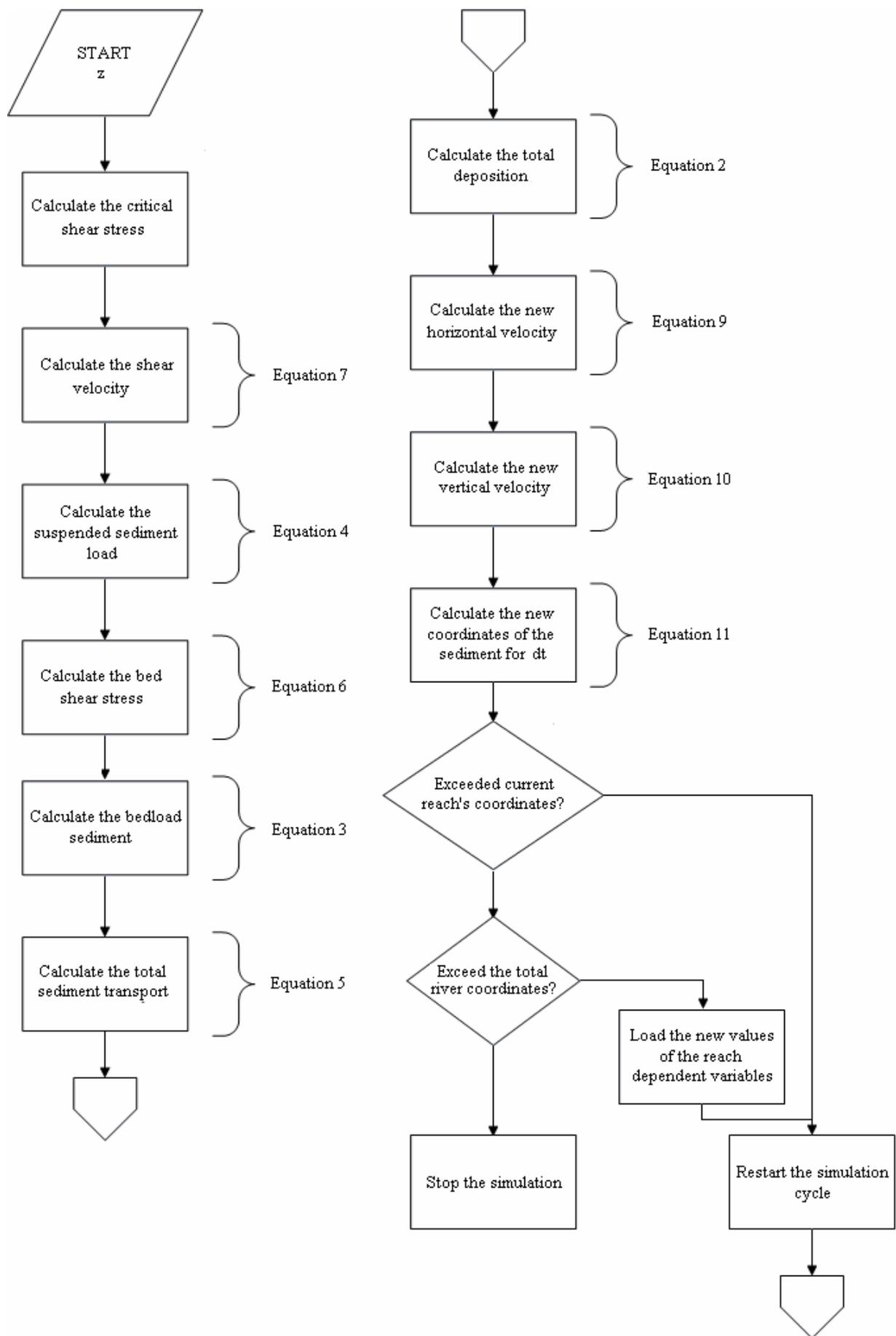
START
z

Calculate the critical shear stress

Calculate the shear velocity — Equation 7

Calculate the suspended sediment load — Equation 4

Calculate the bed shear stress — Equation 6

Calculate the bedload sediment — Equation 3

Calculate the total sediment transport — Equation 5

Calculate the total deposition — Equation 2

Calculate the new horizontal velocity — Equation 9

Calculate the new vertical velocity — Equation 10

Calculate the new coordinates of the sediment for dt — Equation 11

Exceeded current reach's coordinates?

