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Hydrological simulation of the Xeropotamos river basin (Greece) with SWAT model

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Mémoire de fin d'études pour l'obtention du Diplôme de Master Sciences et Techniques

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Abstract

Xeropotamos is a Mediterranean intermittent ungauged river in the central part Crete, Greece. It discharges into the Aegean sea at Ammoudara beach which is one of the most attracting touristic destination in Crete Island. Due to flood disaster that occurred in the neighbor watershed on 13th January 1994, this study is established in order to provide flow data that can help for forecasting and preventing potential flash floods, it will also reduce the problem of plumes that concerns the authorities and, then protecting this economical resource from obliteration. Hydrological modeling is the first step of flood prevention.

In this study, SWAT (Soil and Water Assessment Tool) is used as a physically based hydrological model for simulating the flow of the ungauged watershed Xeropotamos ($48.6km^2$), using the daily weather data of the juxtaposed basin of Giofyros that has similar characteristics with the watershed in subject.

The simulation results for SWAT model are satisfactory. The predicted values show a quite good agreement with the observed data, based on qualitative criteria. However, concerning the quantitative criteria such as nash-sutcliff, the results are not acceptable. The conclusion drained is that quantitative criteria are not always reliable for evaluation of the calibration.

The flow provided by SWAT is used for flood frequency analysis. To predict the return period of flash floods, the Gumbel and log Pearson III distributions are calculated using the method of moments and then verified using Hyfran. The log pearson III is more suitable for this study case.

Keywords: Xeropotamos, SWAT, Flood, Frequency Analysis, Hydrological Model

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Table of Contents

Table of Figures

Tables

1 Introduction

Extreme events such as floods are one of the most dangerous meteorological hazards affecting the Mediterranean countries. They have the potential to cause damage to the environment and also a huge impact on the economic development and the economic activities of the community especially in coastal areas. This damage is due not only to high flooding frequency, but also by the urbanization and various human activities.

Xeropotamos is a typical intermittent Mediterranean river, with high flow during winter and low or non flow during summer. The river discharges in the Aegean Sea, at Ammoudara beach. This area is one of the most important touristic sites in Heraklion city in Crete Island.

On 13th January 1994, a flash flood has occurred on Giofyros the neighbor watershed of Xerapotamos. By that time, the resulting flash flood had catastrophic impacts on Giofyros watershed;many houses located near the coast were flooded leaving 49 locals homeless. Due to this extreme event, to the Water Framework Directive and the Flood Directive (WFD-2000/60/EC) that this study focuses on the assessment and the management of the flood risks. Indeed, the study was carried on the Xerapotamos watershed in order to prevent from potential flash floods.

SWAT (Soil and Water Assessment Tool) as semi distributed physically-based model, for flood forecast and protection, was used to study the Xerapotamos ungauged watershed. The model simulates the flow of Xerapotamos river based on Giofyros available data. The two watersheds have similar characteristics regarding geology and climate. The SWAT model needs as land use, soil, DEM (Digital Elevation Model) and meteorological data from Giofiros gauges stations.

In order to do flood frequency analysis methods, The SWAT model provides simulated flow that will be used to apply. This will help in predicting extreme events and their returning periods.

Chapter I : Literature Review

The modeling of the hydrologic behavior of watersheds is essential when we are more interested in problems related to the water resources, land management or many facets of hydrologic risks.

1.1 Hydrologic models

A hydrologic model is nothing but a simplification of a complex system (Payrau and Dean, 2002). It is mainly used to understand the different hydrologic process inside the watershed and predict the behavior of the system. The best model is the one that gives the closest results to reality with less complexity and using the least of parameters. The most important inputs for all models are meteorological data and the drainage area along with the various characteristics of the watershed such as topography, land use, soils properties and also the groundwater aquifer.

The function of thesehydrologic models is basically calculating the river flow based on meteorological data.It's a composite of subroutines for the most important parameters of the hydrologic process, such as snow accumulation and melt at different elevations, soil moisture dynamics, evapotranspiration, recharge of groundwater, runoff generation and routing in lakes and rivers.

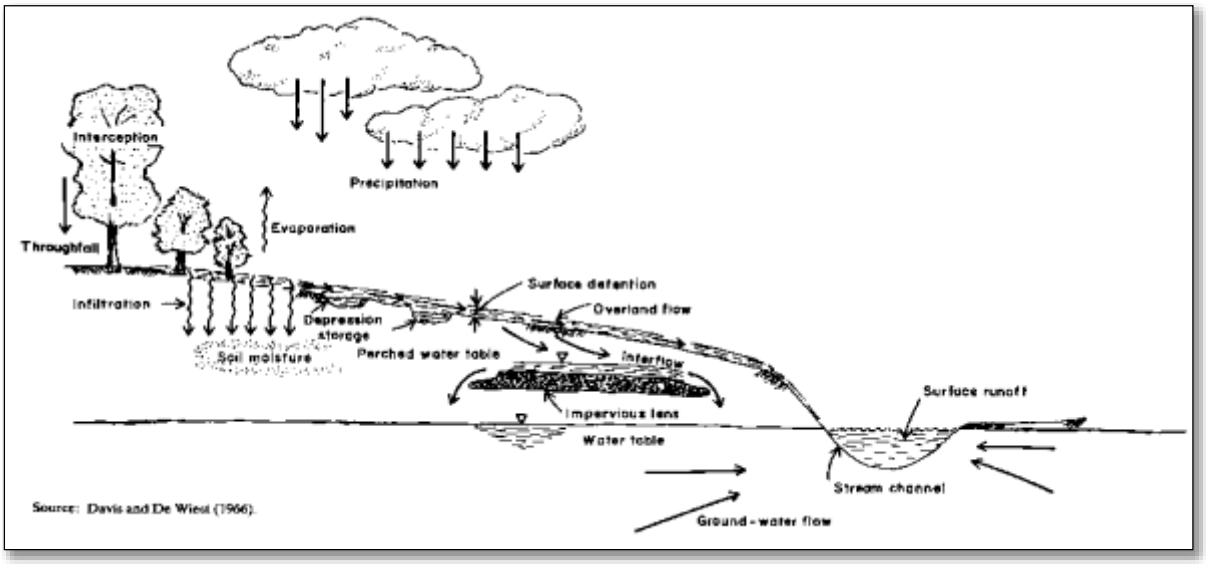

Figure 1. Diagrammatic representation of the hydrologic process (Davis and De Wiest (1966)

Most physically based runoff models are based on the water balance, using precipitation as a driving variable and calculating the quantities directed as runoff, from the water balance

equation. The general expression describing the water balance of a catchment over a given period is:

$$R = Q + AE + D_S + D_G$$

where:

- R,Q: are precipitation and stream flow respectively and can usually be measured directly.
- AE: is actual evaporation and transpiration.
- D_S, D_G: are changes in soil moisture and groundwater storage respectively.

1.1.1 Types of models

There are many hydrologic models that have been developed to identify the impact of climate and soil properties on hydrology and water resources. Each model has its own unique characteristics. Hydrologic models compute runoff from precipitation in a drainage basin. Then, the runoff is routed to the outlet of the basin. Excess precipitation is determined by subtracting what is intercepted by vegetation, stored in surface depressions, evaporated from such depressions and, infiltrated into the soil. The output of a hydrologic model is usually a hydrograph, which shows the outflow from the basin over time. From the hydrograph, the peak flow magnitude and time to peak can be determined. Information on the water surface elevation within the basin cannot be determined with a hydrologic model (Bengstone and Padmanabhan, 1999).

The hydrologic models are classified based on model input and parameters and, the extent of physical principles applied in the model. They can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on the other criteria. They can also be divided, according to the time steps, into event-based (single-event) and continuous models.

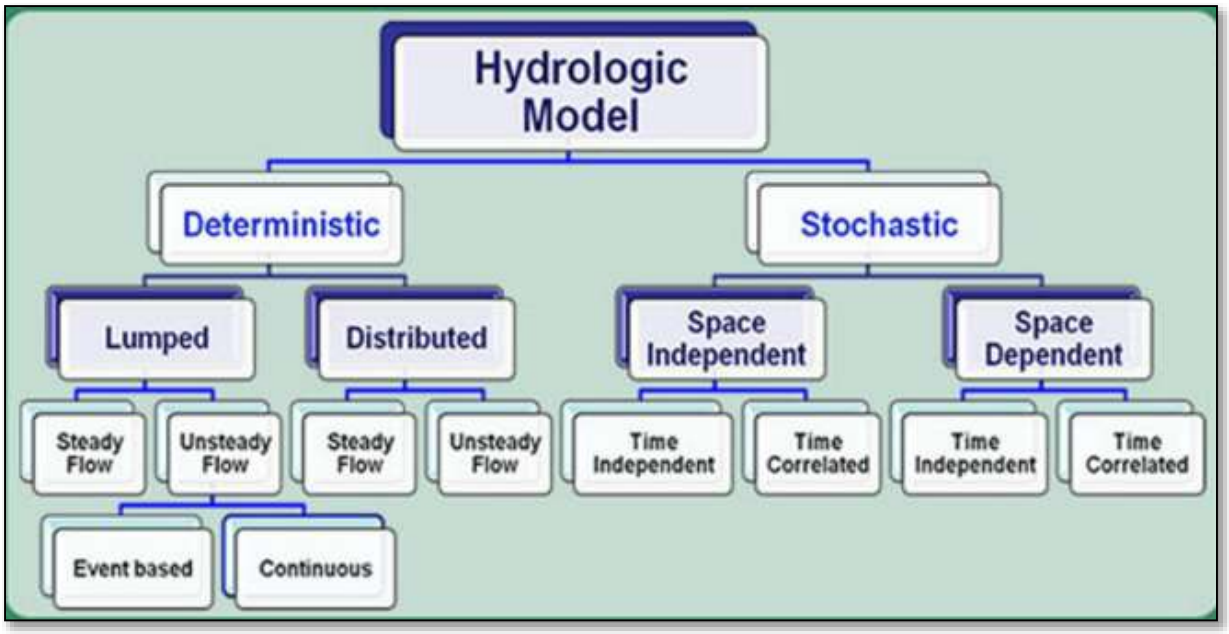

Figure 2.Hydrologic models classification by criteria

One of the most important classifications of Sorooshian et al. (2008) is empirical model, conceptual models and physically based models.

- **Empirical models**

The aim of these models is to reproduce the dynamics of the output variables depending on the input data without considering the process of the hydrologicsystem. They usesimple mathematical equations to transform certain inputs (as precipitation...) to outputs, without any association with the real process. In these models, it is assumed that the catchment is static and climate boundary is unmodified. However, they cannot apply land use or soil moisture changes. An empirical model identifies the mean annual flood by a correlation. Another type of empirical model considers temporal variability and is applied in real-time flood forecasting. For example, IHACES and Instantaneous Unit Hydrograph (IUH) are empirical models that show unit hydrographs (Littlewood and Jakeman, 1994;Noorbakhsh et al., 2005).

- **Conceptual models**

As a simple definition, conceptual models are a substitution between deterministic and black-box models. They describe all of the component hydrologic process. Generally, these models are formulated with a number of conceptual elements which are simple representations of a reference system. (Salarpour et al.,2011).In this method,we usually use semi empirical

equations and the model assessed not estimated only from field data but also through calibration. In order to achieve the calibration, numerous hydrologic and meteorological records are required. Standford Watershed Model IV (SWM) is the first major conceptual model developed by Crawford and Linsley with 16 to 20 parameters(Gayathri K.Devi et al., 2015).

- **Physically based model**

A physically based model is defined as a scaled-down form of a real system (Brooks et al., 1991; Salarpour et al., 2011).Physically-based models try to represent relevant process by physically considering the meaning of the full procedure in a hydrologic system (Hapuarachchi et al., 2003). They are based on spatial distribution, evaluation of parameters describing physical characteristics and require data about initial state of model and morphology of catchment. This kind of models is complex and requires human expertise next to computation capability (Gayathri et al., 2015), SWAT model is an example.

Most hydrologic systems are extremely complex, and we cannot hope to understand them in all details. Therefore, abstraction is necessary if we are to understand or control some aspects of their behavior. Indeed, man has found through experiences that understanding and predicting the behavior of any significant part of his environment requires abstraction.

This overview on hydrologic models and their main classification will help to better understand how work the model used in this study (SWAT).

1.2 SWAT model

1.2.1 Historical view

The development of SWAT is continuation of USDA Agricultural Research Service (ARS) modeling experience since 1980. The beginning of SWAT was founded in 1980 as mentioned by (Gassman et al. 2007)and the base for the SWAT model were Ground water loading effect on agricultural management systems (GLEAMS), chemicals, runoff and, erosion from agricultural land (CREAM) and environmental impact policy climate (EPIC). According to a review of history of SWAT development by (Gassman et al., 2007), this model is the combination of simulators for water resources in rural basin (SWRRB) models (Arnold and Williams, 1987)and routing output to outlet (ROTO) to overcome the flaws and awkwardness of both model but retaining all the features of both models at the same time. SWAT has undergone continued review and expansion since it was developed in 1990s and detailed

theoretical documents (Neitsch et al., 2009)and user's manual (Neitsch et al., 2000)are available to give theoretical background and guide to the users. SAWT model is generally used to predict the long term impacts in large basins of agricultural land management and timing of agricultural practice within a year. However, it is also used to assess the environmental efficiency of best management practice (BMP) and alternative management policies for large watershed.

1.2.2 Description

SWAT refers to Soil and Water Assessment Tool which is a basin scale, continuous time model that operates on a daily time step. It's designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient and, capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens and land management. In SWAT, the watershed is divided into multiple sub-basins, which are further subdivided into hydrologic response units (HRUs). These units consist of homogeneous land-use, management, slope and soil characteristics. The water balance of each HRU is represented by four storage volumes: snow, soil profile, shallow aquifer and deep aquifer (Arnold et al. 1998).

Hydrologic cycle and water balance are the driving force in model simulation. Hydrology split into land phase (runoff) and the routing phase of the hydrologic cycle.

- Land phase: controls amount of water, sediment, nutrient, and pesticide loading to the main channel in each sub-watershed.
- Routing phase: defines the movement of water, sediments, etc., through the channel network of the watershed to the outlet.

Simulation of the hydrologic balance is foundational for all SWAT watershed applications and is usually described in same form, regardless of the focus of the analysis. The SWAT water balance equation is the following:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_{\alpha} - w_{seep} - Q_{gw} \right)$$

where:

- SW_t: is the final soil water content (mm),

- $SW_{o:}$ is the initial soil water content onday i (mm),
- T: is the time (days),
- $R_{day:}$ is the amount of precipitation on day i (mm),
- $Q_{surf::}$ is the amount of surface runoff on day i (mm),
- $E_{a:}$ is the amount of evapotranspirationon day i (mm),
- $W_{seep:}$ is the amount of water entering the vadose zone from the soil profile on day i (mm),
- $Q_{gw:}$ is the amount of return flow on day i (mm).

