Geoinformatics as a tool for the application of energy policy

Konstantinos Ioannou*
Hellenic Agricultural Organization ‘DEMETER’,
Forest Research Institute,
Vasilika, Thessaloniki, 57006, Greece
Email: ioanko@fri.gr
Email: ioannou.konstantinos@gmail.com
*Corresponding author

Lazaros Kosmatopoulos
Aristotelous 30, Kozani, Greece
Email: lazos_k@yahoo.com

George N. Zaimes
Department of Forestry and Natural Environment,
Eastern Macedonia and Thrace Institute of Technology,
Drama, 1st Km Drama Mikrochoriou, Greece
Email: zaimesgeorge@gmail.com

Georgios Tsantopoulos
Department of Forestry and Management of the
Environment and Natural Resources,
Democritus University of Thrace,
Orestiada, Pantazidou 191, Greece
Email: tsantopo@fmenr.duth.gr

Abstract: The present study focuses on the combination of a hydrologic simulation model and a climate reanalysis system for the estimation of a watershed’s hydrologic characteristics, mainly stream flow, which will help in small hydropower plant’s placement decision making. The SWAT semi distributed hydrologic model in the form of ArcSWAT extension for ArcMap, was used for running a series of hydraulic simulations of Ekaterini’s stream watershed for extracting average monthly and annual streamflow data in each one delineated sub-watershed outlets by SWAT. Because of the lack of a weather station close to the study area with the adequate climatic data, weather parameter’s time series generated by the global climate model Climate Forecast System Reanalysis (CFSR) were used as inputs for the SWAT model. The results of the simulation show a realistic prediction regarding the produced streamflow data in many predefined selection points within the whole watershed.
Keywords: GIS SWAT; climate forecast system reanalysis; CFSR; hydropower plant; watersheds.


Biographical notes: Konstantinos Ioannou has PhD, MSc in Forester and currently working as a researcher at the Eastern Macedonia and Thrace Institute of Technology. He is specialised in the development of information systems using modern computer languages and statistical tools. In detail he works in the field of artificial intelligence, creating and studying decision support systems, expert systems, artificial neural networks, in the fields of planning and development of natural resources. He has great teaching experience in universities, where he teaches information technologies, geographical information systems and computer design. His published work includes 25 papers in international science journals, most of them recorded by web of science. Additionally, he has published 50 papers in Greek and international conferences, on planning and development of natural resources, with the use of information systems and statistical tools.

Lazaros Kosmatopoulos studied Forestry at Aristotle University of Thessaloniki from 1997 through 2002. He returned to Kozani and worked for one year in Grevena forestry service and one year in the Environmental Department of prefecture of Kozani. Since then he work as a freelancer forester dealing mostly with forest and environmental studies using tools such as photointerpretation and G.I.S. In 2012, he was accepted as a postgraduate student at the Eastern Macedonia and Thrace Institute of Technology for a Master in Management of Water Resources in the Mediterranean.

George N. Zaimes is an Assistant Professor in the Management of Mountainous Water, Riparian Areas and Geomorphology of the Department of Forestry and Natural Environment Management of the Eastern Macedonia and Thrace Institute of Technology (EMaTtech), Greece. He is also the Deputy Chair of the UNESCO Chair Con-E-Ect for the Conservation and Ecotourism of Riparian and Deltaic Ecosystem that is hosted at the EMaTTech. He received his PhD in Water Resources Program from the Iowa State University. Some of his main research interests are riparian areas management and conservation, watershed and stream management and restoration, climate change and the hydrological cycle, water pollution, hydrological modelling urbanisation and streams, erosion and protected areas. He has been the author of several book chapters, numerous publications in scientific journals (more than 45), while also presenting to more than 70 conference worldwide and is a reviewer of several SCI scientific journals.