Exceed the total river coordinates?

Load the new values of the reach dependent variables

Stop the simulation

Restart the simulation cycle

Figure 3. Flowchart of the computer simulation model.

Table 1. Data required for the model together with values and ranges

| Data	Value/Range	Source
Channel slope	0.02-0.10	GIS based data system
Elevation	0-1000 m	GIS based data system
Channel length	4000-15000 m	GIS based data system
Sediment density (p_s)	1.5 g cm^{-3}	Estimated from data provided by EIE
Water density (p_w)	1 g cm^{-3}	Literature
Porosity (λ)	0.30	Estimated from data
River flow (Q)	Variable	Data provided by EIE
River velocity (u)	Variable	Calculated by the model
Cross-sectional area (A)	Variable	Calculated by the model
Shields parameter (τ^*)	Variable	Calculated by the model
Critical shear stress	Variable	Calculated by the model
Particle diameter (D)	0.05×10^{-3} m	Estimated from data
Shear velocity (u_*)	Variable	Calculated by the model
River depth (d)	8 m	Estimated from flow rating curve (EIE)
Distance from the water surface (z)	Variable	Calculated by the model
Zero-velocity height (z_0)	1.5 m	Estimated from flow rating curve
Sediment concentration profile (C_s (z))	Variable	Data provided by EIE
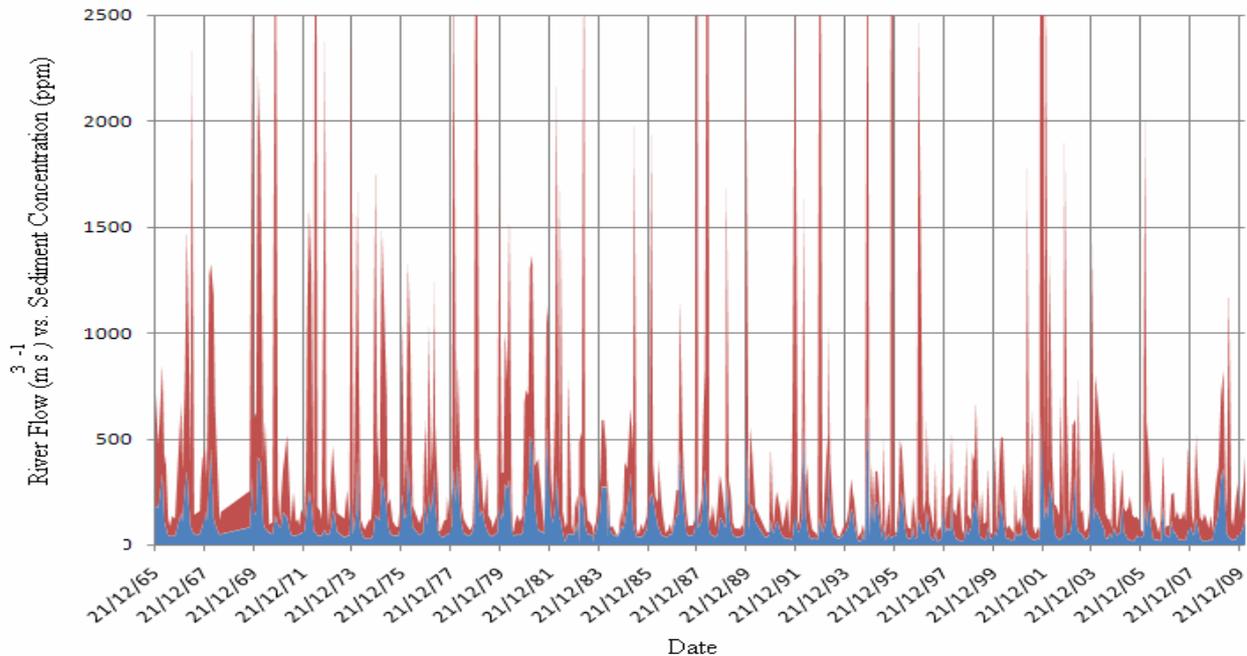
Figure 4. Discharge and sediment concentrations of the Göksu River between years 1965 and 2010.

