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Combined hydrological, rainfall–runoff, hydraulic and sediment transport modeling in Upper Acheloos River catchment

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ABSTRACT

The downstream impact of dams may solve but may also cause problems in catchment management. The present study assesses the hydrodynamic and sand transport regime of Acheloos River, focusing in the area upstream of the Kremasta Dam. Calibration and validation of water discharge presented very satisfactory coefficients of efficiency (Nash–Sutcliffe up to 85%). The proposed and applied in this study system of models and methods may be used as a water and sediment management tool in dammed or undammed catchments. The results from the present study are deemed to contribute towards improving the existing knowledge of the Acheloos hydrodynamic regime and better comprehending the sediment transport mechanisms.

Keywords: Acheloos; Hydrological model; Rainfall–runoff model; Hydrodynamic model; Sediment transport; Erosion; MIKE SHE; MIKE 11

1. Introduction

Erosion constitutes a critical issue within the fields of integrated water resources and sediment management. Sediment yield, as a result of rainfall erosion and transport mechanisms by the river network, amounts to the sediment exported by a catchment over a period of time, but may also be the amount that will enter a reservoir further downstream in the catchment. It is documented that most sediment is exported out of catchments during relatively short periods of flood discharges [1]. Since it is difficult to estimate the sediment load entering a reservoir a need has been acknowledged for monitoring the sediment yields using fluvial gauge stations and conducting sediment surveys in reservoirs. Successful management of sediment yield problems require accurate conceptual and quantitative models of the hydrodynamics and the erosion and transport processes involved. We believe that this effort combines different models and methodologies providing the required means for addressing catchment water resources and sediment management problems. This study is part of a

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research project "Cybersensors" (High Frequency Monitoring System for Integrated Water Resources Management of Rivers) which aims to develop and implement an intelligent, integrated environmental data collection system, combining high frequency monitoring for the quantification of the hydrologic and geochemical processes in rivers. Acheloos River will be one of the locations where the monitoring system will be tested.

A study was carried out in order to contribute to the understanding of the aforementioned issues, with the following objectives:

(1) To calibrate and validate a hydrological model of the Upper Acheloos River catchment.
(2) To assess river discharge through the creation of a lumped catchment rainfall–runoff model using the previous hydrological input and subsequently combining it with a hydrodynamic river (hydraulic) model.
(3) To add a sediment transport model component and run this combined with the aforementioned rainfall–runoff and hydrodynamic models focusing on sediment transport resulting from sediment loads in the catchment.
(4) Overall propose a workflow methodology that could be used to address sediment transport problems in river catchments.

2. Materials and methods

2.1. Study area

The conceptual model that was initially considered for the entire Acheloos catchment (extended south to the sea) revealed the complexity of assessing the catchment's hydrology. This was mainly due to the occurrence of multiple and interconnected water uses downstream of the Kremasta Dam/reservoir (related to irrigation, water distribution and natural or human-made lakes), as well as the human intervention on the physical river flow with the construction of three dams, namely (from upstream to downstream) Kremasta, Kastraki, and Stratos. Other dams upstream of Kremasta, such as Avlaki, Sykia, and Mesochora, have either been proposed in the past or not been operated yet. For these reasons, it was decided that the study area ought to focus on the Acheloos River sub-catchments with the least human intervention, i.e. the sub-catchments upstream of the Kremasta reservoir. These sub-catchments are named after (starting clockwise from north) "Avlaki" (sub-catchments upstream of Avlaki), "Agrafiotis", Megdovas, "Trikeriotis1", "Trikeriotis 2", "Intermediate" (sub-catchment between sub-catchments Megdovas, Trikeriotis1, and Trikeriotis2) and the sub-catchment between Avlaki and the Kremasta Reservoir, that hereafter will be referred to as "Avlaki-Kremasta" (while

