Science of the Total Environment 508 (2015) 354–365

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Water and sediment transport modeling of a large temporary river basin in Greece

C. Gamvroudis [a,*], N.P. Nikolaidis [a], O. Tzoraki [b], V. Papadoulakis [c], N. Karalemas [c]

[a] Technical University of Crete (TUC), Department of Environmental Engineering, Chania, Greece
[b] Marine Sciences Department, School of Environment, University of the Aegean, Greece
[c] Department of Environment and Hydrology, Region of Peloponnesus, Regional Unit of Lakonia, Sparta, Greece

HIGHLIGHTS

- We studied the spatial distribution of runoff and sediment of a large river basin.
- The developed methodology constrained the parameter values of the hydrologic and sediment simulation.
- Model simulation of hydrology and sediment was in good agreement with field data.
- During a dry year 77% of the river segments dried out while during a wet year 51% of the river segments dried out.
- The average sediment yield for the whole watershed was 0.85 t ha^{-1} yr^{-1} (2000–2011).

ARTICLE INFO

Article history:
Received 6 October 2014
Received in revised form 2 December 2014
Accepted 2 December 2014
Available online xxxx

Editor: D. Barcelo

Keywords:
Temporary rivers
Water yield
Sediment yield
Suspended sediment transport
Mediterranean
SWAT

ABSTRACT

The objective of this research was to study the spatial distribution of runoff and sediment transport in a large Mediterranean watershed (Evrotas River Basin) consisting of temporary flow tributaries and high mountain areas and springs by focusing on the collection and use of a variety of data to constrain the model parameters and characterize hydrologic and geophysical processes at various scales. Both monthly and daily discharge data (2004–2011) and monthly sediment concentration data (2010–2011) from an extended monitoring network of 8 sites were used to calibrate and validate the Soil and Water Assessment Tool (SWAT) model. In addition flow desiccation maps showing wet and dry aquatic states obtained during a dry year were used to calibrate the simulation of low flows. Annual measurements of sediment accumulation in two reaches were used to further calibrate the sediment simulation. Model simulation of hydrology and sediment transport was in good agreement with field observations as indicated by a variety of statistical measures used to evaluate the goodness of fit. A water balance was constructed using a 12 year long (2000-2011) simulation. The average precipitation of the basin for this period was estimated to be 903 mm yr^{-1}. The actual evapotranspiration was 46.9% (424 mm yr^{-1}), and the total water yield was 13.4% (121 mm yr^{-1}). The remaining 33.4% (302 mm yr^{-1}) was the amount of water that was lost through the deep groundwater of Taygetos and Parnonas Mountains to areas outside the watershed and for drinking water demands (6.3%). The results suggest that the catchment has on average significant water surplus to cover drinking water and irrigation demands. However, the situation is different during the dry years, where the majority of the reaches (85% of the river network are perennial and temporary) completely dry up as a result of the limited rainfall and the substantial water abstraction for irrigation purposes. There is a large variability in the sediment yield within the catchment with the highest annual sediment yield (3.5 t ha^{-1} yr^{-1}) to be generated from the western part of the watershed. The developed methodology facilitated the simulation of hydrology and sediment transport of the catchment providing consistent results and suggesting its usefulness as a tool for temporary rivers management.

1. Introduction

Climate change is projected to impact the Mediterranean region with increasing risk of water scarcity and drought. Most climatic models predict a shift of the climate over the next century affecting the natural flow regime of rivers in the region (Klausmeyer and Shaw, 2009) and increase the spatial extent of temporary rivers and streams. Temporary

* Corresponding author at: Technical University of Crete, Department of Environmental engineering, Greece.
E-mail addresses: christos.gamvroudis@gmail.com (C. Gamvroudis), v.papadoulakis@lakonia.gr (V. Papadoulakis).

http://dx.doi.org/10.1016/j.scitotenv.2014.12.005

rivers are characterized by the repeated onset and cessation of flow, and by complex hydrological dynamics in the longitudinal dimension such as advancing and retreating wetted fronts, hydrological connections and disconnections, and gradients in flow permanence, influence biotic communities and nutrient and organic matter processing (Larned et al., 2010). The extent of temporary rivers in the Mediterranean region is high while many perennial rivers become temporary during drought years due to irrigation demands of agriculture and the water needs of the industrial and domestic sectors (Tzoraki and Nikolaidis, 2007). Temporary rivers respond to the annual variability of precipitation by producing first flush events of high intensity and infrequent erosional events difficult to study and anticipate (Gallart et al., 2008; Kirkby, 2005).

Sediment production, transport and deposition have an impact on water and nutrient circulation at a global scale. The world suspended sediment production is estimated to be 20×10^9 t y^{-1} of which over 25% is trapped in large dams constructed around the world (Takeuchi, 2004).

Quantification of sediment transport is important in order to characterize conditions and processes governing water quality, invertebrate and fish habitat, reservoir sedimentation and coastline dynamics (Bull and Kirkby, 2002; Vericat and Batalla, 2010; Syvitski et al., 2003). The most serious environmental impacts of sediment transport are manifested in lowland areas.