Georgios Tsantopoulos has an undergraduate degree from the Department of Forestry and Natural Environment of Aristotle University of Thessaloniki (1995). He received his PhD degree from the Department of Forestry and Natural Environment of Aristotle University of Thessaloniki in 2000. In March 2003, he was elected as a Lecturer in the Department of Forestry and Management of the Environment and Natural Resources of Democritus University of Thrace, while in 2010 he was elected as an Assistant Professor and in 2014 as an Associate Professor. He has written more than 160 papers in international journals, chapters in books, proceedings of international and national conferences, etc. He has also participated in 23 research programs financed by the European Union and national funds.
1 Introduction

Since the invention of electricity, mankind is searching for ways to enhance and increase its production. Until recently the main production methods included the usage of fossil fuels (coal, oil, etc.) for electricity production. However, these methods produce high amounts of air pollutants in the forms of aerosols and greenhouse gas emissions (GHG) (Páez-Osuna et al., 2017). Today the atmospheric carbon emissions from fossil fuel usage is estimated to be 368 ppm compared to 280 ppm measured in 1860 (Sims, 2004). The production of GHGs from fossil fuel usage is the main driving force for the climate change which is expressed by the global warming as a result of the greenhouse effect (Hansen et al., 2000). Additionally, Sims et al. (2003) note in their studies that fossil fuel power production efficiency is below 52% and in many countries is estimated to be only 30% for coal burning with a perspective to reach 60% in the long term using pioneering technologies. At the same time fossil fuels reserves are continuously decreasing as an effect of the enormous production requirements.

Finally, another problem caused by the usage of fossil fuels and the subsequent atmospheric pollution is the financial cost in order to take measures to prevent climate change (Dincer, 2000).

An alternative method for producing energy is the usage of renewable energy sources (Frey and Linke, 2002). Renewable sources include wind, solar, hydro-electric and tidal power as well as geothermal energy and biomass. The production of energy using sustainable (renewable) resources is enhanced by many governmental and international policies. In EU, a framework for the promotion of renewable energy has been established with the Renewable Energy Directive 2009/28/EC which sets the target of a 20% share of renewable energy in energy consumption in EU by 2020. The expectation of all these policies is solar electricity installed capacity to increase from 26 GW in 2010 to 90 GW by 2020 and wind electricity installed capacity from 85 GW to 211 GW respectively (Bódis et al., 2014). The aim is to boost industrial innovation and technological leadership in renewable energy sector as well as reducing emissions (EC, 2013).

Hydroelectric power is one of the most promising solutions for sustainable energy production in the near future. As water is replenished through the hydrologic cycle, hydropower can be considered as a renewable technology (Frey and Linke, 2002). Another environmental advantage of hydro power is the fact that most dams constructed as hydroelectric plants are multi-purpose, meaning the dam is also used for irrigation, water supply and flood control, maximising their positive social impact (Oud, 2002). However, there are some negative environmental consequences of hydro power, such as the transformation of a riverine environment into a lake environment upstream and the change of water flow (Klimpt et al., 2002).
For the aforementioned reasons there is an increasing trend towards the implementation of a new type of hydro power plant, called small hydro power plant (SHP) (Jager et al., 2017).

Small scale hydro power is a cost effective energy technology using renewable resources with minor environmental cost (Paish, 2002). There is not a global specific magnitude for defining ‘small hydropower plant’. Many countries have established different upper power limits for their determination. Frey and Linke (2002), point out that definition of ‘small hydro’ around the world varies widely from 1 MW capacity to 100 MW in some cases. The maximum allowed installed capacity for SHPs varies from 3 MW in Luxemburg, 5 MW in Germany, to 12 MW in France. Outside Europe, in countries like Brazil, USA, Russia, the capacity of SHPs is limited to 30 MW, while in China the upper limit for SHPs is 50 MW (Panić et al., 2013). An upper limit of 2.5 to 25 MW is used in most cases with the 10 MW value being the most accepted one worldwide (Paish, 2002). Additionally, less than 10 MW is the rated capacity for the definition of small hydropower plants proposed by European Small Hydropower Association (ESHA, 2012).

**Figure 1** Small hydro site layout

There are three major parts of the hydro power facilities:

a The impoundment facility uses a dam to store river water in a reservoir from where water is released towards the turbine according to energy needs.

b The diversion facility channels a portion of the river flow through a penstock to the turbine. This facility may require a small dam or even not at all.
c The run-of-river facility uses water within the natural flow range and does not require a reservoir.

d The pumped storage facility, a hybrid one that pumps water from a reservoir uphill to a second reservoir when there is little or no demand for electricity and acts vice versa like a normal hydropower facility on increased demands (EERE, 2015).