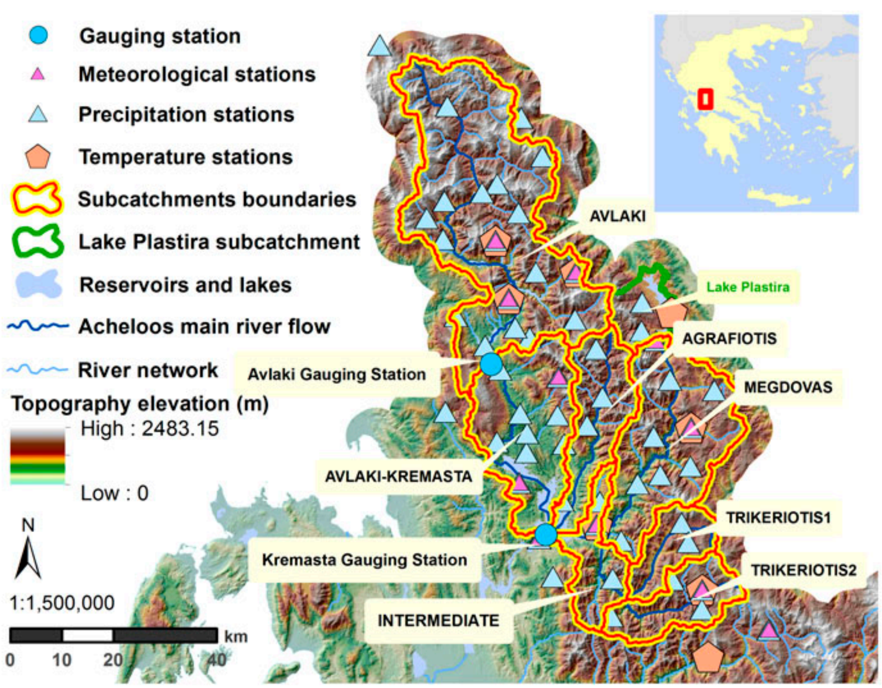

Fig. 1. Study area with the delineated sub-catchments, and the location of gauging, precipitation, meteorological and temperature stations in the Kremasta catchment.

the "Kremasta" catchment will refer to the entire catchment area including all the sub-catchments; Fig. 1). The sub-catchment of Lake Plastira was not assessed herein as its water resources are diverted to the neighbor eastern catchments in the Region of Thessaly. The sub-catchments were delineated based on a 25 m × 25 m DEM (originally created using digitized isolines with a 20 m interval. Sub-catchments' parameters, such as average slope, and elevation, area, were determined using GIS techniques and methods.

Calibration targets included hydrometric gages (discharge and/or water level measurements) at Avlaki for the period 1980–2000 (mean monthly values) and at Kremasta (obtained from the reservoir's water balance) for the same period (Fig. 1, provided by the Greek Public Power Corporation, PPC). The precipitation and meteorological network used in the present work comprised 57 and 11 stations, respectively. Daily data of recorded precipitation, relative humidity, wind velocity, solar radiation, vapor pressure, and air temperature were acquired for a 20-year period (1980–2000), from PPC and other public utilities/ministries.

2.2. Methodological approach

The modeling framework chosen in this study to simulate the hydrology, the surface runoff, and sediment transport for the sub-catchments included MIKE SHE and MIKE 11. MIKE SHE is a derivative of the Système Hydrologique Européen (SHE), first developed by Abbott et al. [2]. It is a deterministic, physically based, distributed, integrated hydrological model, widely used to study various water resource management problems and tested under diverse conditions [3]. In this study, a semi-distributed approach was followed to describe the processes of surface runoff, evapotranspiration (parameters based on land use distribution), unsaturated vertical flow (two-layer soil column), and saturated subsurface flow (linear reservoirs approach with slower groundwater movement in the baseflow and a relatively faster groundwater flow in the interflow linear reservoirs), while empirical solutions were used for interception, evapotranspiration, and snow melt [3].