The model is run to simulate the bed elevation change over a 40 km distance and the result is shown in figure 7a. Figure 7a suggests an altering trend of deposition (high-low-high). This is probably because, higher sections experiences larger amounts of sediment deposition so that there is less amount of sediment supply to be transported to the proceeding link. The high-low-high pattern can also be associated with a 'periodic' or 'wave-like' situation, which is usually observed in rivers where the down-channel slope is very low (Peckham, 2003). Similary, effect of varying flow values on bed elevation change over the same distance is simulated and the graph is provided in figure 8. For each of the subsequent simulations, input flow data, obtained from figure 5, are multiplied by factors of 2 (Fig. 8b) and 3 (Fig. 8c). Results clearly indicate that higher discharge values increase the sediment transporting capacity of the river and carry the sediment load downstream. Yet, in case of a fixed sediment supply, the sediment supply will eventually be exhausted and the system will reach to a more steady condition when a new equilibrium profile is reached (Fig. 8).
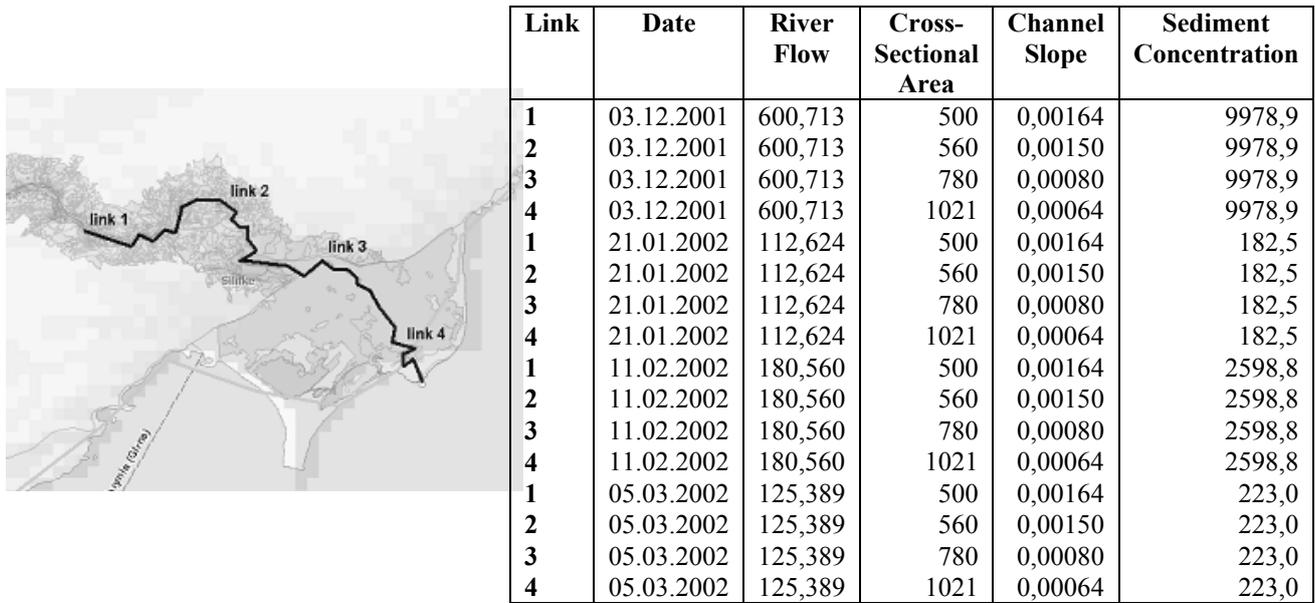
Link	Date	River Flow	Cross-Sectional Area	Channel Slope	Sediment Concentration
1	03.12.2001	600,713	500	0,00164	9978,9
2	03.12.2001	600,713	560	0,00150	9978,9
3	03.12.2001	600,713	780	0,00080	9978,9
4	03.12.2001	600,713	1021	0,00064	9978,9
1	21.01.2002	112,624	500	0,00164	182,5
2	21.01.2002	112,624	560	0,00150	182,5
3	21.01.2002	112,624	780	0,00080	182,5
4	21.01.2002	112,624	1021	0,00064	182,5
1	11.02.2002	180,560	500	0,00164	2598,8
2	11.02.2002	180,560	560	0,00150	2598,8
3	11.02.2002	180,560	780	0,00080	2598,8
4	11.02.2002	180,560	1021	0,00064	2598,8
1	05.03.2002	125,389	500	0,00164	223,0
2	05.03.2002	125,389	560	0,00150	223,0
3	05.03.2002	125,389	780	0,00080	223,0
4	05.03.2002	125,389	1021	0,00064	223,0