Subdivision of the watershed enables the model to reflect the difference in evapotransparation for various crops and soils. Thus, the runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy and gives a much better physical description of the watershed (Neitsh, 2009).

Surface runoff volume is calculated using SCS curve number method (USDA Soil Conservation Service, 1972). This method provides a consistent basis for estimating the amount of runoff under varying land use and soil types (Rallison and Miller,1981).

SCS curve number equation is as follow:

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{\left(R_{day} - I_a + S\right)}$$

$Q_{surf:}$ is the accumulated runoff or rainfall excess (mm H2O)

$R_{day:}$ is the rainfall depth for the day (mm H2O)

$I_{a:}$ are the initial abstractions which includes surface storage interception and infiltration prior of runoff(mm H2O)

S: is there tention parameter (mm H2O)calculated by:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

Where:

CN: is the curve number of the day

SWAT incorporates some of the most common hydrologic equations for the simulation of flow. For the accurate implementation of these equations, detailed input data are needed. The digital elevation model (DEM) of the watershed, the soil, land use and the climatic data of the area are of significant value to the simulation.

1.2.3 SWAT strength

The main advantage of the SWAT model isa physically based model that represents the complexity of the real watershed water system. It allows obtaining data at the outlet of each subbasin once the parameters of the modeled watershed calibrated. Also it allows having access to the various balance water sheets for the every hydrologic response unit (finer scale than the subbassin). It provides data at each time step or globally throughout the period of simulation, as the equivalent in mm of water of the amount of melted snow, the biomass produced in tons/hectare, the flow discharged through surface runoff, by the flow in aquifer, etc ... which gives an idea of the impacts on many variables of the water cycle, at any time or within any basin area slope, in addition to its primary mission: to provide the flow and quality of water at the outlet basin. We will focus in this study that the quantitative aspect of water, and not his quality.

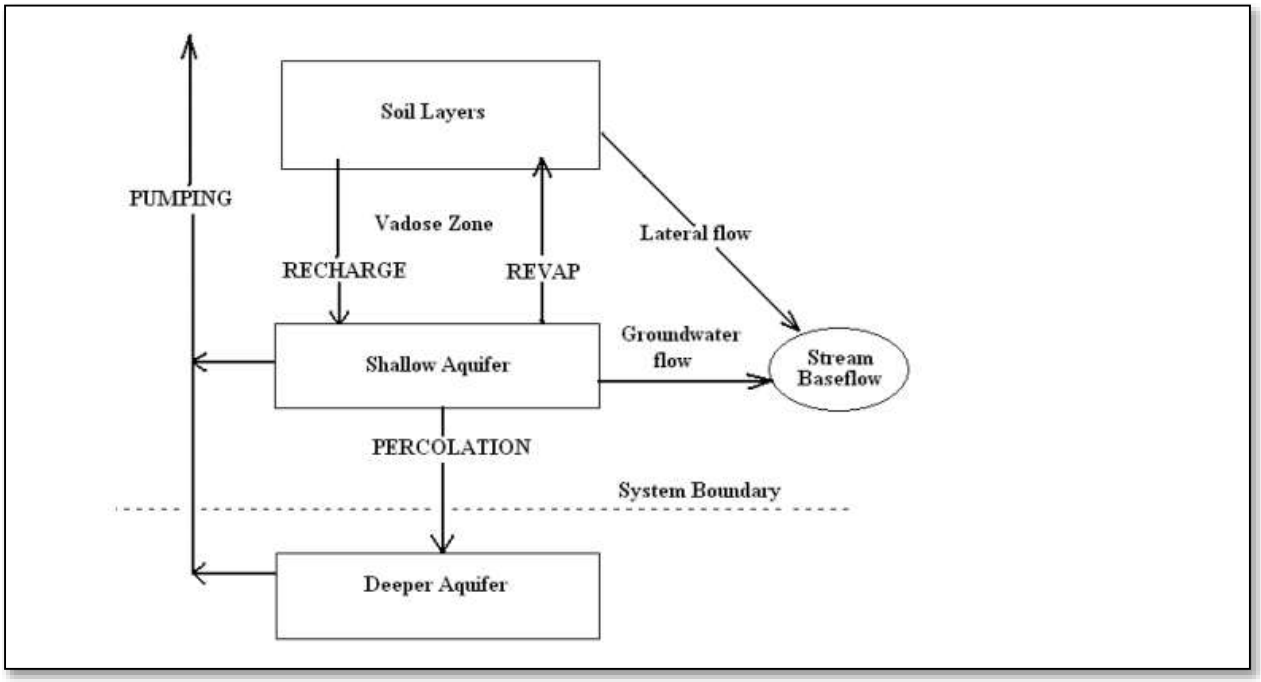

Figure 3.Main groundwater process in SWAT

1.3 Performance criteria

According to Moriasi et al, 2007, the hydrologic models are very important tools for the simulation of a watershed process effect and soil management and water resources but the main problem is to define the accuracy of the results and level of simulation comparing to observed data. Model output is compared to corresponding measured data with the assumption that all error variance is contained within the predicted values and that observed values are error free. But this is not the case. It may be some errors related to lack of measurement data.

Based on this analysis, for quantitative statistics, Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and Pearson's correlation coefficient (r) and coefficient of determination (R2), in addition to the graphical techniques, will be used in the model evaluation.

1.3.1 Model evaluation statistics (standard regression):

Pearson's correlation coefficient (r) and coefficient of determination (R2): Pearson's correlation coefficient (r)and coefficient of determination (R2) describe the degree of co linearity between simulated and measured data. The correlation coefficient, which ranges from −1 to 1, is an index of the degree of linear relationship between observed and simulated data. If r = 0, no linear relationship exists. If r = 1 or −1, a perfect positive or negative linear relationship exists. Similarly, R2 describes the proportion of the variance in measured data explained by the model. R2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al.,2001, Van Liew et al., 2003). Although r and R2 have been widely used for model evaluation, these statistics are over sensitiveto high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999).

1.3.2 Model evaluation statistics (dimensionless)

Nash-Sutcliffe efficiency (NSE): The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information" (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation 1:

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right]$$

where

Y_i^{obs} is the ith observation for the constituent being evaluated,

Y_i^{sim} is the ith simulated value for the constituent being evaluated,

Y^{mean} is the mean of observed data for the constituent being evaluated

n is the total number of observations.

NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE=1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

1.3.3 Model evaluation statistics (error index)

Percent bias (PBIAS): Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999). PBIAS is calculated with the following equation:

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n} \left(Y_i^{obs}\right)} \right]$$

where

Y_i^{obs} is the ith observation for the constituent being evaluated

Y_i^{sim} is the ith simulated value for the constituent being evaluated

n is the total number of observations

PBIAS is the deviation of data being evaluated, expressed as a percentage. Percent streamflow volume error (PVE; Singh et al., 2004), prediction error (PE; Fernandez et al., 2005), and

percent deviation of stream flow volume (Dv) are calculated in a similar manner as PBIAS. The deviation term (Dv) is used to evaluate the accumulation of differences in stream flow volume between simulated and measured data for a particular period of analysis.
PBIAS has the ability to clearly indicate poor model performance (Gupta et al., 1999)

MAE, MSE, and RMSE: Several error indices are commonly used in model evaluation. These include mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE). These indices are valuable because they indicate error in the units (or squared units) of the constituent of interest, which aids in analysis of the results. RMSE, MAE, and MSE values of 0 indicate a perfect fit. Singh et al. (2004) state that RMSE and MAE values less than half the standard deviation of the measured data may be considered low and that either is appropriate for model evaluation.

1.4 Flood Frequency Analysis

1.5 Definition :

Flood frequency analysis uses statistical probability distributions in order to extrapolate and predict less frequent and more extreme flood events. There is no specific distribution that fits perfectly the flood potential of every watershed so different distribution functions are used, compared and combined to approximate the true distribution. Flood frequency analysis results are essential for the economical planning and safe design of bridges, dams, levees, and other structures located along rivers and streams and for the effective management of flood plains.

In this study the simulated annual peak flow data are used to estimate the statistical parameters of two probability distributions, Gumbel and log-Pearson III with the method of moments. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various flood peaks as a function of the return period.

This method is accurate, easy to apply and needed to estimate flood frequency discharges at ungauged stream sites like the case of Xeropotamos River using simulated peak flow data. Continuous hydrologic simulation is a valuable tool to determine flood frequencies in an ungauged watershed.

1.6 Gumbel distribution

from (Rao and Hamed, 2000)

Gumbel refers to extreme value distribution type I and is the current required method for all precipitation frequency analysis in Canada. The probability density function is calculated by:

$$f(x) = \frac{1}{\sigma} * \exp\left[-\left(\frac{x-\mu}{\sigma} \right) - e^{-\left\{ \frac{x-\mu}{\sigma} \right\}} \right]$$

where

μ is the location parameter

σ is the scale parameter

The cumulative density function is given by:

$$F(x) = \exp\left[-e^{-\left\{ \frac{x-\mu}{\sigma} \right\}} \right]$$

The quantile estimation is carried by the next equation:

$$\hat{x}_T = \hat{\mu} - \hat{\sigma} * \ln(-\ln(F))$$

where

F is the non-exceedance probability

The frequency factor is calculated by:

$$K_T = -0.45 - 0.7797 * \ln(-\ln F)$$

And finally the standard error for each return period is given by:

$$s_T^2 = \frac{\sigma^2}{N} * \left(1.15894 + 0.19187 * Y + 1.1 * Y^2\right)$$

$$Y = -\ln(-\ln F)$$

1.7 Log-Pearson III distribution

from (Rao and Hamed, 2000)

Log-Pearson III distribution is the current distribution suggested by the USA Water Resources Council (WCR) and is used throughout the world. The probability density function of log-Pearson III in this study will be calculated with the method of moments using log-transformed data and is presented below:

$$f(x) = \frac{1}{\alpha * x * \Gamma(\beta)} * \left[\frac{\ln(x) - \gamma}{\alpha} \right]^{\beta - 1} * e^{-\left\{ \frac{\ln(x) - \gamma}{\alpha} \right\}}$$

where:

α,β,γ are the parameters of log-Pearson III

Γ(β) is the Gamma distribution function for parameter β

As far as flood frequency analysis is concerned we have to be careful when the distribution parameters are, α>0 and β>1, because this denotes that the distribution function is upper bounded. The cumulative distribution function is:

$$F(x) = \frac{1}{\alpha * \Gamma(\beta)} * \int_0^x \frac{1}{x} * \left[\frac{\ln(x) - \gamma}{\alpha} \right]^{\beta - 1} * e^{-\left\{ \frac{\ln(x) - \gamma}{\alpha} \right\}} dx$$

If this transformation takes place, y=ln(x), the distribution degenerates into Pearson III. The quantile estimation is done after the transformation of $x = e^y$:

$$\hat{y}_T = \bar{y} + K_T * \sigma_y$$

where:

σ_y is the standard deviation

K_T the frequency factor corresponding to T-year return period given by:

$$K_T = \frac{\chi^2 * C_{s,y}}{4} - \frac{2}{C_{s,y}}$$

where:

χ^2 is the χ^2distribution

$C_{s,y}$ is the skewness coefficient

The frequency factor can be calculated by the Wilson-Hilferty, (1931) approximation:

$$K_T = \frac{2}{C_{s,y}} * \left[\left\{ \frac{C_{s,y}}{6} * \left(u - \frac{C_{s,y}}{6} \right) + 1 \right\}^3 - 1 \right], 0 < C_{s,y} \leq 1$$

where:

u is the normal distribution parameter for each non-exceedance probability

The standard error is calculated by:

$$s_T^2 = \left(\frac{\partial x_T}{\partial y_T} \right)^2 * \mathrm{var}(y_T) = x_T^2 * \mathrm{var}(y_T)$$

Where : var(y_T) is the standard error in Pearson III

Chapter II: Study Area

Xeropotamos is an ungauged basin which means that flow data are not available to be used to calibrate a hydrologic model and simulate its flow. In order to overcome this obstacle the model was calibrated using the adjacent, gauged watershed of Giofyros.The two watersheds have similar characteristics regarding the geology, the land use and climate. Then the calibrated model of Giofyros watershed was applied on Xeropotamos.

1 Location

Greece is located in South-Eastern Europe, precisely at the crossroads of Europe, Asia, and Africa. Its mainland is located at the southernmost tip of the Balkan Peninsula and is surrounded on the north by Albania, the Republic of Macedonia and Bulgaria, to the east by the Aegean Sea and Turkey, to the south by the Mediterranean Sea and to the west by the Ionian Sea and Italy.

Crete Island is in the south of Greece, it's the largest of the Greek islands that covers an area of 8,336 km^2, which is 6.3% of the total area of the country, withlength to width dimensions of 260km to 60km. Xeropotamos watershed lies in the northern part of Crete Island juxtaposed with Giofyros catchment. It's an ungauged catchment that covers an area 48.6km^2.