MIKE 11 is a software package for simulating flows, water quality, and sediment transport in estuaries, rivers, irrigation channels, and other water bodies. The MIKE 11 model framework applied in this study is comprised of three major components: (1) the Rainfall–Runoff (NAM) module; (2) the Hydrodynamic (HD) module, and (3) the Sediment Transport (ST) module. The MIKE 11 model has been successfully applied in several studies e.g. [4] for a variety of purposes, ranging from water resources planning, flood forecasting to water quality. The NAM model constitutes part of the MIKE 11 RR modeling interface. It is a lumped, conceptual model, which simulates rainfall–runoff processes based on meteorological inputs of precipitation, potential evapotranspiration, and air temperature by continuously accounting for the water content in four storages: (1) snow storage; (2) surface storage, (3) lower (root zone) storage, and (4) groundwater storage. The NAM module can therefore simulate the volume of runoff produced for a given river catchment, which can then be routed along the river network using the hydrodynamic capabilities of the HD module. The MIKE 11 hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of one-dimensional, unsteady flows in rivers and estuaries. The module can describe subcritical as well as supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). MIKE 11 HD applied with the dynamic wave description solves the vertically integrated equations of conservation of continuity and momentum (the "Saint Venant" equations) [5]. The MIKE 11 non-cohesive sediment transport module (ST) permits the computation of non-cohesive sediment transport capacity, morphological changes, and alluvial resistance changes of a river system. The MIKE 11 ST model uses a highly non-linear function of the flow velocity, while the methodology by Engelund—Fredsøe was followed. According to this method, the total sediment transport is split up into bed load and suspended load and the sediment transport is calculated from the skin friction, i.e. the shear stress which is acting on the surface of the dunes [6]. Fig. 2 shows the flowchart of the structure of the present study.

The model domain cell size was 250 m × 250 m and the time step 1 d for a simulation period of 20 hydrological years, from 1980 to 2000. Potential evapotranspiration time series were calculated using the modified Penman–Monteith methodology [7]. Using the available timeseries data for each monitoring station and a spatial integration tool (that applies the Inverse Distance Weighted interpolation technique), the respective time-varying distributed precipitation, potential evapotranspiration, and temperature grid maps were created and applied as model inputs.

The spatial variability of the subsurface soil and geology within the study area was obtained from a hydrolithological map that was created after digitization of hard-copy 1:50,000 maps produced from the Greek Institute of Geology and Mineral Exploration (IGME) and aggregation of similar geological units. Soil parameter values of water content at saturated

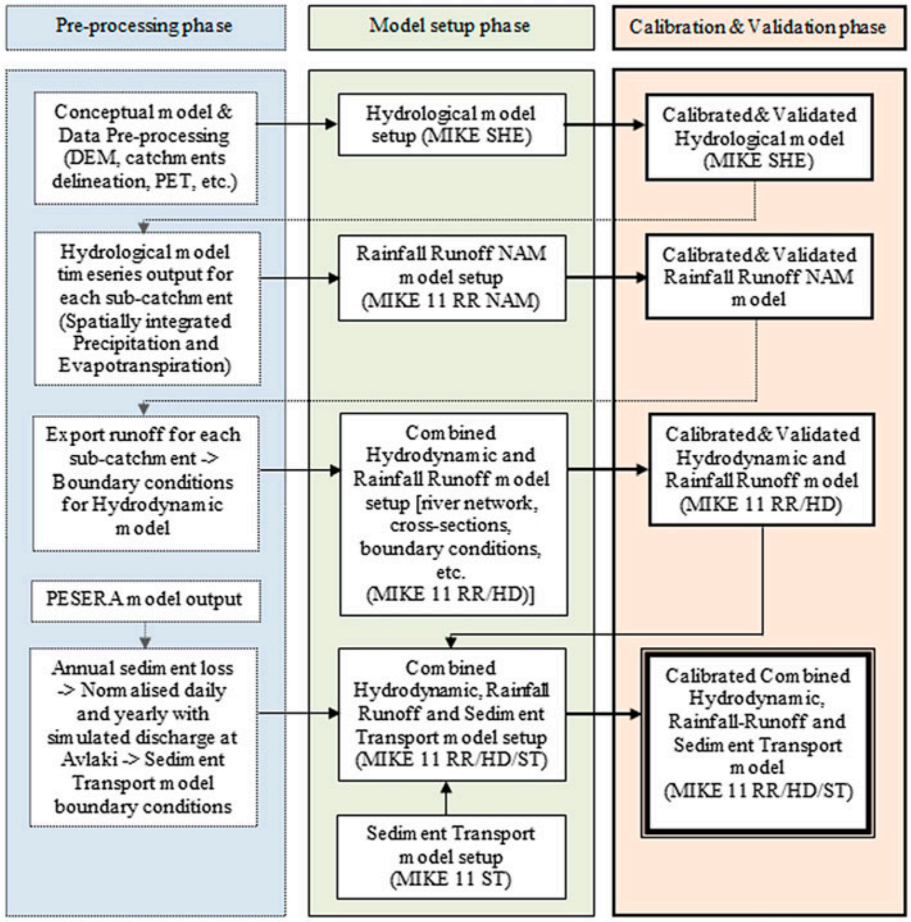

Fig. 2. Model flow for the followed methodology.

conditions and at field capacity, field wilting point, and infiltration rate were also defined and used as calibration parameters for simulating water balance components and discharge. For each of the 18 different land use classes of the Corine polygons cover, the corresponding leaf area index (LAI), root depth (RD), and crop coefficient (Kc) values were defined based on relevant literature studies [8]. Similarly the literature values were assigned for the overland flow component parameters (e.g. Manning number, slope, detention storage), for each of the defined overland flow zones (lowland, semi-mountainous, and mountainous).