Figure 5. River channel where the simulations are carried out and characteristics of modelled links
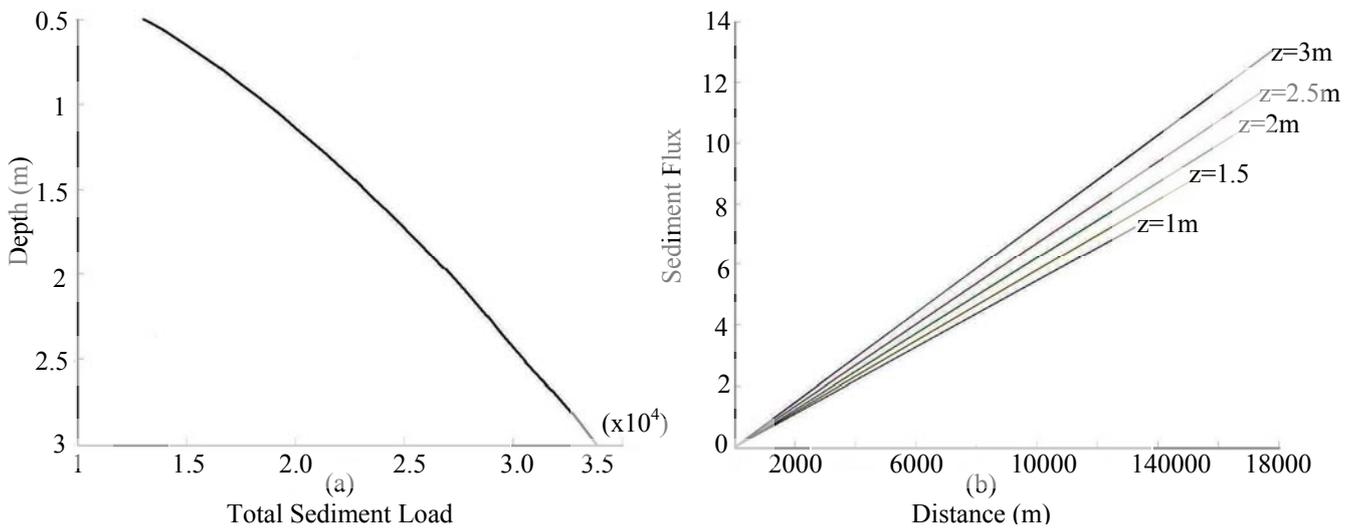

Figure 6. (a) Sediment load profile (b) The effect of varying depth on sediment flux

Model results suggest that simulation results are in agreement with the previously published literature (Bogaart & van Balen, 2000; Peckham, 2003). Suspended loads can be measured at a number of points in the vertical-cross section of the river and it is possible to calculate the suspended sediment concentration at any point in the vertical profile by knowing its concetration at a reference depth (Allen, 1997). However, reliable measurements of bedload are extremely difficult to make, and our understanding of global patterns of bedload tranport is still insufficient. Hence, estimation of bedload fraction in total sediment load constitutes another important aspect of sediment transport modelling. Figure 7b shows the simulation of distribution of bedload and suspended load profle in the vertical channel profile. While bedload represents a small fraction of the total load, its concentration begins to increase linearly with increasing depth as suspended load tends to decrease.