The river outfalls through the western suburbs of the city of Heraklion to the Aegean Sea in the coastal area of Ammoudara.(Ganoulis, 1995)

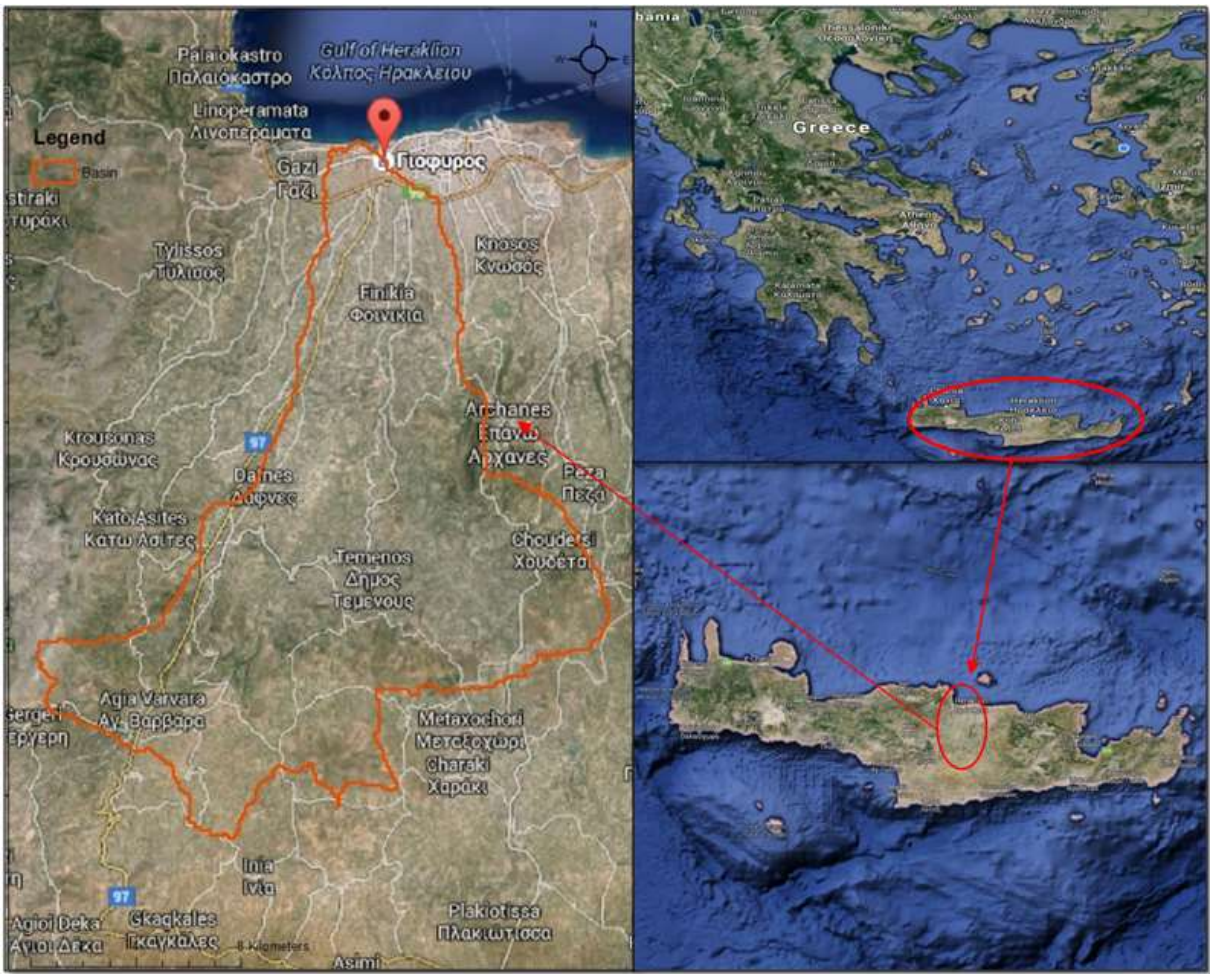

Figure 4. Location of the study area. Clockwise from upper right: Greece,Crete, Giofyros and Xeropotamos basins

2 Morphology

2.1 Altitude

The watershed can be separated into two zones, the coastal and the mountainous. The basin Xeropotamos covers an area 48.6km^2, where 31% of the area are lowland located in the northern part then 31% are semi-mountain and mountain represent 38% especially in the south part, while the average altitude is 475m and the maximum reach 1764m.The watershed has an elongated form.

Giofyros extent on an area of 186.5 km^2, the plain is represented by 27%, semi-mountain by 39% and mountain by 34% in the southern part of the average altitude is 330m and the maximum reach 900m.

2.2 Slope

Crete is a rugged mountainous island with high variation in altitude (sea level up to 2,445m) within relatively short distance. Actually, 79.5% of the island has slopes greater than 12% and only 6.9% of it comprises lowlands with 2 slope less than 6%. In the study area, the slope classification is divided into 4 classes:

- 0-8 (%)
- 8-16 (%)
- 16-24 (%)
- 24-100 (%)

Table 1. Distribution of slope in the study area

Slopes (%)	XEROPOTAMOS	GIOFYROS
0-8	12%	14%
8-16	22%	33%,
16-24	25%	36%
25-100	41%	17%

The slope in the, Xeropotamos and Giofyros watersheds is smooth in the northern part, mainly ranging between 0-8(%), while it is steeper in the south-west direction. In general the slope gradient in the two basins is steep which favors the surface runoff.

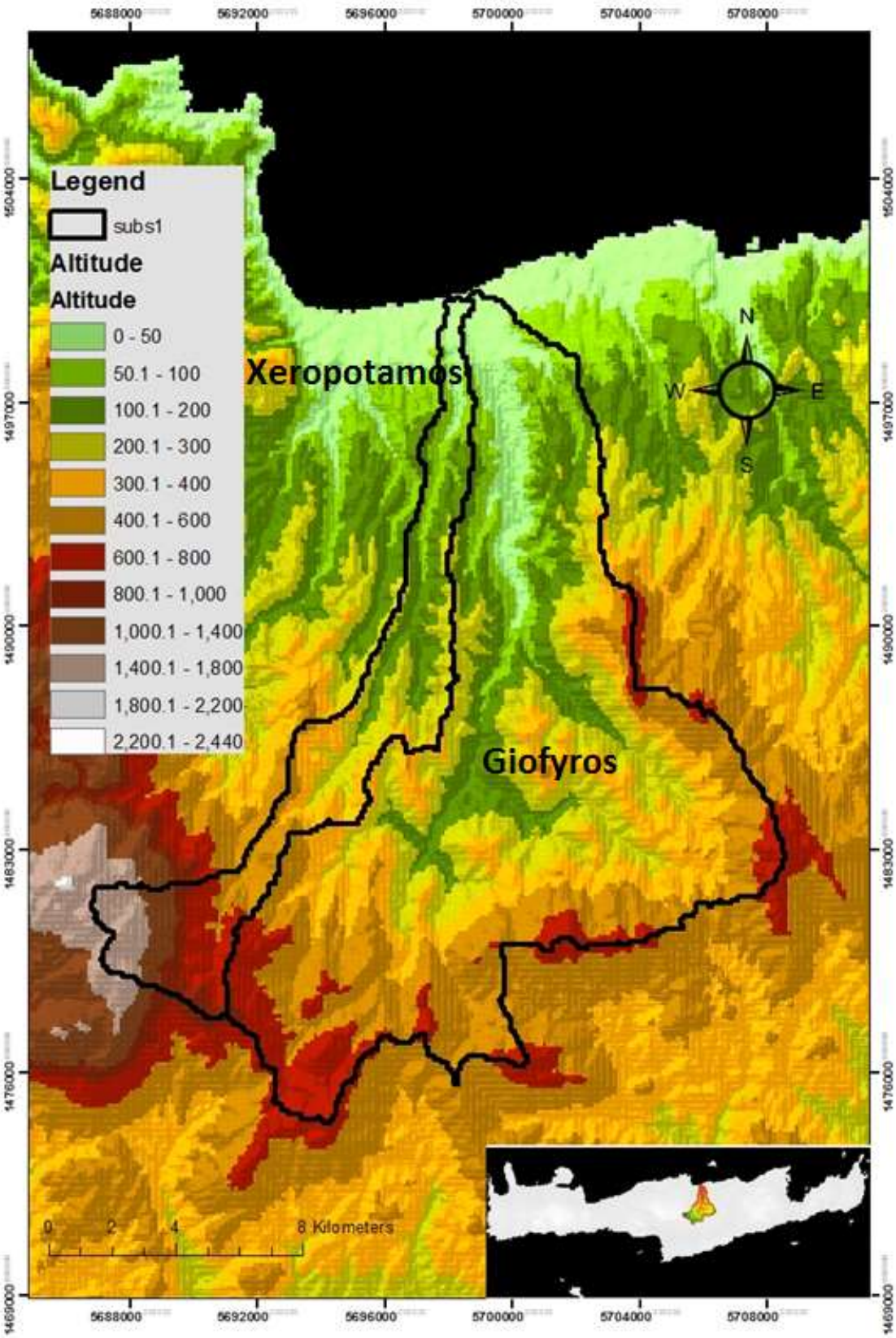

Figure 5.Morphological map of study area SWAT

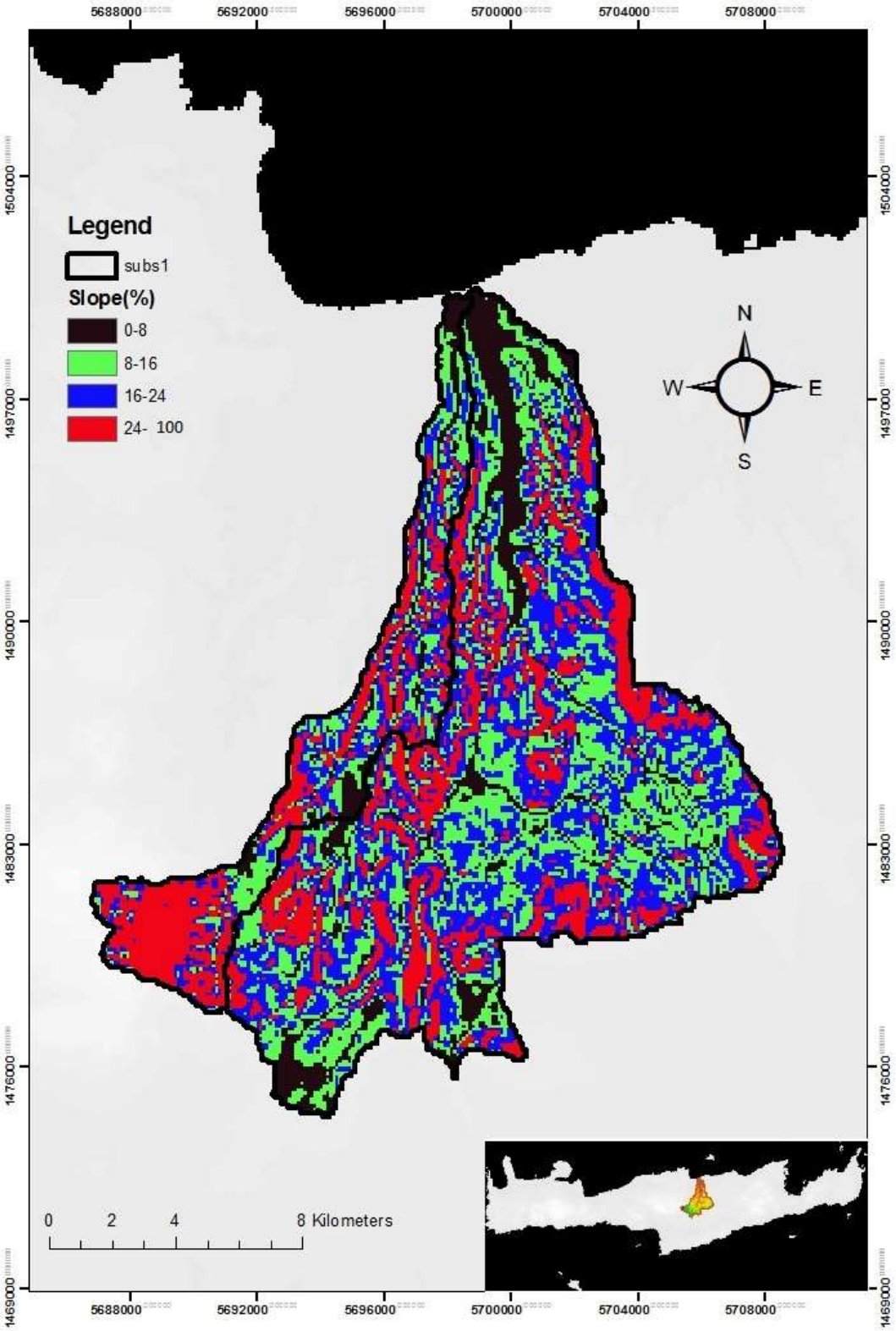

Figure 6.Slope classification map of study area.

3 Geology

The island of Crete was part of the Aegean mainland during the Paleocene-age (65.5 to 55.8 million years ago). Its present form, however, began only with new ground motion and the quaternary calanques the Pliocene era (before 5.3 to 1.8 million years ago) to emerge. These tectonic processes cut the island in its unusual, elongated narrow shape on the Aegean continental plate. New breaks and shifts in the earth's crust created the textured surface shape of the island in its main features and the final present form was created by last movements of the earth's solid crust. The latest rock layers are deposits from the Quaternary (1.8 million years ago) (site web 1)

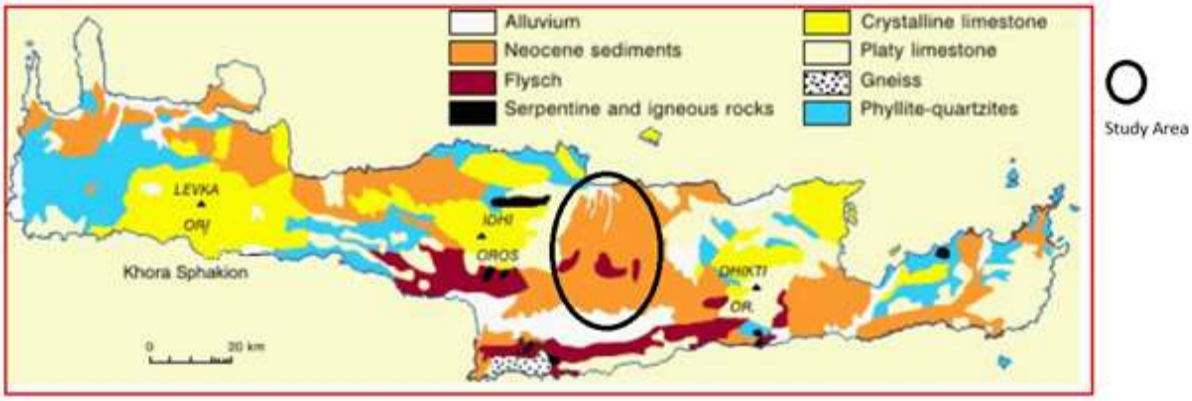

Figure 7.Geological map of Crete (Der Krtek,2007)

According to Koutroulis, 1994 the basin is composed of extensive strata of limestone especially in the west part of Xeropotamos watershed, also flysch and sandstone, gypsum and alluvial deposits. There is also a small part of karstic land in the south-west of the basin but there’s no karstic springs.