2.3. Hydrological, rainfall–runoff, and hydraulic models calibration and validation

Initially the MIKE SHE model was calibrated and validated using a split-sample test at the calibration targets of Avlaki and Kremasta. The principal calibrated parameter values are presented in Table 1. Subsequently, the water balance components of spatially integrated rainfall and actual evapotranspiration for the catchments of Avlaki and Kremasta were used to set up, run, calibrate, and validate (using a split-sample test) the Rainfall–Runoff model, "NAM" at the same calibration targets. The calibration parameters were then transferred to the Kremasta sub-catchments. Subsequently a 1D Hydrodynamic model, MIKE 11 HD, simulating the main river branches within the sub-catchments of "Avlaki-Kremasta" and "Intermediate" was prepared by defining the river network, cross-sections and hydrodynamic parameters. A MIKE 11 RR NAM model was added on top of the MIKE 11 HD model and was utilized as a sub-catchment-based boundary condition generating model. Both models were run simultaneously and river discharge was calibrated and validated in MIKE 11 HD for the entire Kremasta catchment.

It is noteworthy that the MIKE 11 RR NAM model could have been omitted and the MIKE SHE output of sub-catchments flows be fed directly to the MIKE 11

Table 1
Principal calibrated parameters values (averaged distributed values over whole study area with min-max ranges in parentheses) for the MIKE SHE model

Calibration parameter	Value
Unsaturated zone hydraulic conductivity (infiltration rate) (m/s)	6×10^{-7} (5×10^{-8}–3×10^{-4})
Water content at wilting point (%)	14 (5–20)
Water content at field capacity (%)	30 (15–45)
Water content at saturation (%)	37 (20–50)
Interflow reservoirs time constant for interflow (d)	7 (1–13)
Interflow reservoirs time constant for percolation (d)	2 (1–3)
Interflow reservoirs specific yield	0.07 (0.001–0.1)
Baseflow reservoirs time constant for baseflow (d)	67 (30–200)
Baseflow reservoirs specific Yield	0.32 (0.1–0.4)
Leaf area index	1.8 (0.0–5.3)
Root depth (m)	0.9 (0.0–1.5)
Crop coefficient Kc	1.0 (0.8–1.2)
Manning number ($M = 1/n$)	7 (5–10)
Slope (%)	40.7 (26–48)
Slope length (m)	833 (500–1,500)

HD hydrodynamic model as boundary conditions. The advantage of this approach would have been the inclusion of the spatial distribution of the inflows to the MIKE 11 HD hydrodynamic model (although both MIKE SHE and MIKE 11 RR NAM models were calibrated successfully). However, the methodology followed demonstrates the different modeling options, so one could either model with NAM only or MIKE SHE only or both (in order to use the actual evapotranspiration MIKE SHE output as in this paper) in order to get the required boundary conditions for the MIKE 11 HD model. An advantage of the NAM model is that it runs simultaneously with MIKE 11 HD and although in this case the NAM model has been applied in two steps (solely as MIKE 11 RR NAM and as combined MIKE 11 RR/HD/ST), one could have run only one model, i.e. MIKE 11 RR/HD/ST, instead of two models. On the other hand, a potential advantage of omitting the MIKE SHE modeling step and using only the MIKE 11 RR NAM model would have been its speed as a lumped rainfall–runoff model compared to the spatially distributed MIKE SHE model.