3.2. Results of the Generalized Sensitivity Analysis

The results of the Kolmogorov-Smirnov (K-S) two sample test, which uses the maximum vertical deviation between the two cumulative distribution curves as the statistic $d_{m,n}$ is given in figure 9. Table 2 provides the parameters studied in the GSA of the model together with their corresponding significance levels and statistics. 5 out of 7 parameters are found to be significant at the 90% confidence level or greater. Table 3 shows the interactions between the model parameters for normalised behaviour.
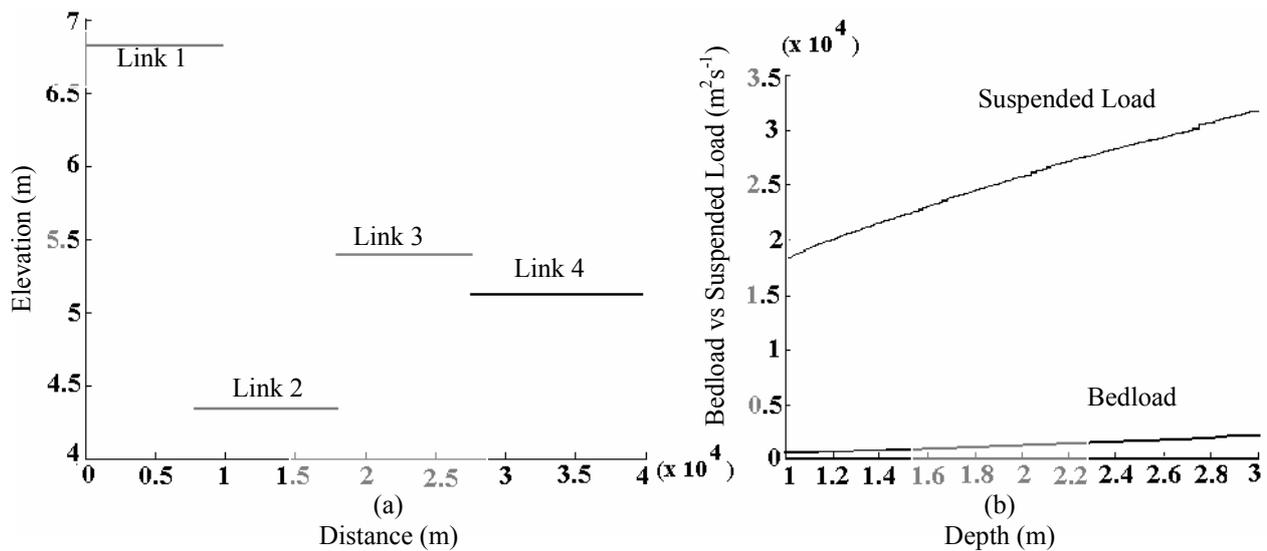
Figure 7. (a) Bed elevation change (b) Suspended load and bedload change profile
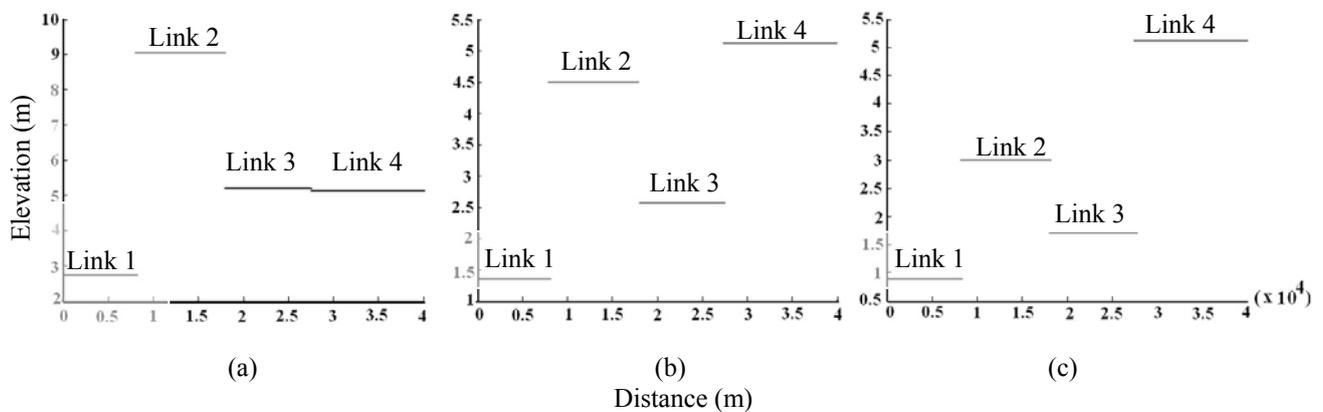

Figure 8. The effect of flow on bed elevation (a, b and c indicate flows of Q, 2Q and 3Q respectively)

Table 2. Sensitivity ranking of parameters included in the GSA

Rank	1	3	3	4	5	6	7
Parameter	p_s	λ	d	S	Q	$C_s(z)$	A
Significance	1.000000	0.993025	0.989764	0.926160	0.910290	0.835457	0.550153
$d_{m,n}$ statistics	0.439716	0.715789	0.760417	0.473118	0.583333	0.439716	0.237542