In Greece until 2006 there were approximately 50 SHPs operating and producing a rated power of 93.3 MW, most of them having a capacity of 1–10 MW (Kaldelis, 2007). In 2010, Greece had 98 small hydropower plants and a total installed capacity of 196 MW, producing 753 GWh of electricity. That is a minor fraction of Greece’s available small hydro potential which is 2000 MW according to United Nations Industrial Development Organization (UNIDO) and International Centre on Small Hydro Power (ICSHP) (Liu et al., 2013). The ground relief, especially in Western Greece, legislation and governmental incentives give the opportunity for the development of a large number of small hydro projects in the future. Between 2001 and 2005, 230 new installations acquired permits for operation with a total rated power of 610 MW. This paper focuses on the unexploited small hydro potential of a stream in Western Macedonia and the methods of citing one within a promising for hydro power generation watershed.

2 Literature review

The usage of modern information tools is invaluable in the study of natural phenomena. Ioannou et al. (2014) and Spanou et al. (2014) have demonstrated the usage of artificial neural networks (ANNs) for the prediction of precipitation and lake’s water level. ANNs in combination with a spatially distributed hydrological model were also used by Papagera et al. (2014) for the simulation and prediction of water allocation in Lake Koronia. Finally, information tools like ANNs were also used for other types of modelling like tree rings appearance (Ioannou and Birbilis, 2011a) for the development of DSS for the study of an area after the occurrence of forest fires (Ioannou et al., 2011b) and for erosion study (Myronidis et al., 2010).

Hydrologic simulations using models have been widely used by researchers in order to study watershed or stream processes or their reaction to human made changes. Geoinformatics and hydrologic models represent the latest tools for such types of researches. The ability of simulating and visualising watershed processes provides scientists with the ability to conduct studies with less effort and time consumption.

2.1 Renewable energy projects allocation using Geoinformatics

Geoinformatics is a powerful tool for spatial analysis and planning of power generating facilities within a region. Many researchers including Ramachandra and Sruthi (2007), Myronidis et al. (2008), Voivontas et al. (1998), Dominguez and Amador (2007) and Van Hoesen and Letendre (2010) studied the potential installation and future electricity production by renewable energy sources like sun, wind, biomass and hydropower using primarily geographic information system (GIS) tools.

Ramachandra and Sruthi (2007) used GIS to map the renewable energy potential in Karnataka State, India. They mapped the different regions of the state according to their suitability for renewable energy generation. Solar radiation data were used for the
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determination of regions suitable for tapping solar energy. Wind velocity data were used to determine regions suitable for tapping wind power. Availability of agricultural residues, forest, horticulture, plantation and livestock were used to determine regions suitable for bioenergy production. The number and total capacity of existing SHPs used to determine regions suitable for hydropower generation. Byrne et al. (2007), integrated GIS alongside other methods for the evaluation of the potential for small-scale (less than 2 KW solar, wind and hybrid combinations) renewable energy options used to meet rural livelihood needs in Western China. They concluded that off-grid renewable energy projects can provide cost-effective and reliable alternatives to conventional energy sources to cope with rural household’s energy needs.

Domínguez and Amador (2007) reviewed GIS applications in the renewable energy field. They analysed the potential use of GIS as a support tool for rural electrification plans and renewable energy integration. Baban and Parry (2001) developed a GIS assisted method to locate wind farms in the UK. Data from a questionnaire and available literature were inserted in a GIS in order to produce maps with the most suitable sites for wind farm allocation in the region of Lancashire.

Rodman and Meentemeyer (2006) developed an analytic framework using a GIS to evaluate site suitability for wind turbines. By taking under consideration land uses the framework may choose locations of land available for feasible wind power development. Simultaneously, with the technical requirements there were added environmental and social parameters into the model to incorporate the social acceptance in the analysis.

Aydin et al. (2013) developed a GIS-based methodology for identifying ideal locations for hybrid wind-solar energy production. In their study GIS used to successively identify priority sites for solar energy systems, priority sites for wind energy systems and environmental acceptable and economically feasible sites. Afterwards, the four created maps were overlaid to obtain locations that fulfilled all the above criteria. The study area was south-western Turkey because it is a region with relatively high wind and solar energy potential.