A standard performance normalized metric that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"), the Nash and Sutcliffe [9] coefficient of efficiency (NSE) e.g. [10], the Mean Absolute Error (MAE), the Relative Root Mean Square Error (RRMSE), and the BIAS were chosen as the likelihood measures to evaluate the overall models performance. These are defined as:

$$\mathrm{NSE} = 1.0 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \tag{1}$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |O_i - P_i|}{n} \tag{2}$$

$$\mathrm{RRMSE} = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}} \frac{1}{\bar{O}} \tag{3}$$

$$\mathrm{BIAS} = \frac{\sum_{i=1}^{n} (O_i - P_i)}{n} \tag{4}$$

where O_i is the ith observation for the constituent being evaluated, $\bar{O}$ is the mean of observed data for the constituent being evaluated, P_i is the ith simulated value for the constituent being evaluated, and n is the total number of observations. NSE ranges from a value of 1 indicate perfect agreement between model and measurement to a value of minus infinity. MAE and RRMSE take values greater than zero (optimum at zero), while BIAS has the same range as NSE and the optimum value is zero.

To minimize the number of parameters used in model calibration, a simple comparative screening parameterization strategy was followed [11], in order to define the most sensitive model parameters. At the same time, multi-variable checks were used during the calibration procedure to ensure that the total and annual water balance components were within the literature range for the specific area. Results were most sensitive to soil hydraulic conductivity, overland flow parameters, and time constants for interflow and baseflow reservoirs and specific yield.

It must be acknowledged that the robustness of the chosen calibration parameters sets has not been evaluated under a range of different hydrological conditions (other than the period of twenty years in total for which there have been available data) for the simulated catchments. It is nowadays widely accepted that an optimum parameter set for a particular model may be sensitive to small changes in the observations, to the period of observations and to changes in the model structure. The concept of equifinality suggests that there may be many different calibration parameters sets that may be equally valid to produce "accurate" results [10,12]. Also, it must be noted that the problem of quantifying model uncertainty, e.g. using the Generalized Likelihood Uncertainty Estimation (GLUE) methodology [13], was not assessed in this study. For these reasons, extrapolating the model simulation outside the calibration period is recognized that it is a task one has carry out with much care e.g. [13,14]. Nonetheless, the model's reliability was enhanced by applying a split-sample test that involved dividing the data-set in two equal periods of 10 hydrological years each, i.e. one calibration period between hydrological years 1980 and 1989 and one validation period for the hydrological years between 1990 and 1999.

In order to reduce the associated uncertainties: (i) efforts were carried out not to include inconsistent data in the calibration process, (ii) the MIKE SHE model was cross-checked for its validity in terms of the water balance output throughout the calibration period, (iii) the model was applied for comparatively wide range of rainfall conditions from −34% (hydrological year 1989) to +29% (hydrological year 1980) of the mean annual rainfall (1,581 mm), and (iv) a split-sample test was carried out.

2.4. The sediment transport model

A sediment transport model, MIKE 11 ST, was subsequently added on top of the combined MIKE 11 HD and RR models to assess sediment transport in the river. The output from the Pan-European Soil Erosion Risk Assessment (PESERA) modeling methodology-a process-based and spatially distributed model-was used to define the sediment loadings for each sub-catchment [15]. The PESERA model quantifies annual sediment loss by soil erosion on a 1 km^2 grid that was acceptable for the purpose of this study. The estimated annual sediment loads from the PESERA model for each sub-catchment were normalized on a daily basis within each year using the calibrated daily discharge distribution within each year. The loadings were also normalized along the 20 years simulation period by applying a yearly discharge weight factor accounting for higher and lower sediment yield generating years. The estimated daily sediment loads timeseries from the PESERA model for each sub-catchment were then imported as boundary conditions to the combined rainfall–runoff, hydrodynamic and sediment transport model, MIKE 11 RR/HD/ST. The combined MIKE 11 RR/HD/ST model was set up for the main river branches within the Avlaki-Kremasta and Intermediate sub-catchments and the sediment transport model was calibrated using the available mean annual sediment discharge estimate at Kremasta.

Except from the PESERA methodology, the mean annual sediment yield for the sub-catchment Avlaki was computed by applying a non-linear regression model of the sediment discharge rating curve developed by Zarris et al. [16] for the specific catchment to the mean daily discharges produced by the MIKE 11 RR (NAM) model. The sediment discharge rating curve methodology involved the use of a broken line interpolation procedure [17] that was found to represent better the sediment discharge measurements compared to other river-sediment discharge relationships. Also, an estimate of the mean annual sediment yield of the Acheloos R. at Kremasta Reservoir was available by a hydrographic survey and a volumetric computation of the deposited sediments of the reservoir for the period 1966–1988 [18].