4 Soils

Cretan soils are formed on a variety of parent materials such as limestone, shale, marl, conglomerates, flysch and alluvial deposits of Neogene and Quaternary period. The study area includes Regosols alluvial depositions and Leptosols slate and limestone.Both soils have various textures. Regosols are free of carbonates and very weakly developed mineral soil in an unconsolidated materials with an argillic horizon and high degree of erosion. Leptosols, these soils are formed in hilly areas, are moderately deep to shallow due to their advanced

degree of erosion with the parent material exposed on the soil surfaces in several cases.(site web 2)

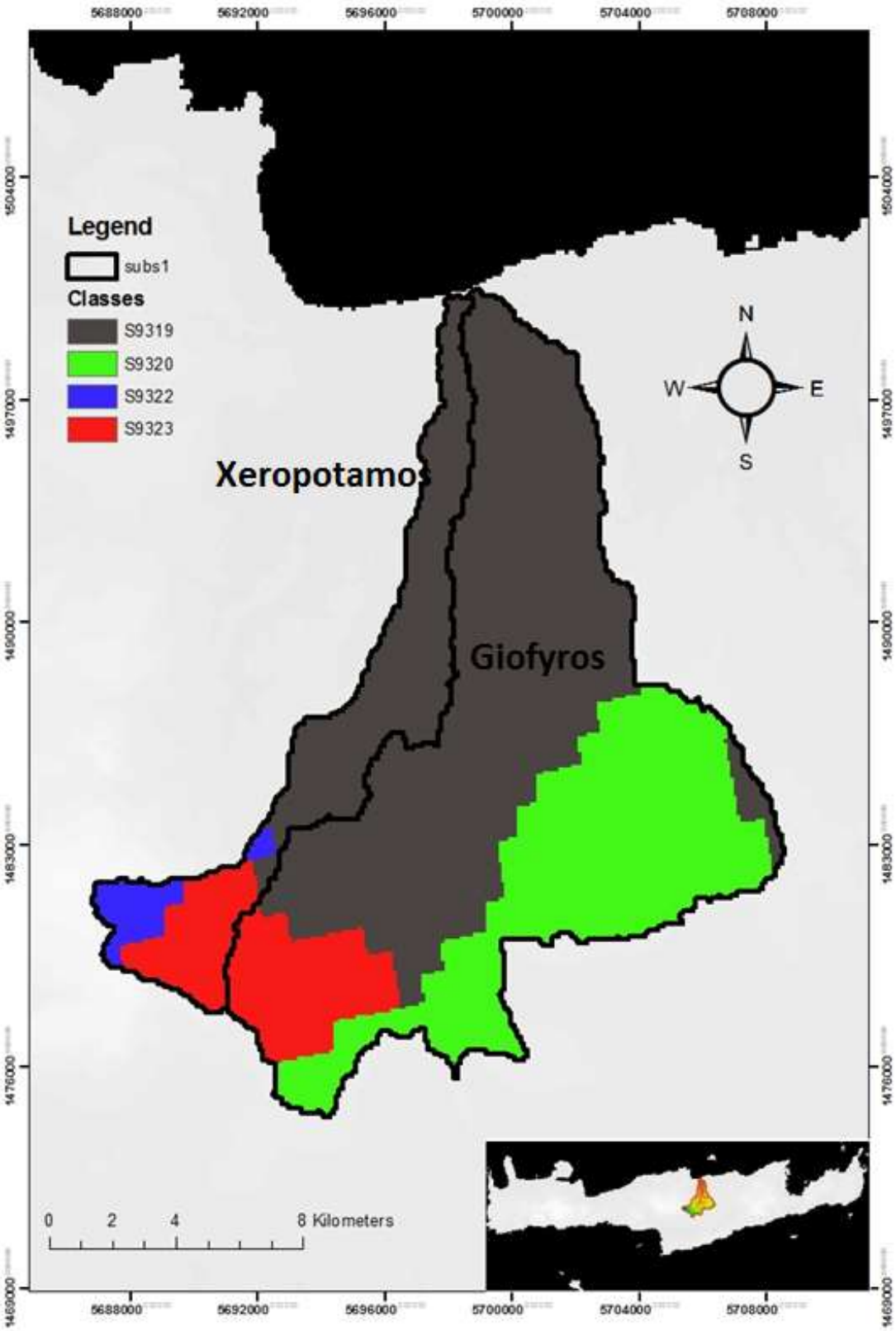

Figure 8. Soil map of the study area.

The basins soils are in the Map are:

- S9319 Regosols alluvial slimes
- S9320 Leptosols Slate
- S9322 Leptosols limestone
- S9323 Leptosols Slate

5 Land use

Land uses in Xeropotamos and Giofyros river basins are mainly vineyard 24.35% and olive groves 34.17%, the rest of the crops are vegetable plantations. Also urban land uses occupy the northern part of the two basins representing 2.75% of the total area of the project.There's also a part of woodland in the Xeropotamos watershed. In the next table are classified the land use and there proportions compared to the two basins, the table is obtained from SWAT after processing the land use map from Corine land cover 2000.

Table 2. Distribution of land uses in the model

Land useSWAT	Description	Area (%)
URHD	Moderate urban	0.06
URMD	Dense urban	2.65
UCOM	Commercial urban	0.01
UTRN	Transportation	0.03
GRAP	Vineyard	24.35
OLIV	Olives	34.17
SWHT	Spring wheat	25.39
RNGE	Range grasses	8.16
RNGB	Range brushes	5.14
SPAS	Summer pasture	0.05

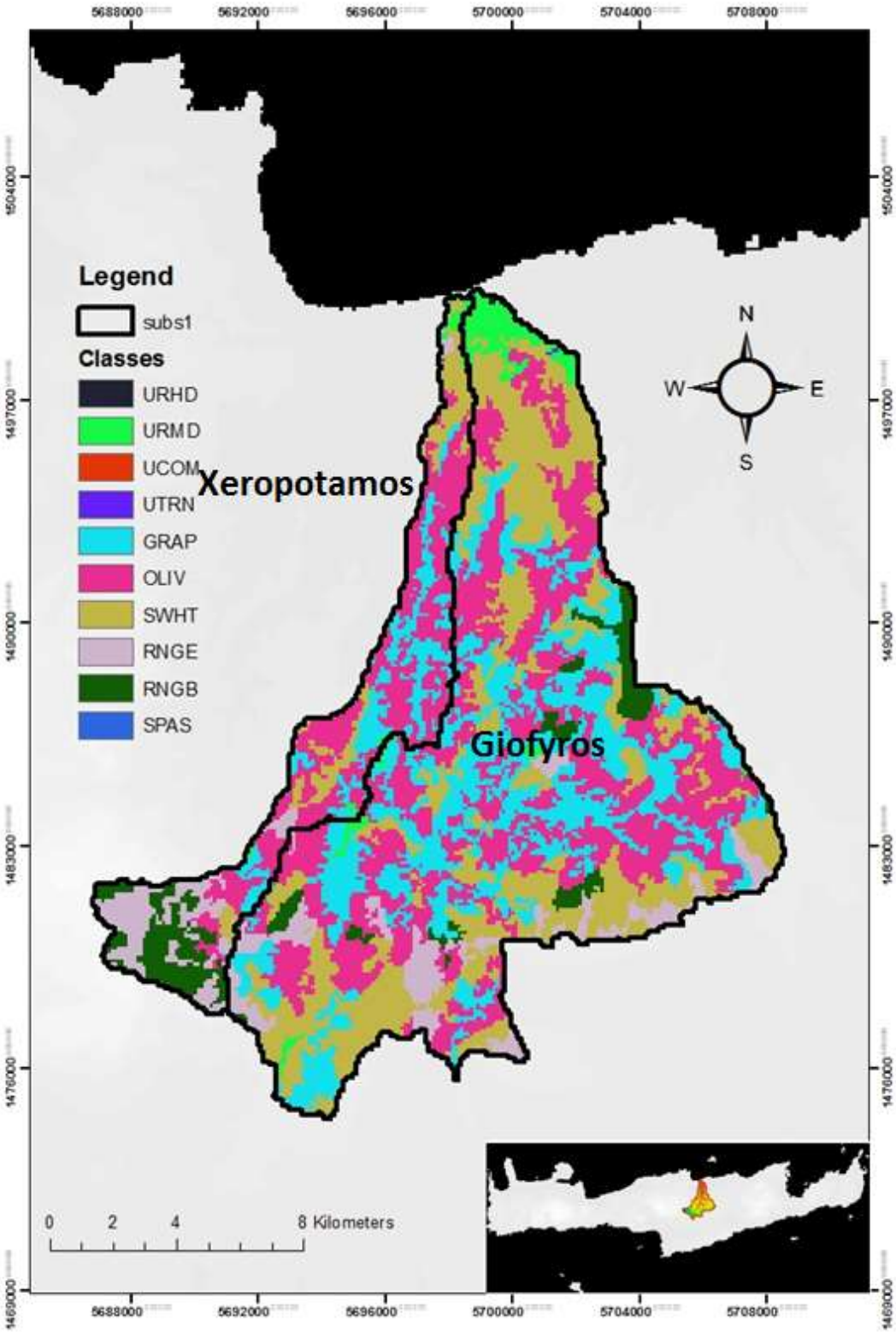

Figure 9. Land use map of study area.

6 Climate

The climate of Crete is typical Mediterranean where mean annual rainfall decreases from west to east and from north to south, but increases with altitude. There is also a slight increase in mean annual temperature from northwest to southeast and a decrease with altitude. The weather is generally characterized by long, hot and dry summers and relatively humid and cold winters. As such, most annual rainfall occurs in winter and rarely during summer (Koutroulis et al., 2010). The annual rainfall ranges from 400 mm to 700 mm in the low areas and along the coast (lerapetra 412 mm, Iraklio 512 mm, Chania 665 mm), and from 700 to 1.000 mm in the plains of the mainland, while in the mountainous areas reaches up to 2.000 mm. Air temperature lies between the isotherms 18.5°C to 19.0°C with an annual amplitude of 14°C to 15°C. The southern part of the island is warmer (the warmest of Greece) than the northern part. In the winter, the lowest temperatures nearly fall below 0°C in the plains. During the summer, temperatures greater than 40°C may occur in the lowlands ofCrete.

Spring is short because of the cold fronts often affecting the region in March, whereas, May is rather warm, especially due to the appearance of the first south winds and thedisappearance of the action of low pressures. North winds are dominant in the island. Insummer the north winds predominate, creating very dry conditions, which are additionallyenhanced by the diminishing of low pressures in the Eastern Mediterranean and are onlyinterrupted by some local rainfall of tropical origin (Chartzoulakis et al., 2001).

The stations used for the hydrologicmodeling project of Xeropotamos are mainly located in Giofyros basin Agia Varvara ,Profiti Ilia,Foinikia and then EMYHeraklion which is located outside the basin close to the coastal area.

The different elevations ofthe 4 measurement stations are :

- Agia Varvara 620m
- Profiti Ilia 272m
- Foinikia 79m
- EMYHeraklion 94m

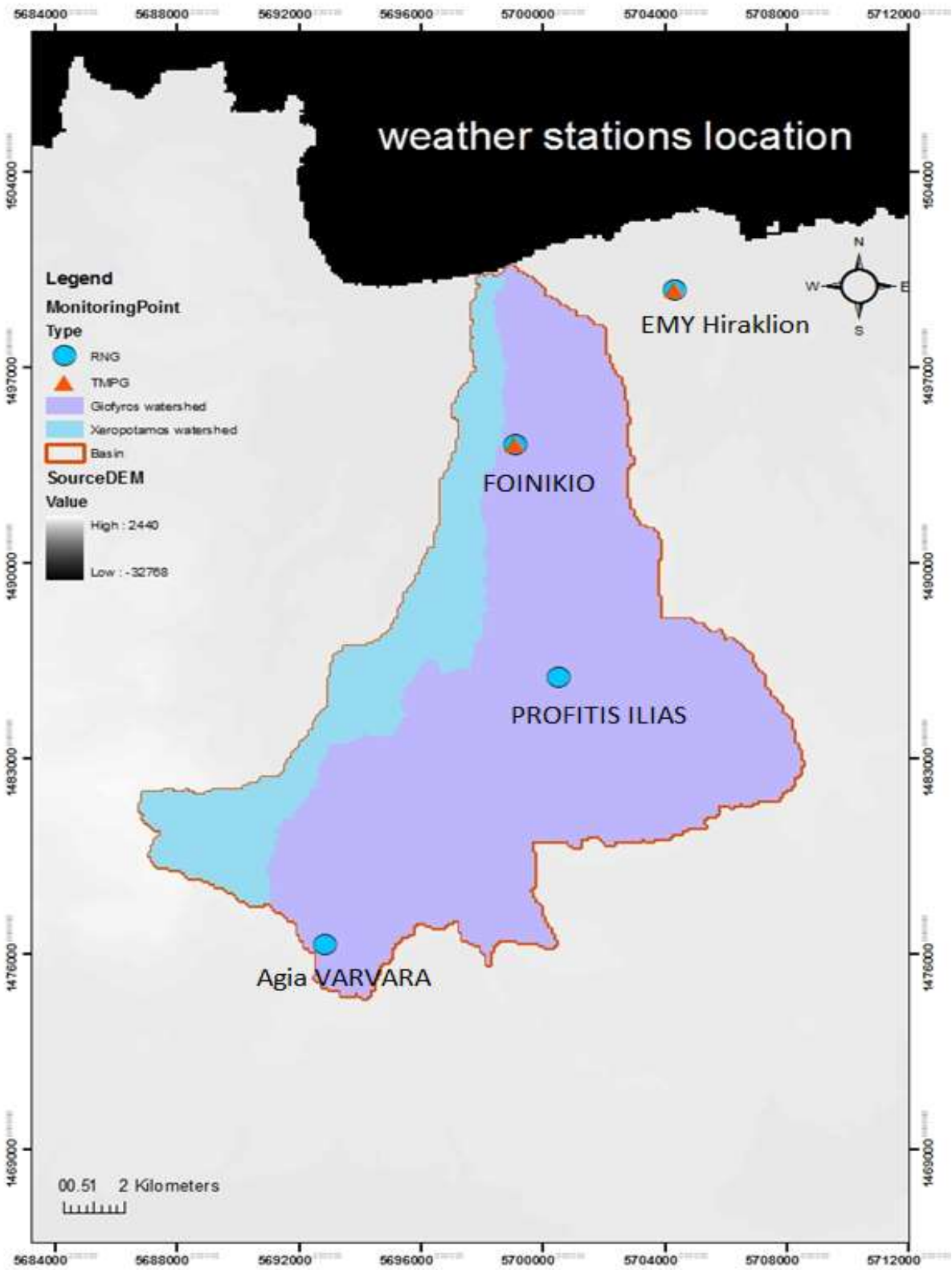

Figure 10. Weather station location map.

6.1 Precipitation

Analyzing the measurement precipitation graphs (figure 11,12) of Agia Varvara, Foinikia, Profitis Ilias and EMY Heraklion, for the period of 1956-2010, we note that Agia Varvara and Profitis Ilias have higher precipitation measurements than the other two stations. This is explained by the high altitude of these stations comparing to the others due to the orographic phenomenon.