GIS can be combined with multi criteria decision making (MCDM) for optimal allocation of renewable energy generating systems. This combination was applied by Sánchez-Lozano et al. (2013), for optimal placement of solar power plants in the area of Cartagena, in southeast Spain. Restrictive criteria inserted into GIS in order to reduce the study area by discarding inappropriate areas and environmental, geomorphological and climatic factors in order to evaluate potential appropriate sites. The same combination of GIS-MCDM method was also used by Latinopoulos and Kechagia (2015) in order to develop a decision tool for wind farm planning. The framework they propose helps in the selection of the most appropriate sites for wind farm projects through the spatial analysis of allocation criteria (technological, economic, social and environmental criteria).

Van Hoesen and Letendre (2010) used GIS to assess the potential for utilising biomass, wind and solar resources in Poultney, Vermont, USA. They created energy potential maps for each of the above mentioned cases using high resolution available data. By incorporating land uses in maps, GIS can help visualise the identification of potential areas for renewable energy production in a region and the better understanding of this information by stakeholders for optimal community decision making processes. Likewise, Yue and Wang (2006), evaluated local potential of renewable energy (wind, solar, biomass) sources in a rural area in south-western Taiwan with the aid of GIS taking into consideration local features, like climate, land uses and environmental restrictions.
2.2 Small hydropower plant allocation using G.I.S.

Spatial allocation of hydropower projects nowadays is inextricably connected with GIS technology. Since GIS became widespread, it turned to an essential tool for every process that involves spatial analysis. Worldwide, many researchers, have developed methodologies that incorporate GIS to aid in determining the most appropriate locations for hydropower project construction or to reject others based on social, environmental or political problems.

Kusre et al. (2010) used GIS and SWAT hydrological model to find potential locations for hydropower generation in a Kopili river basin watershed, in Assam (India). GIS was used to produce a digital terrain model of the watershed with the stream network in it. SWAT2000 was used for the assessment of flow rate through its capability of simulating hydrological processes within a catchment. The model estimated the discharges at the confluence points of two streams and finally 107 sites could be identified with a theoretical hydropower potential of 133 MW, most of which would be available through micro units (< 0.5 MW).

Cuya et al. (2013) in their study estimated the maximum potential hydropower production in the transboundary La Plata Basin in South America, the 5th largest in the world. For this purpose, they used a GIS-based tool (VAPIDRO-ASTE) which was developed by Alterach et al. (2008) and is able to split the river into hundreds of cross sections for calculating the available discharges and potential hydropower production, considering constraints like minimum flow, withdrawals and restitutions scheme, etc.

Gonca Coskun et al. (2010) established a methodology for the determination of hydroelectric water potential in a poorly gauged basin. The case study was Solakli watershed in Eastern Black Sea Region of Turkey for which the authors constructed a macro-scale hydrology model via remote sensing and GIS to determine the stream flow for ungauged parts of the studied basin.

Larentis et al. (2010) proposed a methodology for large scale survey of hydropower potential sites. The hydropower potential survey methodology – hydrospot – comprises from the earliest identification of promising sites in the river basin to the multi-criteria pre-feasibility assessment and selection of the final set of projects. In their study the researchers describe in detail the GIS-based procedures for hydropower potential sites spotting and selection. They present their preliminary results and compare them with those obtained from an existing hydropower survey study in Brazil.

Yi et al. (2010), proposed in their study a new location analysis methodology to search for potential SHP sites using geo-spatial information system (GSIS). They allege that by applying the methodology that they developed, a large area can be precisely surveyed within a short period of time, as the location analysis they propose, focuses on establishing the criteria and methodology for searching for alternative locations rather than selecting the most suitable site among the alternatives. Case study area was the upper part of Geum River Basin, in Korea where six potential SHP sites was found.