3. Results and discussion

3.1. Discharge calibration

The calibration and validation results of water discharge for both Avlaki and Kremasta calibration targets demonstrate a very good ability of the model to predict the observed discharge values (both at low and high flows, Figs. 3 and 4). Moreover, the efficiency results for different models are not affected by the type of the model used (i.e. Hydrological-Distributed vs. Rainfall–Runoff lumped vs. Combined Hydrodynamic and Rainfall–Runoff), as the coefficient of efficiency (EF Nash–Sutcliffe) presents high values (63–85%), for all tested models both for Kremasta and

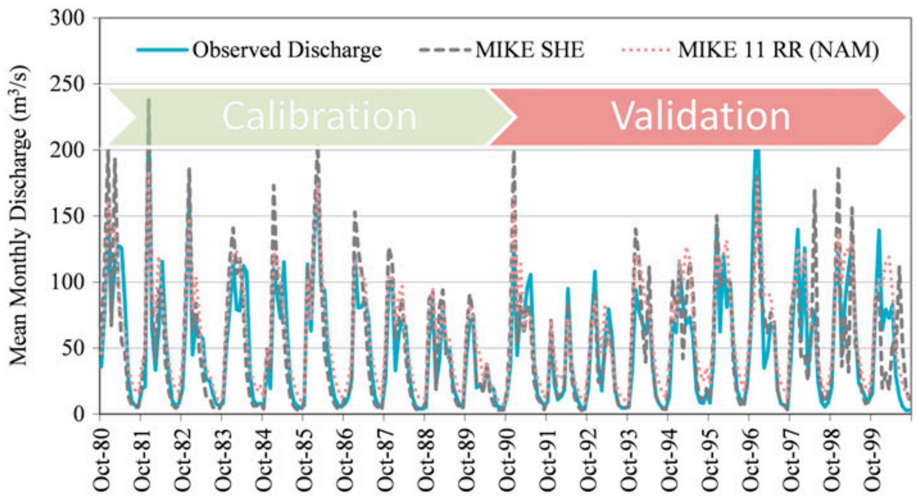

Fig. 3. Simulated vs. actual mean monthly discharge at Avlaki for the MIKE 11 RR (NAM) and MIKE SHE models during the calibration (hydrological years 1980–1989) and validation (hydrological years 1990–1999) periods.

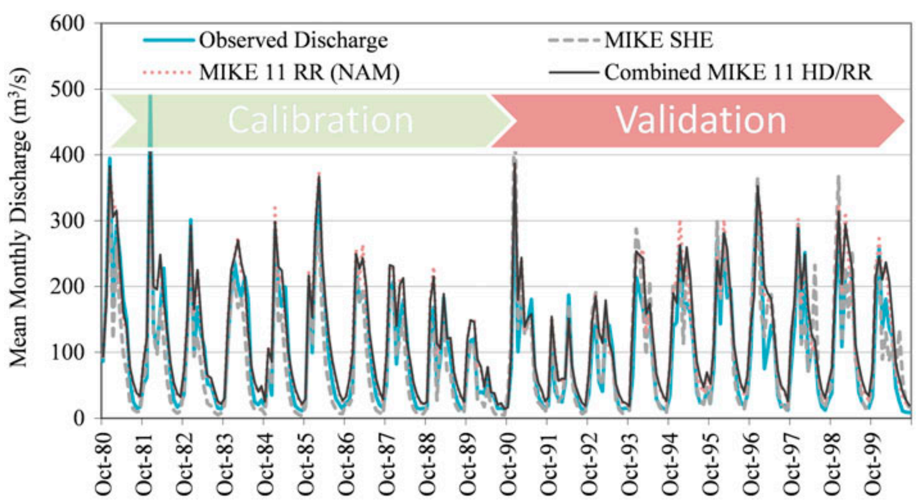

Fig. 4. Simulated vs. actual mean monthly discharge at Kremasta for Combined MIKE 11 RR/HD, MIKE 11 RR (NAM) and MIKE SHE models during the calibration (hydrological years 1980–1989) and validation (hydrological years 1990–1999) periods.

Avlaki calibration targets. The error statistical criteria results (RRMSE close to zero) also suggest a good fit for the applied models. The statistical criteria tested to assess the model's usefulness are listed in Table 2.