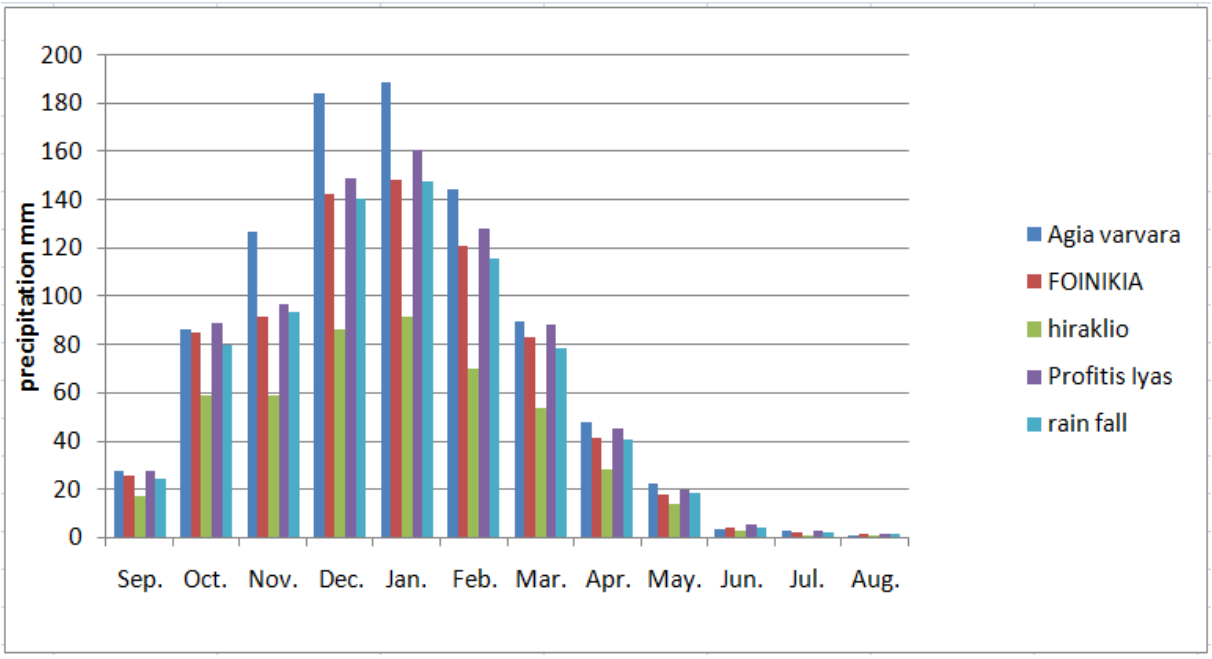

Figure 11.Monthly average of the precipitationsfor the 4 station, hydrologic year(1956-2010)

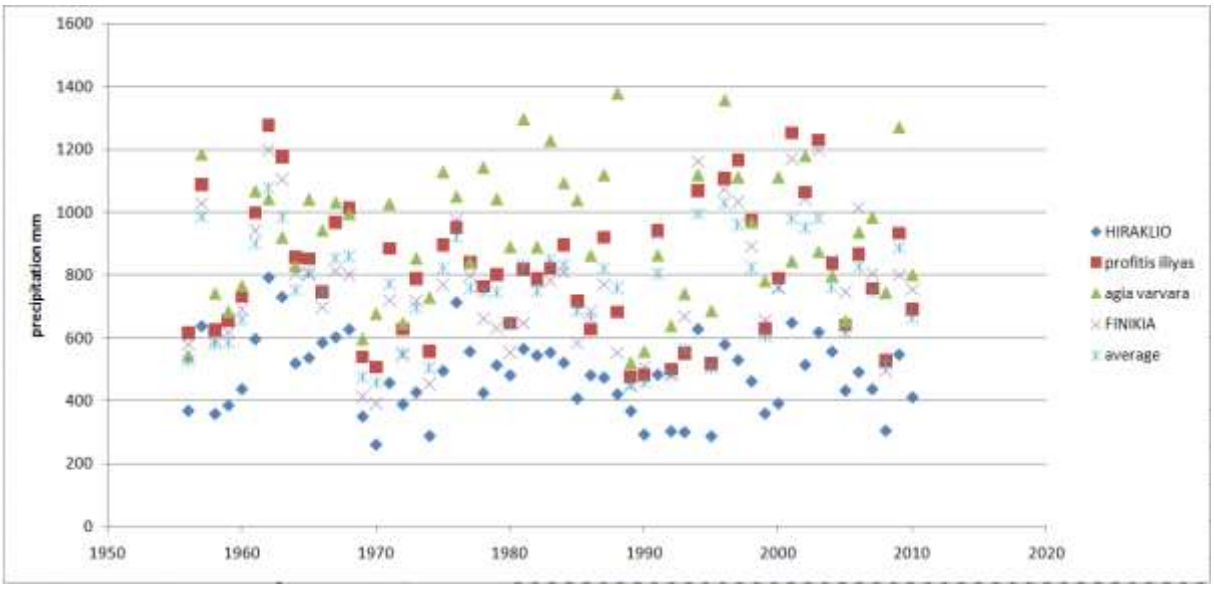

Figure 12.Ten-yearmoving averageprecipitationsmeasurements, in the four stations, hydrologic years (1956-2010),

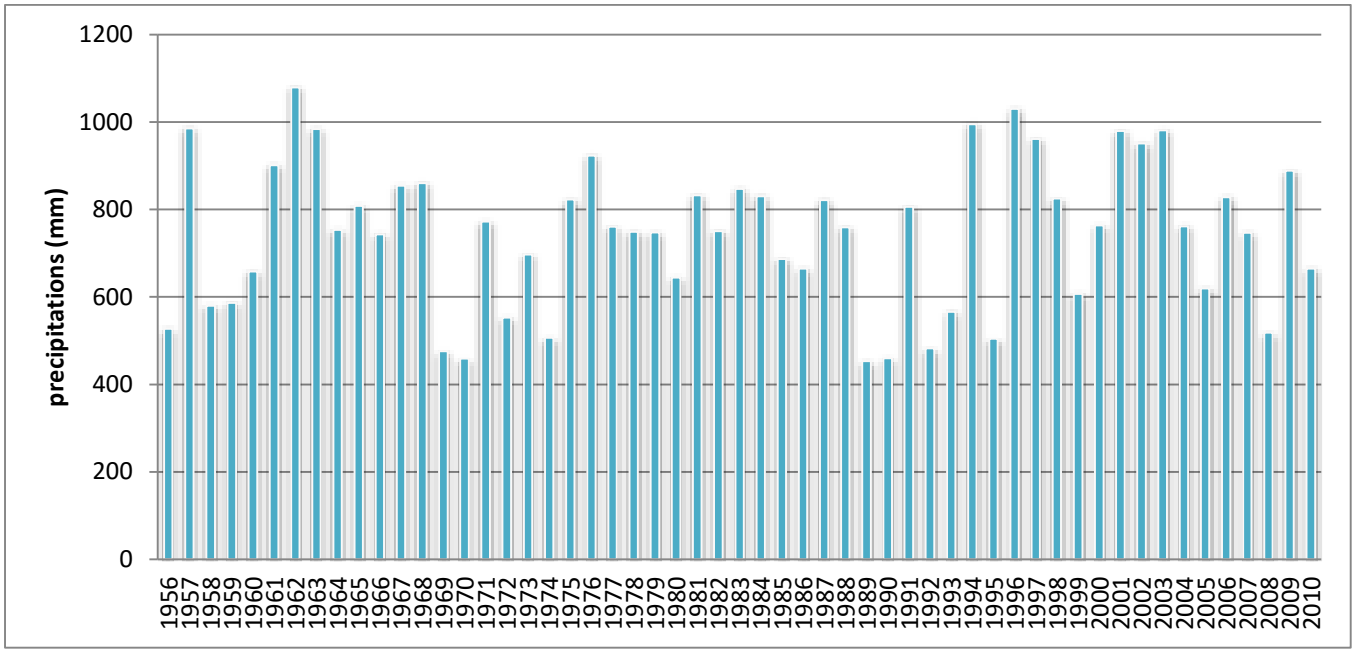

Figure 13. Annual average precipitation, hydrologic year (1956-2010)

According to the graph of the annual moving average of precipitation in the four stations (figure 13), the trend of precipitation is decreasing between 1970 and 1995 comparing to the previous years. This decrease is mostly observed at PROFITIS ILIAS and FOINIKIA stations. Also the amount of rainfall increases notably in the period of 1978 to 1991 at the Agia VARVARA weather station. Regarding the EMY Heraklion station, the trend curve is less than the other stations, because it's located in a lower area and also follows the changes of wet period and dry period.

In summary, the annual precipitations tend to change from years with very low amount of precipitations, like the dry years from 1996-1970 and 1988-1989. Also some years with really high rainfall measurement are 1961-1963 and 1996-1997.

6.2 Temperature

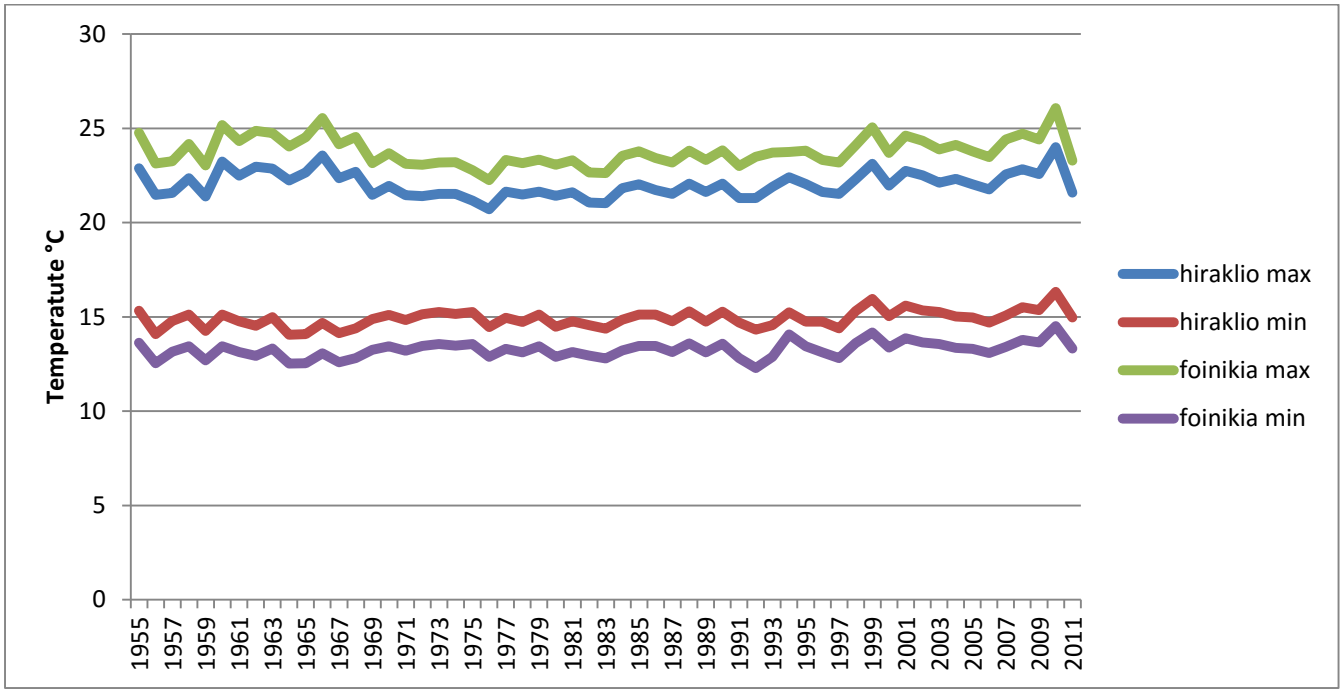

Figure 14. Annual minimum and maximum temperature in Heraklion EMY and FOINIKIA hydrologic year (1956_2010)

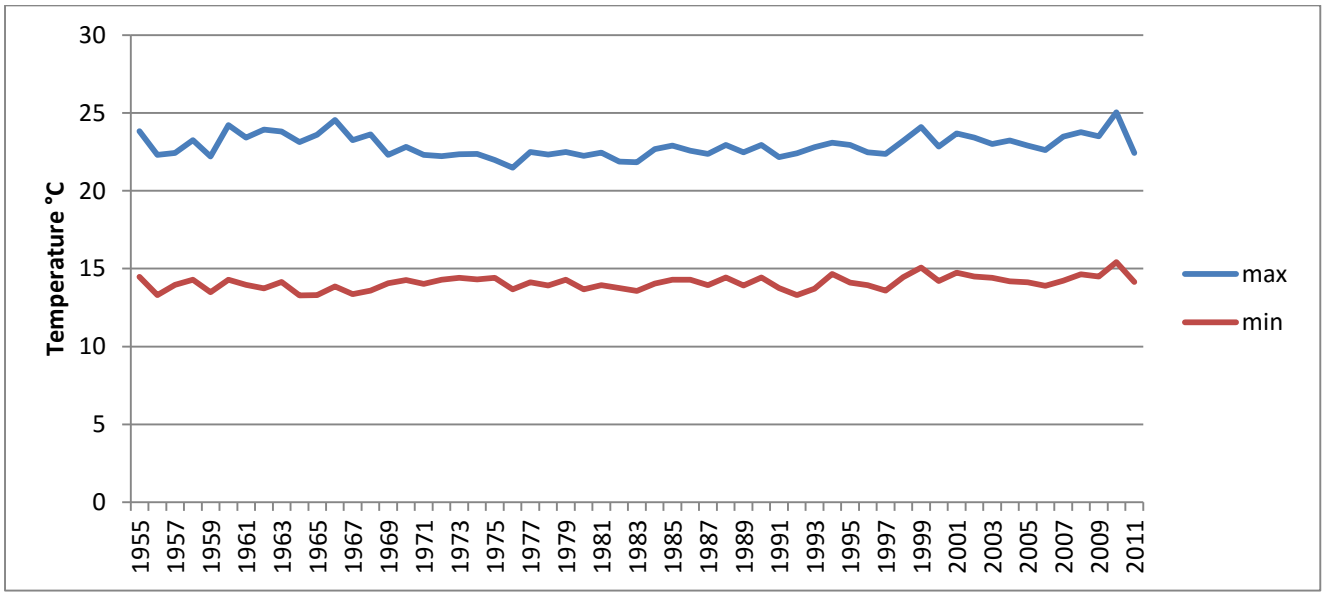

Figure 15. Annual temperature average, hydrologic year (1956-2012)

Focusing on the graph of annual minimum and maximum temperature (figure 14), the EMY Heraklion station has higher values than Foinikia. These stations are located in the lower part of the basin which give us an idea about the temperature next to the sea is more important than in the middle of the basin. Of course if we had observations from Agia Varvara and

Profitis Ilias we could be more informed about the temperature variation on the mountainous areas.

For the annual average temperature in the basin, the variation follows up with the precipitation changes especially on the period 1970-1980. It starts to increase remarkablyafter the 1970 year until 2000 where it stabilizes until 2005 where it increase again

7 Hydrology

The Xeropotamos and Giofyros are typical intermittent rivers, normally dry during a long period of the year and have flow only during winter; they expand during wet period and contract and fragment during dry period. These rivers usually are shaped by sequential events of flooding and drying over an annual cycle in the Mediterranean regions.

Xeropotamos river drains the basin and it is classified as second class according to Horton's classification, The hydrographic network in mountainous area is developed too. The watershed covers an area of 48.6Km^2, it has its name after the main river Xeropotamos.

For Giofyros basin, the surface is 186.5Km2; its main stream is Giofyros river in order 4 .