Table 3. Covariance matrix for normalised behaviour produced from the GSA

	S	A	d	$C_s(z)$	Q	p_s	λ
S		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A	0.0000		0.0011	-0.0015	0.0023	-0.0976	-0.0001
d	0.0000	0.0011		0.0000	0.0001	-0.0004	0.0000
$C_s(z)$	0.0000	-0.0015	0.0000		-0.0003	-0.0025	0.0000
Q	0.0000	0.0023	0.0001	-0.0003		0.0050	0.0000
p_s	0.0000	-0.0976	-0.0004	-0.0025	0.0050		0.0001
λ	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0001	

Parameters should ideally be independent, but in some cases there may be correlations between them (Spear and Hornberger, 1980). For the reliability of a model, it is important that high degree of correlations should not be observed between significant parameters. The results of the simulations suggested that most of the parameters were independent with no correlations in obtaining the correct behaviour, while some indicated a low degree of correlation and interdependence. Of the significant parameters slope and porosity showed almost no correlation with other parameters.
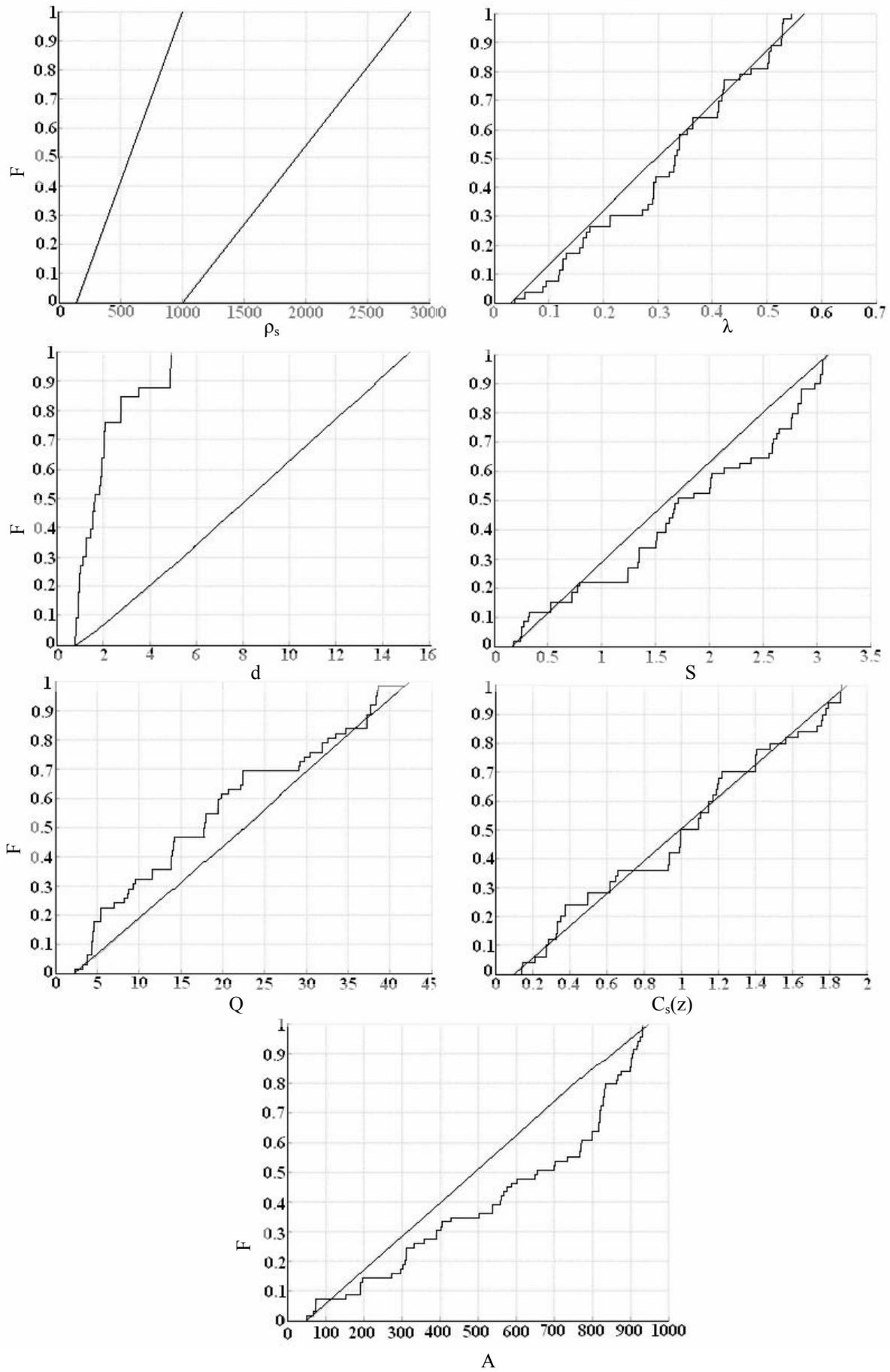
Figure 9. Cumulative distribution function under the behavioural mapping for selected parameters