Rojanamon et al. (2009) in their study proposed a new method to select feasible sites of small run-of-river hydropower projects by using GIS technology and employing it into a combination of engineering, economic, environmental and social impact criteria. Potential locations of small hydropower projects in the upper Nan river basin in Thailand was found by using GIS and then economic, environmental and social impact studies conducted to finalise the best site selection.
In Greece, Karapanos (2008) used GIS to find candidate sites for the location of a SHP within the Grias stream watershed in Pella, Northern Greece. After the creation of a geodatabase and the calculation of the watershed’s parameters he used functions to delineate the entire basin in sub basins. Having found an optimal site for a SHP, he used HEC-RAS to model the water flow downstream of it and define the flood plain area so that a safe from flooding zone to be designated.

2.3 Hydrological models for stream flow simulation

Akiner and Akkoyunlu (2012), in their study used SWAT to forecast river flow rates in Melen Watershed in Turkey and concluded that there is a considerable relation between the simulated model and observed results. Forecasting of river flow rate in Pracana basin, Portugal, using SWAT, was also the subject of Demirel et al. (2009) GSIS, who then compared the model’s results to those derived by an ANN model application to the same area. Their study’s results showed that SWAT had better performance in forecasting mean flow rate values, in contrary to peak flow values where ANN was more successful.

Panhalkar (2014) applied the SWAT model at Satluj basin in India, in order to execute a hydrological simulation of the basin. The intent of the study was the estimation of the runoff and sediment yield through a hydrological model. In India the availability of accurate information is scarce due to lack of watershed monitoring. Imported data into the model included a digital elevation model (DEM), land use map, weather and soil data. Execution of SWAT for a 30-year period provided basin’s average monthly stream flow values that were in close accordance to the observed data. The author concluded that hydrological modelling is of immense importance for reservoir and water resources management for a basin like the studied one.

Ullrich and Volk (2009) used SWAT model to simulate water processes in a semi-virtual watershed as a result of varying farming management practices, like conventional tillage, conservation tillage and no-tillage. The model’s prediction for water, sediment and nutrient yield showed a considerable sensitivity to applied crop rotations and in some cases even to small variations of management practices therefore SWAT turned out to be a significant tool in watershed water balance studies.

Yang et al. (2009) used SWAT to simulate stream discharges as well as sediment and nutrients yields, in studying the efficacy of agricultural erosion preventing practises, on maintaining surface water quality at the watershed level. The study area was Black Brook watershed in Canada and results showed that SWAT predicted very well water yield although predictions for sediment and nutrient yields were not so reliable.

Dixon and Earls (2012) used SWAT to simulate stream flow in a USA watershed in studying the effects of urbanisation in water runoff. They inserted varying land use and meteorological data in the model in order to examine any changes in watershed’s stream flow. One of the conclusions of the study regarding SWAT’s performance was that the model can predict stream flow with reasonable accuracy if there are plentiful available input data.

Huang et al. (2009) applied SWAT in Gucheng Lake Basin, located in South-eastern China, in order to simulate stream flow and nutrient loadings in it. Other researchers, including Baker and Miller (2013), Xie and Cui (2011), Hörmann et al. (2008), Wu and Chen (2013) and Lu et al. (2015), applied SWAT for hydrological simulation in various
watersheds all over the world. Their studies aimed at different objectives, from land use change consequences to effects of various crops cultivation in water balance, but they all used SWAT in order to estimate stream flow values, especially in ungauged basins in developing countries.

SWAT was used by Githui et al. (2009), to investigate the impact of climatic change on streamflow of the Nzoia catchment in the Lake Victoria basin in Kenya. A pair of climate models generated various possible climate change scenarios (temperature/rainfall) through to year 2050, for obtaining a number of global circulation model’s outputs which afterwards were introduced to the SWAT model. Results showed an increasing pattern for precipitation and streamflow in all scenarios from present climate condition up to year 2050.