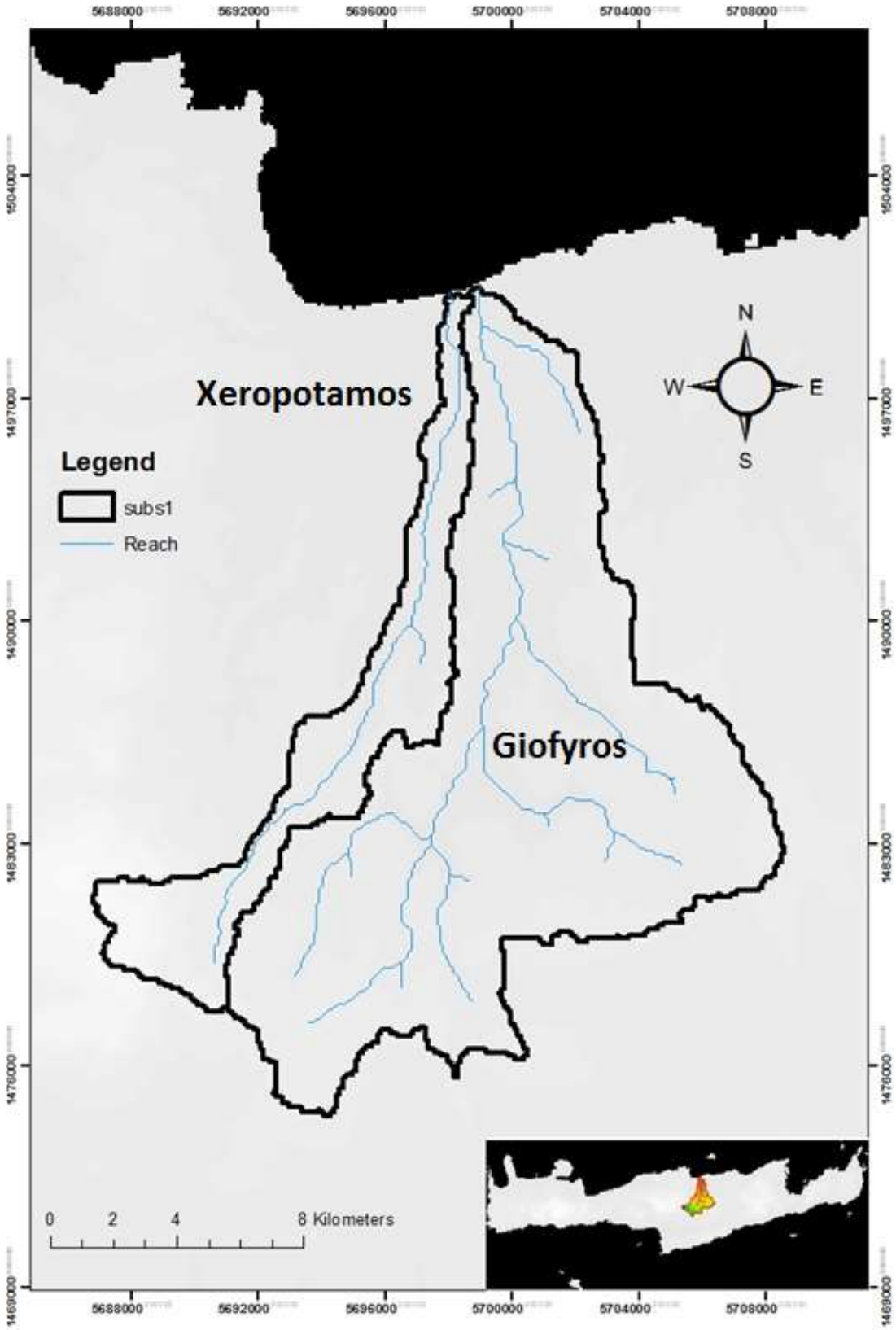

Figure 16. Hydrologic map of study Area

Chapter III : Results and Discussion

For this study the version of ArcMap 9.3 Service Pack 1 (Build 1850) was used coupled the version 2009.93.5 of ArcSWAT.SWAT process ismainly divided into three big steps, setup, calibration and validation.Each one of these steps needs to be carefully executed in order not to have any problems during the modeling work and also to have a good representative graph.

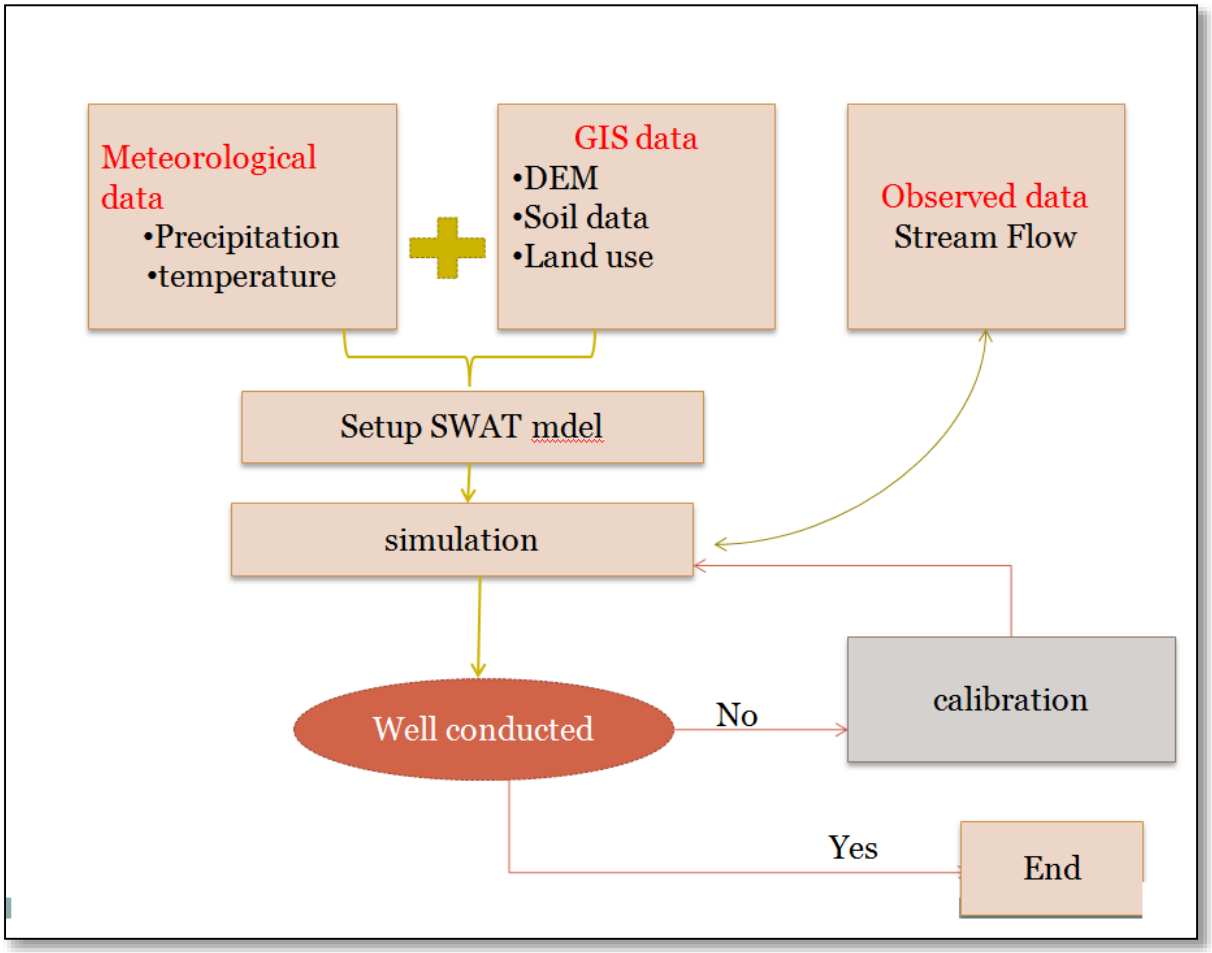

Figure 17. SWAT process scheme

1 Project Setup

In this part we start by setting-up the model, for this, different data inputs are needed:

- The soil map was takes from Greek soils map.
- The land use map from corine land cover 2000.
- The digital terrain of Crete (DEM digital elevation model),

- The daily rainfall measurement stations Agia Varvara, Profitis Ilias, Foinikia and EMY 754 Heraklion from 01/09/1955 until 31/08/2011
- The daily maximum and minimum temperature measurements of Foinikia and EMY 754 Heraklion stations from 01/01/1955 until 31/12/2011

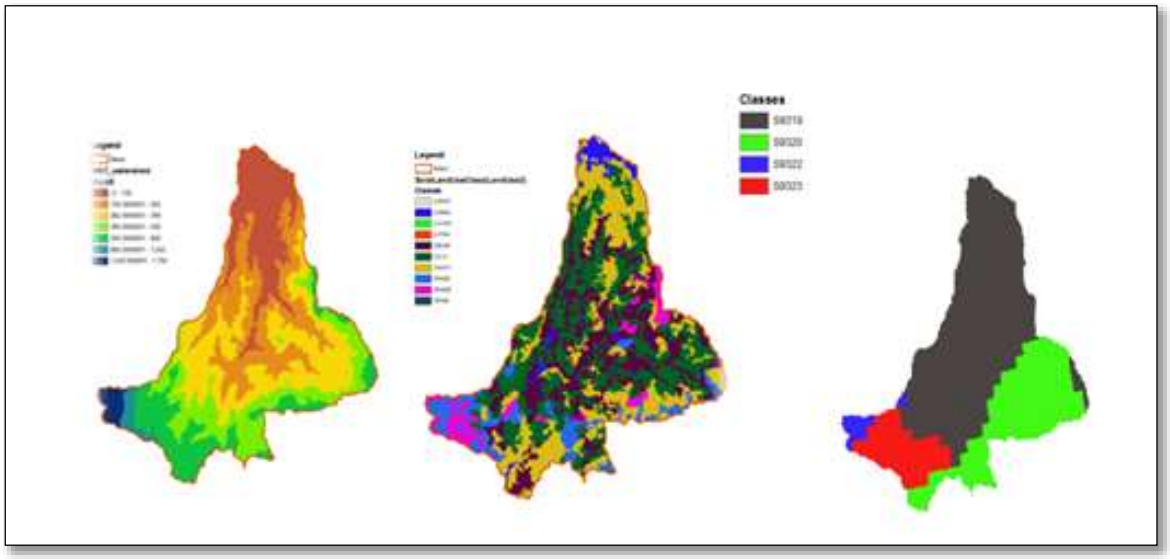

Figure 18. SWAT input maps from left to right, , DEM Digital Elevation Model, Land use map, Soils map

1.1 Watersheddelineation

In this step we use the DEM (Digital Elevation Model) to define the water routing based on the topography of the watershed. We can also choose the outlet of the catchment.The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the case of our study we had 30 subbasins.

The number of subbasins was 3 for Xerapotamos (number 8, 9 and 25) and the rest 27 for Giofyros.

1.2 Hydrologic Response Units (HRU)

We use the HRU analysis tool in Arc-SWAT to load land use, soil layer and define slopes in order to divide the watershed into hydrologic Unit responses. It includes divisions of HRUs by slope, classes in addition to land use and soils. For our project, we used multiple slope classes (8/16/24).CN number in literature are given for slopes 0-8 , Slopes lower than 8% lead to rill and interrill erosion for slopes higher than 24% the erosion follows a different pattern, the processes of stream and channel erosion start, so the classification was designed to include

these classes. Furthermore, due to the diverse morphology of the study area, two more classes were included, 8-16 and 16-24, depicting in an accurate way this heterogeneity.Then the determination of HRUs (Hydrologic Response Units) was done using as threshold values the 300ha for soil, 100ha for land uses and the 50ha for the slope.The land use, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition.A total of 165 Hydrologic Response Unit was obtained, 136 for Giofyros and 29 forXeropotamos.