There is a limited number of sediment transport studies and field measurements in temporary rivers in Mediterranean region and this creates a significant gap in our understanding of soil erosion processes as well as the ecological and landscape impacts of sediment management (Rovira and Batalla, 2006). Models such as USLE (Wischmeier and Smith, 1965), SHETRAN (Bathurst et al., 1996, 2002, 2006), RUSLE (Renard et al., 1997), EUROSEM (Quinton, 1997) or WEPP (Flanagan et al., 2001) have been developed to estimate erosion rates at the field or catchment scale while global scale models such as Corine (Corine, 1992), Pesera (Kirkby et al., 2003), Medalus (Kirkby et al., 1998) have been used to estimate such rates at a continental scale. Erosion studies in Mediterranean countries underwent an important push during the last decade and a wide variety of empirical, conceptual or physically based models have been used (mostly in Spain and Italy) to understand erosion and sediment transport processes. On most of these studies the quantification of sediment loads is estimated either by using statistical techniques on past field measurements (sediment rating curves) or by creating erosion plots combining field water or sediment measurements (Vericat and Batalla, 2010; Rovira and Batalla, 2006; López-Tarazón et al., 2009; Rodríguez-Blanco et al., 2010; Nunes et al., 2011). Mean annual sediment yield can be also calculated from mathematical models calibrating and validating the total volume of sediment retained behind check dams with high siltation rates (De Vente et al., 2008; Bussi et al., 2014).

Few sediment transport studies have been conducted in Greece and these have been mostly for lakes and coastal environments. Valmis et al. (2005) developed a relationship using the instability index for estimation of soil interrill erosion rate. Hrissanthou et al. (2010) calculated the sediment inflow into Vistonis Lake by combining a physically based erosion model with a conceptual hydrological model and a stream sediment transport model while Kosmas et al. (2003) evaluated the effect of land parameters such as soil texture, soil depth, parent material, topography and climate on vegetation performance and degree of erosion for the island of Lesvos in Greece. Zarris et al. (2007) developed two equations in order to qualitatively describe the phenomena in terms of the relation between sediment yield and catchment geomorphology in eleven river catchments in Northwest Greece and compared these with earlier estimates published by other researchers. Panagopoulos et al. (2008) quantified soil losses and river sediment yields in Arachtos (Western Greece) catchment by implementing the SWAT model and regression relationships relating hydrometeorologic and/or geomorphologic catchment characteristics to sediment yields.

Sediment transport is one of the fundamentals processes that shape the physical environment. In the case of the Mediterranean countries, soil erosion has been identified as a major problem, resulting changes in soil characteristics, loss of productivity, reservoir calibration and changes on the quantity and quality of water resources. Quantification of sediment transport is important not only to understand river dynamics in general, but also to characterize and model associated fluvial features and processes such as fish and invertebrate habitat, stability of infrastructures, water quality, reservoir sedimentation and coastline dynamics. Predicting the spatial patterns and intensity of hydrology and sediment transport for large river basins can be problematic in areas where few reliable experimental data are available so other approaches that facilitate model simulations must be applied.

It is important to understand and quantify sediment loads in basins better despite the uncertainties of data scarcity arising from the technical difficulties of obtaining adequate and reliable suspended sediment data (López-Tarazón et al., 2009). Predicting spatial patterns and intensity of soil erosion and sediment transport can be problematic in areas where few reliable experimental data are available so other approaches must be applied.

The objective of this research was to study the spatial and temporal distribution of runoff and sediment transport of a large temporary river basin in Greece (Evrotas River Basin) by focusing on the collection of a variety of data to constrain modeling processes at various scales given existing budgetary limitations and the large area of the catchment. In particular, data such as river desiccation maps and sediment accumulation measurements in river reaches were systematically used to constrain the uncertainty in hydrology and sediment transport simulation of the basin.

In this work, the semi-distributed Soil and Water Assessment Tool (SWAT) model was used since SWAT model has shown to be an effective tool for assessing catchment management plans on hydrologic, sediment transport and water quality impacts on large watersheds (Nikolaidis et al., 2013; Oeurng et al., 2011; Betrie et al., 2011; Ndomba et al., 2008; Baffaut and Benson, 2009; Amatya et al., 2011).

2. Study area description

Evrotas River Basin has a drainage area of 1348 km^2 and is a complex hydrological system consisting of intermittent flow tributaries, high relief areas and springs which are the main contributors to base-flow (Fig. 1). It is located in the southeast part of Peloponnesus, Greece and drains into Laconikos Gulf. The Evrotas River develops from north to south, between the Taygetos and Parnonas mountains. The mountains of Taygetos and Parnonas, reaching a maximum elevation of 2404 m, affect Evrotas River hydrologic patterns. 65% of the basin area has slopes higher than 15%, 24% of the area ranges between 5–15%, and only 11% has slopes less than 5% depicting the rugged nature of the terrain. Its population density is 34 residents km^{-2}.

The Evrotas basin has a mild Mediterranean climate influenced by orography with wet winters (November to March) and long dry summers (April to October). Monthly mean temperatures are typically 4–11 °C in the winter and 22–29 °C in the summer (Tzoraki et al., 2011). The main activities in the catchment are agriculture, livestock and small agricultural industries. The land cover classes derived from Corine are scrub and/or herbaceous vegetation associations (60.8%), forests (16.0%), heterogeneous agricultural areas (15.0%), permanent crops (6.5%), open spaces with little or no vegetation (1.1%), urban fabric (0.3%), arable land (0.1%) and the rest (0.2%) are industrial, commercial and transport units, mine, dump and construction sites and artificial, non-agricultural vegetated areas. Many of Evrotas River tributaries and part of the main course become dry during the summer. The main tributaries are Inountas, Xerias, Magoulitsa, Gerakaris, Kakaris and Rasina. The main soil types that can be found on the watershed are Rendzina, Podzol and Alluvial Deposits.