3.2. Sediment discharge results

The results of mean annual sediment yields for the catchments Avlaki and Kremasta are presented in Table 3. The mean annual sediment discharge for the catchment Avlaki was estimated using the sediment rating curve developed by Zarris et al. [16] and the calibrated daily discharge timeseries from the MIKE 11 RR (NAM) model for the specific catchment. The calculated result of 34.5 kg/s is close to the value calculated by the PPC, but differs from the PESERA model value, which can be attributed to the lack of the PESERA model to simulate in a satisfactory way the sediment transport in the streams and rivers water ways. The difference with the Zarris et al. estimate (73.3 kg/s) is due to the application of different river discharge data-sets/periods (e.g. a high value of sediment discharge of 337 kg/s during the hydrological year 1970). The mean annual sediment discharge for

Table 2
Calibration and validation results for the MIKE SHE, the MIKE 11 RR (NAM) and the combined MIKE 11 RR/HD models (normal and italics fonts are used for calibration and validation values, respectively)

Statistical criterion	MIKE SHE Avlaki	MIKE 11 RR (NAM) Avlaki	MIKE SHE Kremasta	MIKE 11 RR (NAM) Kremasta	Combined MIKE 11 RR/HD Kremasta
Average Discharge (m^3/s)	51.7 *52.1* (50.0)[a]	59.2 *62.5* (50.0)[a]	103.8 *100.1* (102.0)[a]	123.6 *125.5* (102.0)[a]	125.7 *129.7* (102.0)[a]
Standard Deviation (m^3/s)	52.8 *45.1* (44.5 *44.1*)[a]	41.5 *40.6* (44.5 *44.1*)[a]	80.9 *94.0* (92.8 *84.6*)[a]	92.1 *88.8* (92.8 *84.6*)[a]	91.2 *86.8* (92.8 *84.6*)[a]
EF (Nash–Sutcliffe)	0.739 *0.627*	0.792 *0.697*	0.835 *0.790*	0.850 *0.794*	0.854 *0.761*
MAE	15.7 *17.2*	15.9 *19.0*	26.2 *26.8*	27.3 *30.2*	27.8 *33.3*
RRMSE	0.46 *0.53*	0.41 *0.48*	0.36 *0.39*	0.35 *0.38*	0.339 *0.412*
BIAS	–2.3 *–1.6*	–9.7 *–12.0*	23.7 *–10.6*	–19.8 *–25.5*	–21.9 *–29.6*

Notes: MAE: the Mean Absolute Error, RRMSE: the Relative Root Mean Square Error, EF: the Coefficient of Efficiency or Nash-Sutcliffe coefficient, and BIAS: Residual Bias.
[a]The observed values are listed in parentheses.

Table 3
Mean annual sediment discharge for catchments Avlaki and Kremasta

	Using sediment discharge rating curve and daily discharge for Avlaki	Using PESERA model for Avlaki	Zarris et al. [16] for Avlaki	Public Power Corporation for Avlaki in [16]	Poulos and Chronis [19] for Avlaki	Combined MIKE 11 RR/HD/ST model for Kremasta	Zarris et al. [18] for Kremasta
Mean annual sediment discharge (kg/s)	34.5	47.6	73.3	36.9	26.2	105.8	106.4