The parameter that has the highest degree of correlation is found to be the cross-sectional area; however, this parameter was the least significant one of the seven parameters studied in the sensitivity analysis.

4. DISCUSSION AND CONCLUSION

Changes in river flow leads to the alteration of the saltwater intrusion pattern in terms of both distance and intensity, and variability in water discharge leads to the alteration of the saltwater intrusion pattern both in terms of distance and intensity (Chen, 2005). Decreased discharge rates can result in saltwater intrusion along deltas affecting the use of freshwater resources, especially domestic and agricultural water. Therefore, investigation of the vulnerability of Göksu Delta to climatic and antropogenic changes is essential as a part of coastal zone management policies for sustainable development. There are complex relationships between the components of a fluvial system. Given this complexity, a large number of factors influence the sediment transport and channel evolution processes in natural channels, especially in areas where precipitation variability occur due to climate change. The process-based hydrodynamic models of these complex systems are expected to contain a degree of uncertainty in their results; therefore, an analysis of the sensitivity of the model is necessary to identify the significant parameters and the effects of parametric uncertainty on model outputs. For this purpose, a Generalized Sensitivity Analysis is carried out for the hydrodynamic model. This technique is based on the utilization of the model together with a classification algorithm. The idea of GSA is to inject uncertainty into the model by randomly selecting the model parameters from probability distributions. These distributions can then be used in Monte Carlo simulation analysis in which the model is run using a set of parameters randomly drawn from the distributions. The method helps to examine a model to determine whether it is capable of addressing the qualitative aspects of the system behaviour that defines the environmental problem, so that the most important components of the model can be identified through a serious of simulations. Several important conclusions can be drawn from the results of model simulations and subsequent generalized sensitivity analysis:

i.   Simulation of sediment concentration profile is in agreement with typical depth averaged sediment profile graphs.
ii. Simulation results suggest that total sediment concentration is higher near the river bed than closer to the surface.
iii. Sediment transporting capacity is higher in stream links with higher velocity and slope values.
iv. Bedload concentration begins to increase linearly with increasing depth while suspended load tend to decrease.
v.   Bed elevations can change considerably according to flow conditions. For example, the majority of deposition occurs seaward of the delta mouth under minimum flow conditions.
vi. The results of the GSA suggest that five out of seven parameters are significant at the 90% confidence level or greater in obtaining the correct behaviour in a simulation.
vii. The parameters that are most significant in determining the correct behaviour contain a low level of uncertainty, because they showed much less correlation with the other parameters.

The main problem with the research described here is that it is difficult to obtain reliable and adequate data representing the system's exact hydrological, topographical and land use characteristics. One of the weaknesses of the model is the lack of direct values of porosity and sediment density data used in the hydrodynamic model. Estimation of these parameters is therefore based on the flow and sediment rating curves. Although, porosity showed almost no correlation with other parameters in terms of uncertainty, it would be possible to produce more robust simulations in the existence of the accurate values for these parameters.

Generally two different sets of field or experimental data are essential to calibrate and validate mathematical models, yet their quality and reliability must be high in order to have accurate models of sediment transport. During this study, although the reliability of obtained data were sufficiently high, the quantity were not so adequate mainly limited by the number of the sampling stations in the research area. This is a general limitation of sediment transport studies and also one of the reasons of number of modelling studies not being much in Turkey.

Further research should focus on increasing the amount and quality of the sampling data and it is hoped that this modelling study that provides a way of running different scenarios, will initiate further research in data gathering and harmonization and will help to increase the amount of modelling attempts regarding sediment transport.

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