There is a limited number of studies with application of the SWAT model in Greece. Pisinaras et al. (2010) applied SWAT (coupled with a GIS interface) to a North-western Greece river watershed. They evaluated the model’s performance in predicting stream flow using several statistical parameters and found it to be extremely reliable. The study showed that SWAT model, if properly validated, can be used effectively in testing management scenarios in Mediterranean watersheds. Pikounis et al. (2003) investigated the hydrological effects of specific land use changes in a Pinios river catchment through the application of SWAT. They used the model to simulate hydrologic processes in three land use change scenarios dealing with urban expansion and deforestation. For the same catchment, Varanou et al. (2002), in their study used SWAT to simulate stream flow and nutrients transport within the basin, for nine climate change scenarios. Boskidis et al. (2010) used SWAT to simulate water qualitative and quantitative characteristics in Vosvozis river basin. After being validated with measured data the model showed good agreement compared to observed values in terms of river flow and nutrient loads. It has been also used to test eight alternative scenarios. Boskidis et al. (2012) applied SWAT, within a GIS interface, to the lower Nestos river basin in Northern Greece. The model was used to test the impact of various management scenarios on the river flow and nutrients loadings. Kalogeropoulos and Chalkias (2012) applied SWAT model in a typical Aegean island catchment in Andros. The aim of the study was to calculate the impact to surface runoff by various climate change scenarios. Baltas and Karaliolidou (2006) examined the impacts of climate change and land use change on water resources in the Aliakmon river basin in northern Greece. They used SWAT to estimate total runoff at the outlet of the basin under various scenarios.

3 Materials and methods

Ekaterinis Lakkos stream is located in North-Western Greece, in the prefecture of Kozani and the region of Western Macedonia (Figure 2). It springs in the Peaks of Kavounia Mountains which are part of the Pieria mountain range. Kavounia Mountain’s ridge is the line that separates Western Macedonia and Thessaly regions. The stream flows from south-east to north-west and empties to the southern point of Polifitos artificial lake, near the recently constructed Ilaria’s dam. It is one of the largest streams in the area that flows directly into the lake.
Ekaterinis lakkos stream which is a perennial stream has two major ephemeral tributaries, Arkoudolakkas and Xirolakkas. The last two have torrential characteristics because of the steep slopes they flow through (Figures 2 and 3).

The basis of this methodology is the GIS software, where all necessary data are imported into for processing and constitutes the graphical display of the framework. The GIS software used in this research is the ESRI’s ArcGIS Desktop 9.3. Raster data are comprised of scanned maps, satellite pictures and aerial photos. Vector datasets are structures of common type feature classes which can be composed by points, lines or polygons.

For the purpose of this study the base layer for all other datasets is the topographic map 1:50,000, labelled ‘LIVADERO’ created and distributed by the geographical service of Greek army (GSA). GSA’s maps are very accurate and detailed and are used in the majority of projects regarding hydrology and land use spatial analysis.

The next step for hydrologic processing is to create the DEM of the study area. The DEM is created by the elevation feature (contours) and can become more accurate by ‘burning’ the stream network into it. DEMs are the main datasets used by most spatial analysis tools and models and can also be created using LiDAR data, satellite images or field collected topographic survey data. The tool for DEM creation in ArcGIS is an extension embedded into the program named 3D analyst. 3D analyst is a specialised tool that can be added to ArcGIS and performs three-dimensional display of GIS layers, in the present case the DEM which is a representation of the terrain elevation. The DEM is the
groundwork for all the other analysis conducted in this study as it is the primary input dataset for the hydrological models. In this study SWAT is used mainly for the estimation of the stream flow in various points of the stream network. The model has been used for this purpose by many researchers and has always been proven to perform very well. In Greece there is a very small amount of rivers monitored regarding their water flow and most of these are large rivers. Most small catchment streams like the Aikaterinis Lakos stream studied here have never been monitored and until now their basins remain ungauged. The SWAT hydrological model is applied in order to perform a simulation of the hydrologic cycle in the basin. The model is able to simulate many other procedures, like instream point and non-point pollutants movement, underground water movement and many others but these are not used in present study. Finally, we used the climate forecast system reanalysis (CFSR) in order to generate weather data for the watershed area using data provided by the Hellenic National Meteorological Service.