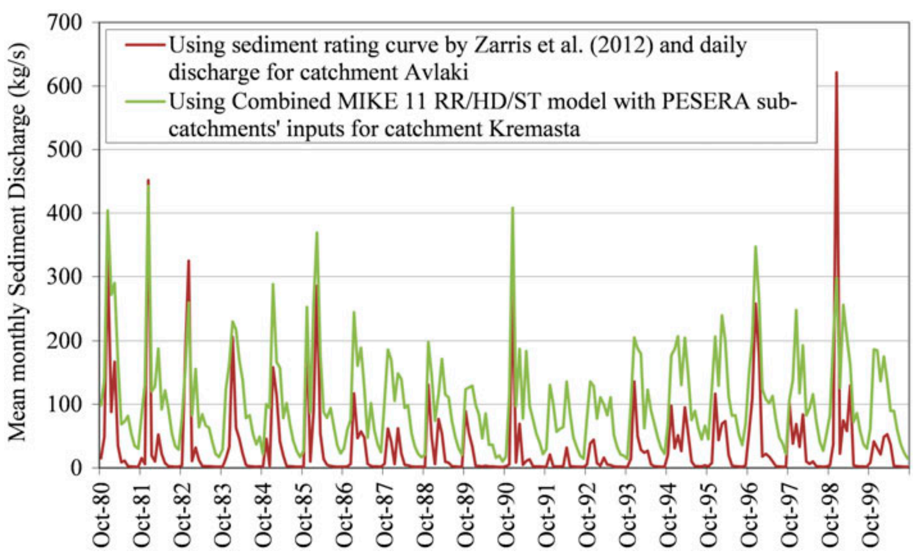

Fig. 5. Mean monthly sediment discharge results for catchments Avlaki (using the sediment rating curve by Zarris et al. [16] and the MIKE 11 RR daily discharge) and Kremasta (Combined MIKE 11 RR/HD/ST model with sub-catchments' PESERA inputs) for the simulation period 1980–1999.

the catchment Kremasta was calculated by the Combined MIKE 11 RR/HD/ST model (105.8 kg/s) and calibrated against the Zarris et al. [18] value (106.4 kg/s) that has resulted from the volumetric study and hydrographic surveys at the Kremasta Reservoir. Mean monthly sediment discharge fluctuation for the catchments Avlaki and Kremasta for the hydrological years 1980–1999 is presented in Fig. 5.

4. Conclusions

The proposed methodology highlighted some useful conclusions that cannot be disregarded:

(1) The use of the distributed hydrological model MIKE SHE enabled the extraction of spatially integrated timeseries output for precipitation, actual evapotranspiration and temperature that were subsequently fed into the Rainfall–Runoff model (NAM). Although calibration of the Rainfall–Runoff model MIKE 11 RR or of the Combined Rainfall–Runoff/Hydrodynamic model MIKE 11 RR/HD was made by a trial and error procedure, due to the accurate spatially integrated hydrological timeseries input, the calibration procedure was considerably shortened.
(2) All models used required limited number of calibration parameters.
(3) The MIKE 11 RR NAM model could have been omitted and the MIKE SHE output of sub-catchments flows be fed directly to the MIKE 11 HD hydrodynamic model as boundary conditions. The advantage of this approach would have been the inclusion of the spatial distribution of the inflows to the MIKE 11 HD hydrodynamic model (although both MIKE SHE and MIKE 11 RR NAM models were calibrated successfully).
(4) The methodology followed demonstrates the different modeling options, so one could either model the required boundary conditions for the MIKE 11 HD model with NAM only or MIKE SHE only or both (in order to use the actual evapotranspiration MIKE SHE output as in this paper).
(5) An advantage of the NAM model is that it runs simultaneously with MIKE 11 HD and although in this case the NAM model has been applied in two steps (solely as MIKE 11 RR NAM and as combined MIKE 11 RR/HD/ST), one could have run only one model, i.e. MIKE 11 RR/HD/ST, instead of two models. The use of the Rainfall–Runoff model combined with the Hydrodynamic model gave the opportunity for the sediment transport modeling to focus on a specific river branch of interest rather than having to set up the model for the whole catchment.

However, at the same time, it was evident that the current approach needs to accommodate better the problem of estimating daily timeseries of sediment transport loads from the eroded sub-catchments. The PESERA model may be a starting point but the modeler should consider carefully the downscaling (spatial and temporal) problem encountered, as this kind of models provide only stationary results in a regional context. An alternative of similar nature would be the application of the USLE (or RUSLE) equation on the sub-catchment scale in the study area, based on detailed soil-cover and land-cover data. An even more sound approach would additionally involve the application of sediment traps or other innovative techniques [20] *in situ*, that would most probably lead to better sediment yield estimates and subsequently improved calibration results for the sediment transport model. Therefore, in order to improve sediment transport results in the river one would need not only sediment transport measurements at various locations within the river, but also a separate calibration methodology for the sediment loads generated by each sub-catchment that are entering the river.

The present methodology may be used to improve the existing knowledge of hydrological and hydrodynamic regimes and also provide better comprehension of the dynamic sediment transport mechanisms. However, the model currently does not support other water uses such as irrigation or water supply. Nonetheless, the system could be operating in real-time mode to simulate the relationships of precipitation, runoff, and sediment transport and to forecast critical parameters for downstream water uses such as discharge/water level and sediment transport input in the reservoirs.

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