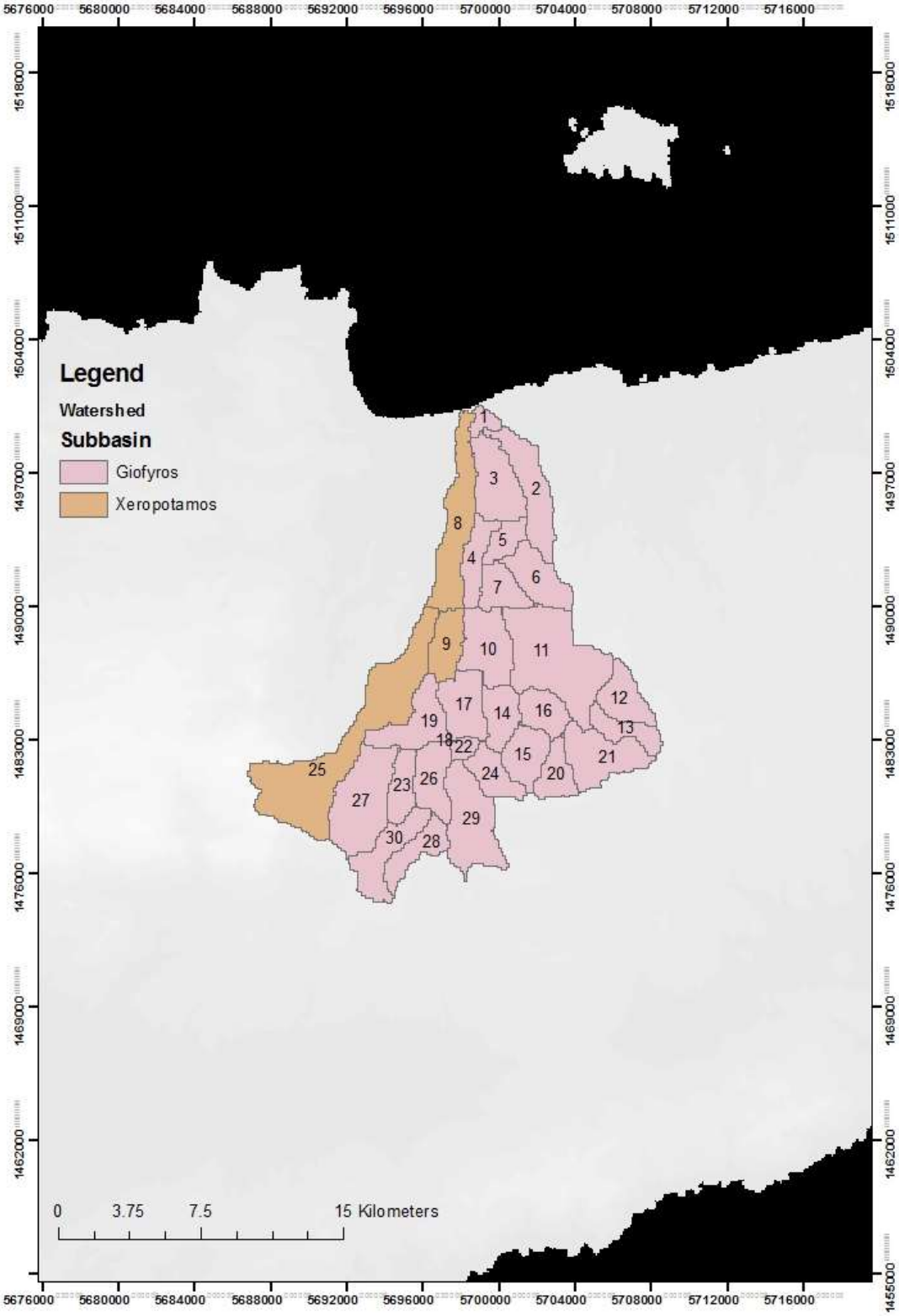

Figure 19. Subbasins map of study area

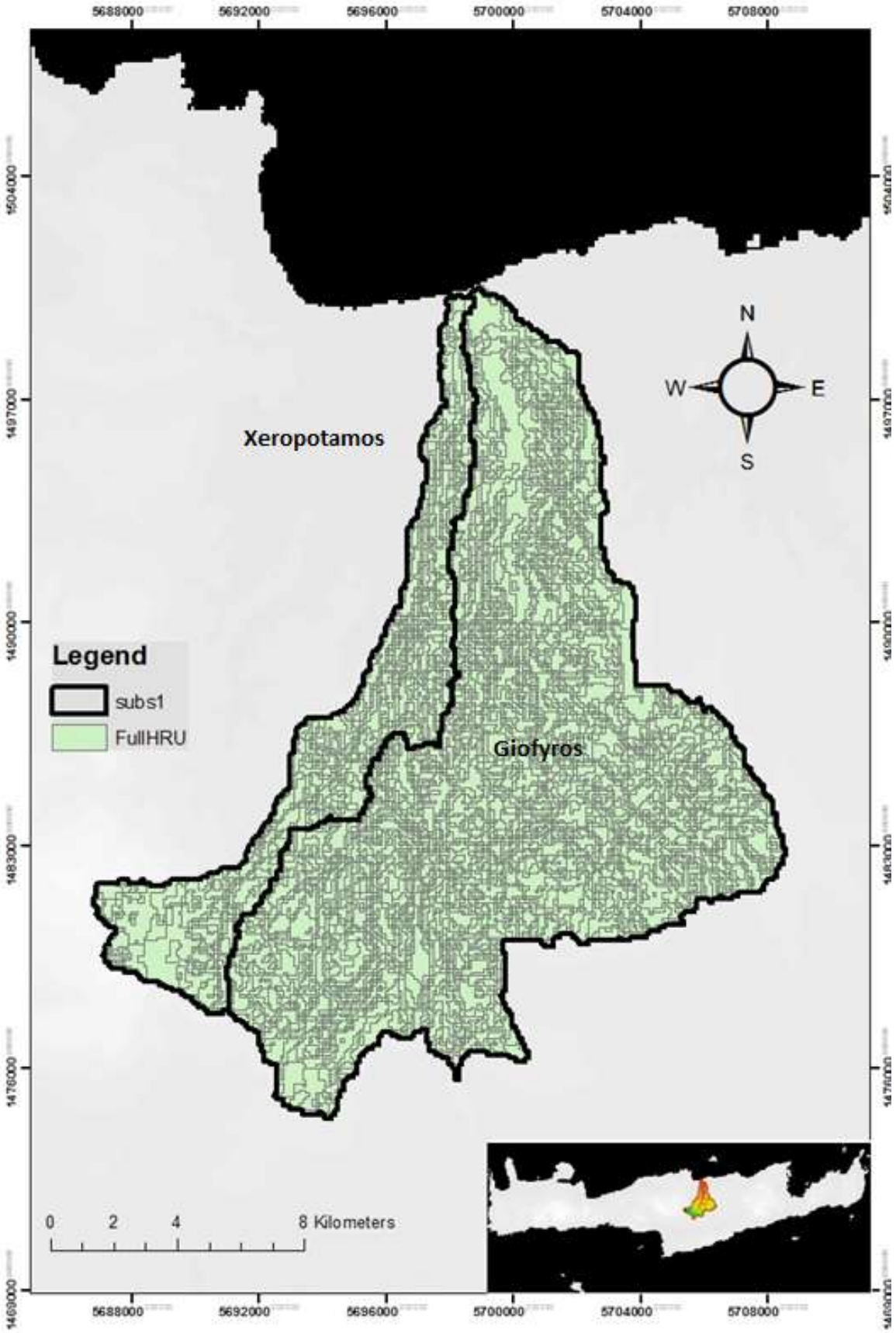

Figure 20. HRUs (Hydrologic Response Units) map of study area

1.3 Model writing inputs and simulation run

In order to feed the model's database, the SWAT inputs must be written. Thenafter the setup of the input for the SWAT model and run the model for a period of simulation, 01/09/1974 until 31/08/1984 in a daily step with 3 years to skip as a warm up so that the modelget the water recycling properly before any comparison between measured and simulated data are made . Finally read the SWAT outputs in order to have information about the different initial values of parameters that need to be calibrated.

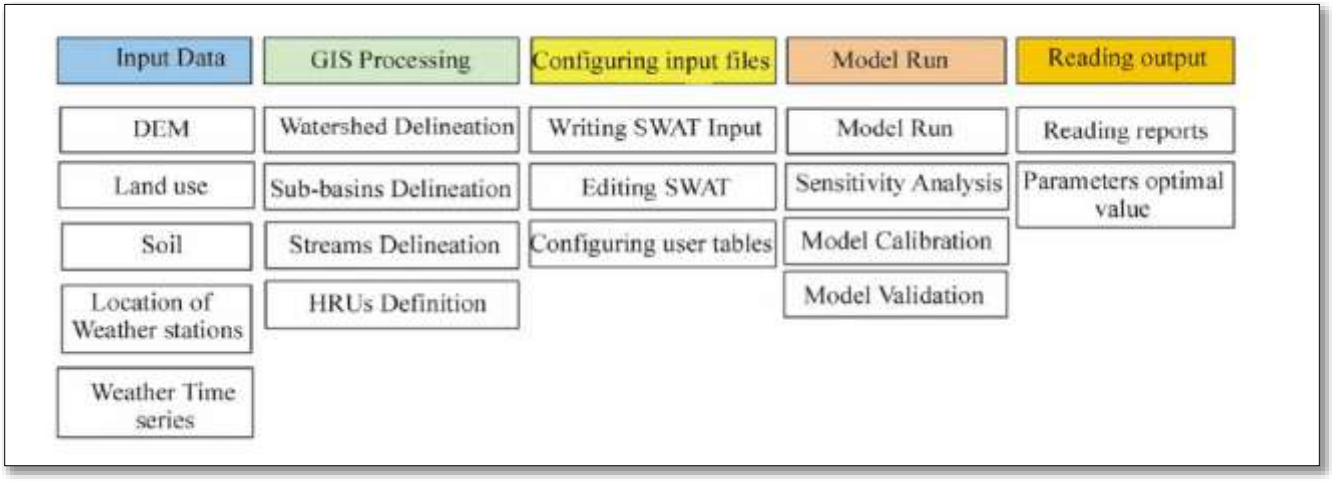

Figure 21.Summary of components and input/output of SWAT model

1.4 Calibration

The model was manually calibrated for the period (1977-1984) to obtain the closest match of simulated outflow to the observed one, by several attempts and changing parameters, based on the hydrograph and the water balance of the watershed. The observed flow out is from gauge station FOINIKIA and simulated flow from subbasin 5, which is the closest point to the station. The first simulation results were an overestimation of surface runoff and baseflow. In order to correct this difference,we followed these steps:

- Decrease **CN2**parameters which lead to decrease in the surface runoff and adjust **Sol_AWC**,**ESCO** and **EPCO** that changes the amount of water that can be evapotranspired or the amount of water available for plants.
- Divide the basin into two parts based on the altitude distribution, because we assume that in the upper part of the basin, the aquifer is deep and not connected to river, which mean that it does not contribute to the outflow of the basin, so we add springs in order to compensate this lack. Then the GWQMN parameter (water depth threshold required

to recharge the water table) that set off the effective groundwater recharge when water reaches a certain level in the shallow aquifer.

- Change the groundwater parameters (**Alpha_BF, GW_DELAY, G RCHRG_DP** and **REVAPMN)**that define the flow of water into the aquifer.
- Modify lag time using **LAT_TIME.**
- Change the soil parameters (Sol**_AWC, Sol_K and SOL_Z**).

The correct visualization of the changes on the simulation was mainly based on the hydrograph as qualitative criteria. But the application of quantitative indicator is also important, for verification and minor changes.

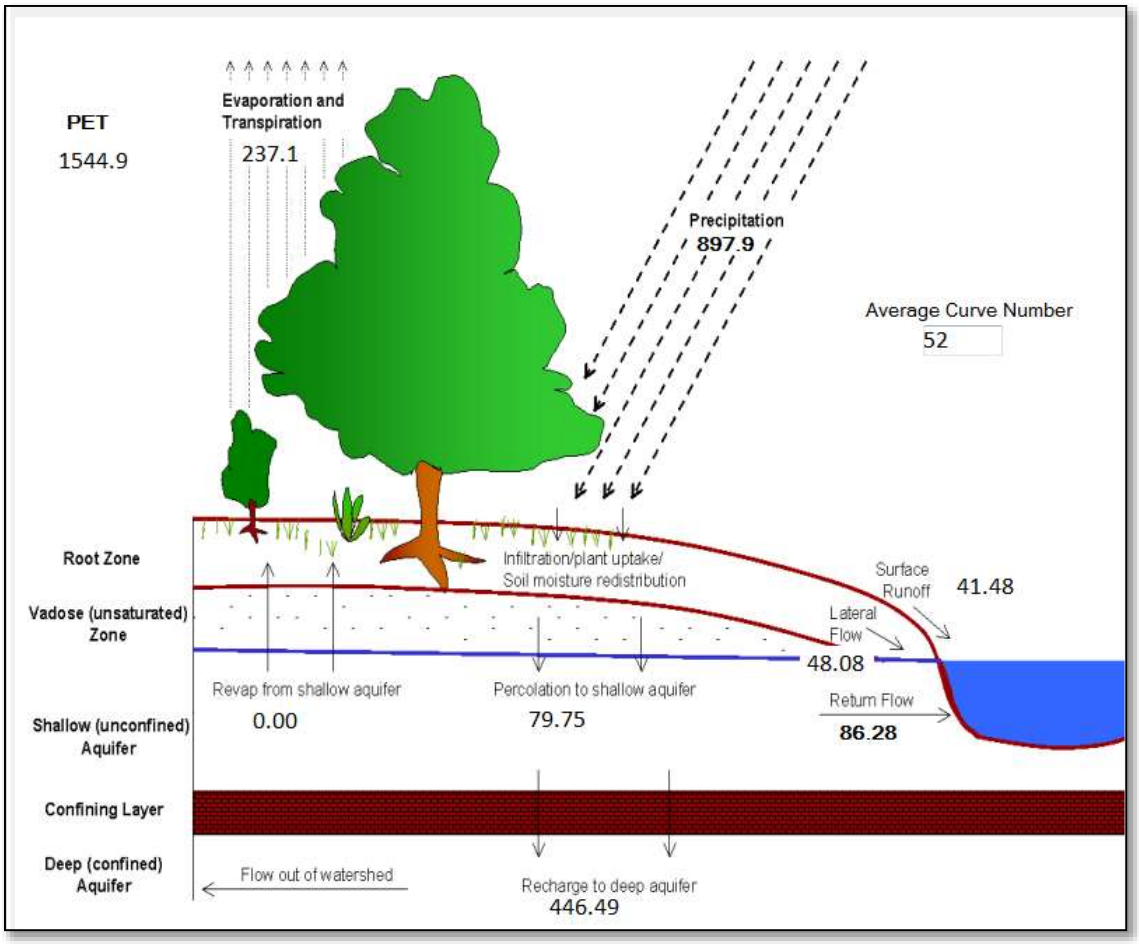

Figure 22.Water balance after calibration using SWATcheck

Table 3.Values used for calibration of the SWAT model.

Input	Parameters	Description	Used values	Limit interval
.GW	GW_DELAY	Groundwater delay time (days)	0	0-500
	ALPHA_BF	Base flow alfa factor	0.025	0-1
	GWQMN	Threshold depth of water in shallow aquifer required for return flow to occur (mm H2O)	150 : upper part 250 : lower part	0-5000
	GW_REVAP	Groundwater Revap coefficient	0.02	0.02-0.2
	REVAPMN	Threshold of water in the shallow aquifer for Revap or percolation to the deep aquifer to occur (mm H2O)	500	0 - 500
	RCHRG_DP	Deep aquifer percolation fraction	0.75: upper part 0.55 : low part	0-1
.SOL	SOL_Z	Depth from soil surface to bottom of layer (mm)	*0.75b y initial values	0-3500
	SOL_AWC	Available water capacity of the soil layer (mm H2O/mm soil)	*1.2 by initial values	0-1
	SOL_K	Saturate hydraulic conductivity 9mm/hr)	*0.8 by initial values	0-2000
.RTE	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	50	(-0.01) until 150
.HRU	LAT_TIME	Lateral flow travel time (days)	2.5	0-18
	EPCO	Plant uptake compensation factor.	0.5	0-1
	ESCO	Soil evapotransporation conpensation factor	0.5	0-1
.MGT	CN2	Initial SCS runoff curve number for moisture condition II.	*0.75 by the initial values	35-98

1.5 Validation

It is a comparison of the model outputs adjustments of the values of the parameters. The process continued till simulation of validation period stream flows confirmed that the model performs satisfactorily. The chosen validation period is from 01/09/1995 to 31/08/1996.

2 SWAT results

Two major problems were faced during the calibration of the model. First, the equifinality problem, we have the same results for different combination of parameters. Second, the quantitative criteria as (NSE, PBIAS and RMSE) showed acceptable values for the calibration with wrong hydrographs. For this reason, the simulation of calibrated parameters was conducted several times in order to have an acceptable hydrograph without giving much weight to the quantitative criteria. The calibration period hydrograph was divided into 1 year period graphs for a better interpretation of the results.

The simulated flow generally follows the pattern of the observed flow, but the model couldn't reach some peaks where the flow was high during a dry period 1979 (figure 26). Also for the same year surface runoff is overestimated; it cannot be reduced because it will affect the base flow. This applies also on the years 1978, 1981, 1884 (figures, 25, 28, 30). For other periods the flow is underestimated but the baseflow either follows the pattern or is overestimated.

The validation period was defined from 1995-1996 with daily steps to evaluate the performance of the model. Acceptable results were obtained comparing to the calibration.

Although the hydrograph represents a good simulation, the evaluation criteria are poor. Nash is affected by the high peaks observed on the graph. Trying to reach them will ruin the baseflow. So these quantitative criteria do not necessarily reflect a good simulation.