Figure 3  Digitised contours and stream network upon the base map (see online version for colours)

4 Results

The digitisation of the features of Ekaterini’s stream watershed offers the possibility of spatial analysis and allows extracting many hydraulic and hydrologic characteristics that are necessary for further processing. The first significant feature that is exported by the ArcGIS processing is the DEM of the studied basin which is the representation of the
area’s morphology. It is produced using the contours and the hydrographic network layers. The DEM incorporates information on elevation of every point within the basin constituting the base dataset for every further management in regards to spatial data. After the initial basic processing in ArcGIS, the DEM layer of the studied area was imported into the ArcSWAT program, which is the GIS interface of SWAT model. The first action of SWAT pre-processing routine is the delineation of the watershed. With the use of the DEM and the ArcHydro toolbox of ArcGIS software, ArcSWAT delineates the watershed of the studied stream and creates sub basins according to the stream network of the major basin. It also defines inlet and outlet points for every single sub basin which are used later as basin’s monitoring points. The program gives the user the chance to define graphically as many monitoring points as he wants according to his simulation needs. In the current study, no extra monitoring points were added because the sub basin’s outlet points are the only required to fulfil the purposes of this research. For Ekaterini’s stream watershed, SWAT delineated 29 sub basins and the corresponding outlets. In Figure 4 there is the layout of the delineated watershed with each sub basin labelled.

Figure 4 Sub basins labelled from 1 to 29 and the corresponding monitoring outlets of studied watershed (see online version for colours)

The watershed delineation tool also provides an output, on the topographic information about the main watershed and sub basins. According to the model, the area of Ekaterini’s stream watershed is 49.35 km² with a minimum elevation of 287 m, a maximum elevation of 1,389 m and a mean elevation 810 m. This information is also provided for every one of the sub basins (Table 1).

After the watershed delineation and input of the land-use, soil and slope data, the SWAT created 172 HRUs for the studied basin. Each HRU has a unique combination of land-use-soil-slope characteristics and is the smallest hydrologic unit that the model uses for analysis.
Table 1  Basic morphometric features of Ekaterini’s stream basin and its delineated sub basins

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SWAT was set to run a simulation for three years, 2011–2013 as for those years’ meteorological data were more reliable and is the closest ones to present time. Two simulations have been performed for the above simulated period, one for yearly outputs and one for monthly ones.
Figure 5  Average monthly and annual streamflow’s in the outlets of the five sub basins of Ekaterini’s stream watershed (for the simulated years 2011–2013) (see online version for colours)

Figure 6  The part of Ekaterini’s stream with permanent streamflow, suitable for hydropower generation (see online version for colours)

The results of the simulation show that many small sub basins have no flow year around or intermittent flow most of the time of the year. These catchments are the most mountainous one’s low order and have only torrential streams, so they are also unsuitable for hydropower capability and are excluded as sites for small hydropower plant
installation. The excluded sub basins no. are: 2, 3, 7, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28 and 29. Sub basin’s 1 outlet is the outlet of the whole watershed and is located in the basin’s mouth, where Ekaterini’s stream meets Polyfytos Lake, so it also cannot be regarded as a possible location for hydropower generation.

The sub basin outlets that this study focuses on, are those numbered 4, 5, 6, 8 and 10. The part of Ekaterini’s stream that runs within these sub basins is shown in Figure 6. The length of the main stream reach has been calculated by ArcGIS and is 8,623 m.

5 Conclusions

The results of this study show that today, there are many tools which can help in decision making regarding spatial allocation of small hydropower units. We can overcome the lack of monitoring through the usage of simulation models, for both hydrologic and climatic ones. The SWAT produced stream flow data, show that reaches with adequate streamflow for hydropower production lie from the middle of Ekaterini’s stream watershed, in the outlet of sub basin ten and downstream through the mouth of the basin. This is absolutely compatible with empirical data and observations, as the more mountainous streams are torrential ones with ephemeral flow and thus inappropriate for hydropower exploitation. The great advantage of SWAT, over other models, is the ability to delineate the watershed into sub basins fast and easy, according to its user’s needs and extract hydrologic information for them.

On the other hand, the advantage of CFSR is the compatibility with SWAT, as the user can retrieve ready for use weather data files formatted according to SWAT specifications, from the University of Texas webpage (http://www.utexas.edu). The use of observed data for the production of simulated time series gives the confidence that the later are highly valid for use in such researches.

The aim of the present study was to propose a methodology comprising of GIS software, a hydrologic simulation model and a global climatic reanalysis system for estimating streamflow’s within an ungauged watershed. With this methodology the need for field measurements is diminished and in the future could be eliminated at all.

References