Table 4. Quantitative criteria results (Moriasi et al, 2007)

Criteria	Satisfactory Level	Calibration	Validation
NSE	>0.5	0.30	0.2
PBIAS	25%	4.3	9.7
RMSE	<0.7	0.81	0.97

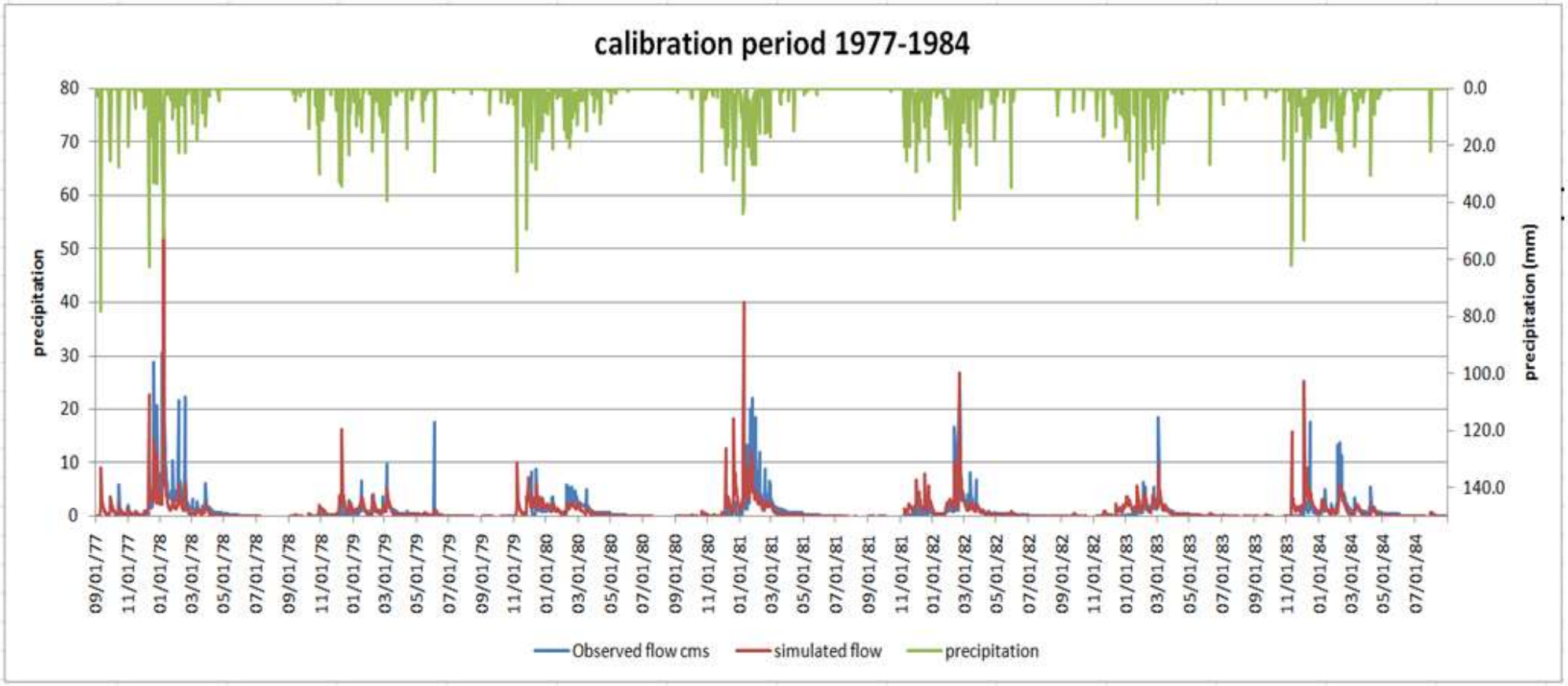

Figure 23. Simulated flow hydrograph of calibration period (1977-1984) Foinikia station.

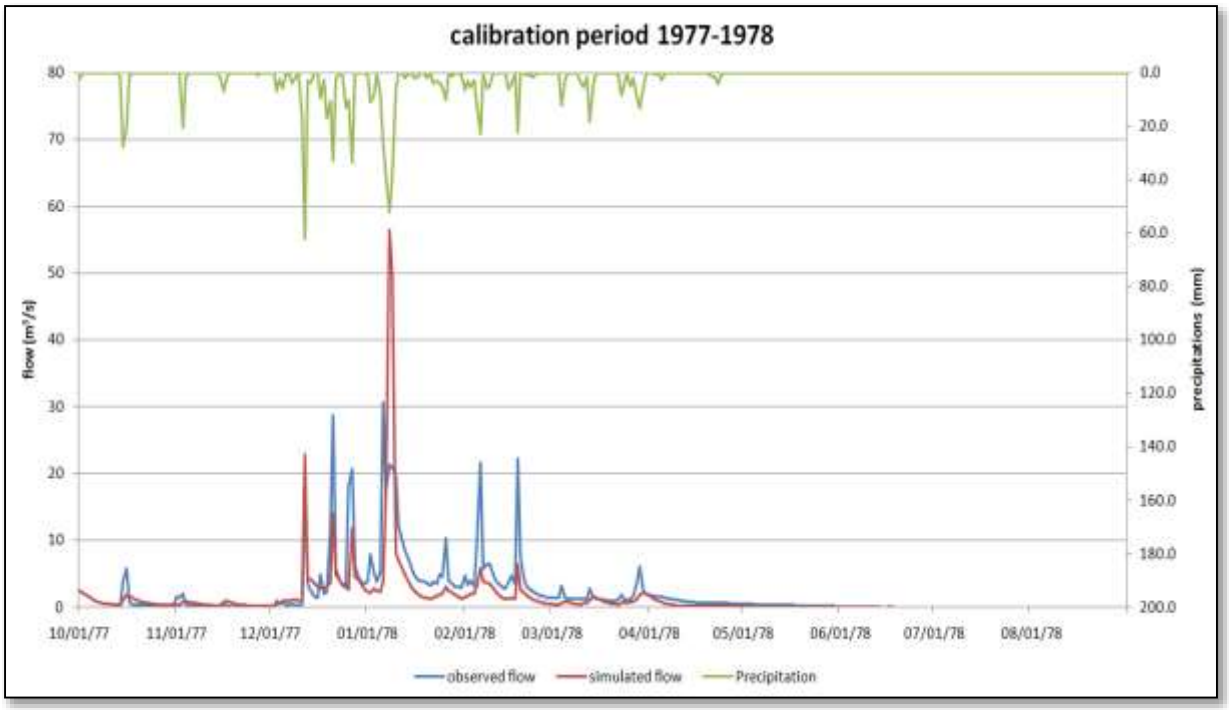

Figure 24. Simulated flow hydrograph of calibration period (1977-1978) Foinikia station.

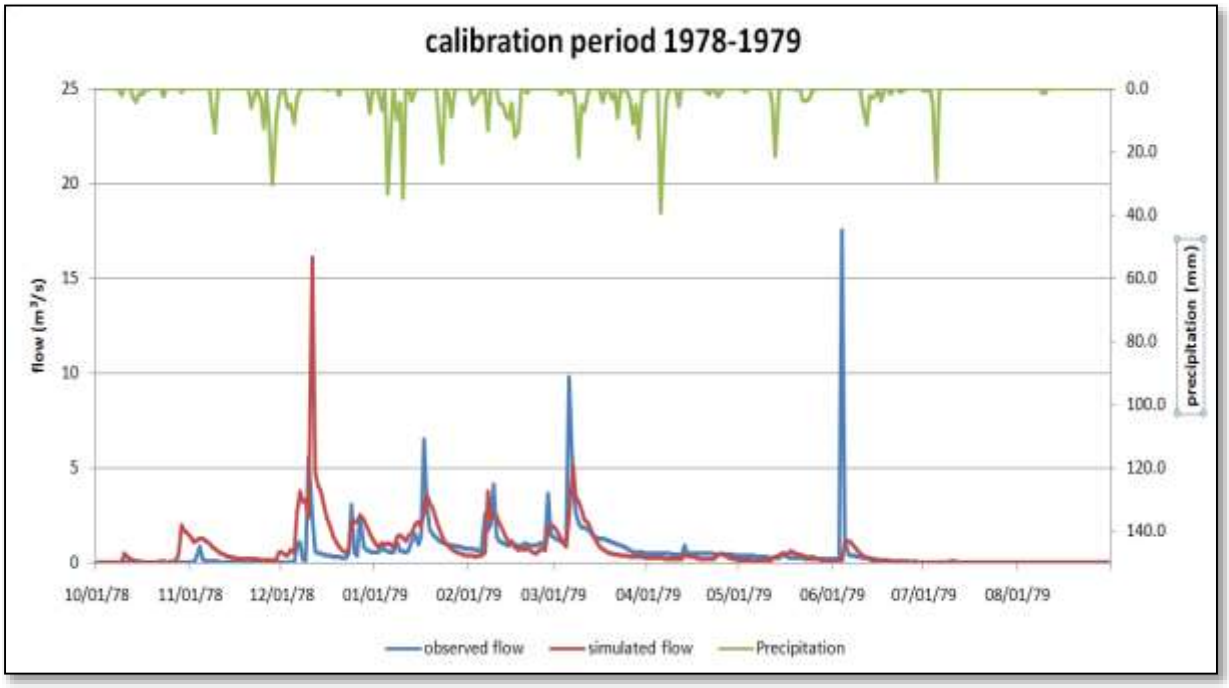

Figure 25.Simulated flow hydrograph of calibration period (1978-1979) Foinikia station.

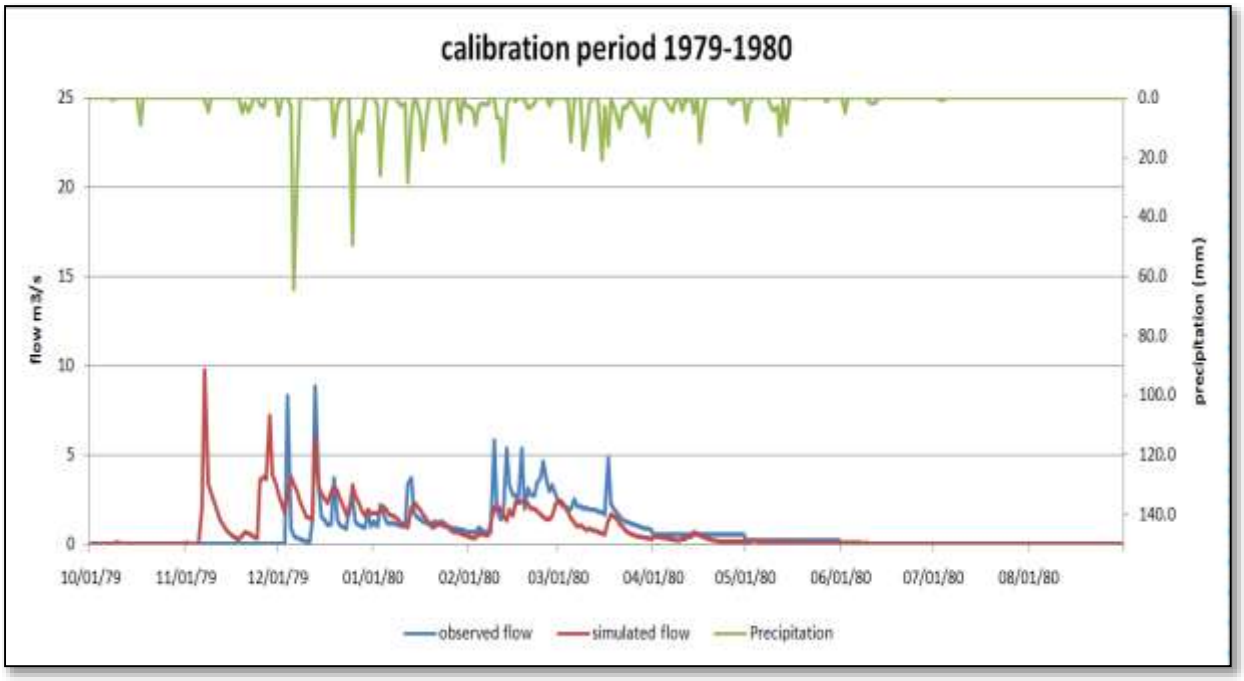

Figure 26. Simulated flow hydrograph of calibration period (1979-1980) Foinikia station.

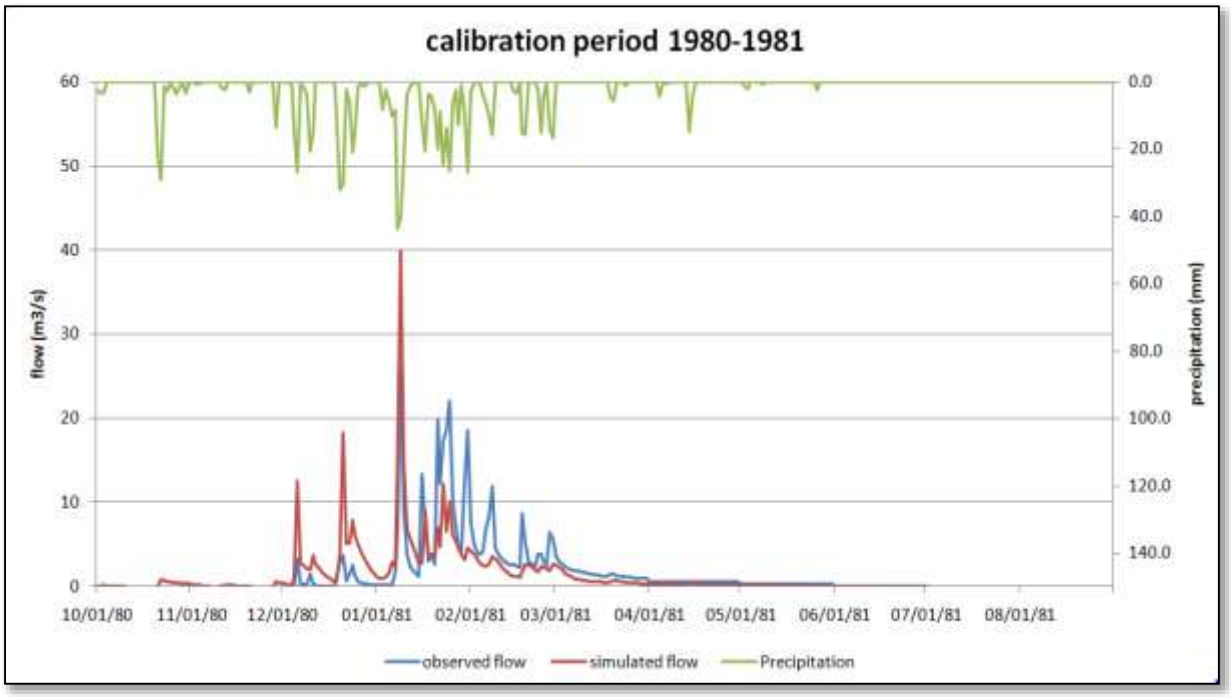

Figure 27Simulated flow hydrograph of calibration period (1980-1981) Foinikia station.

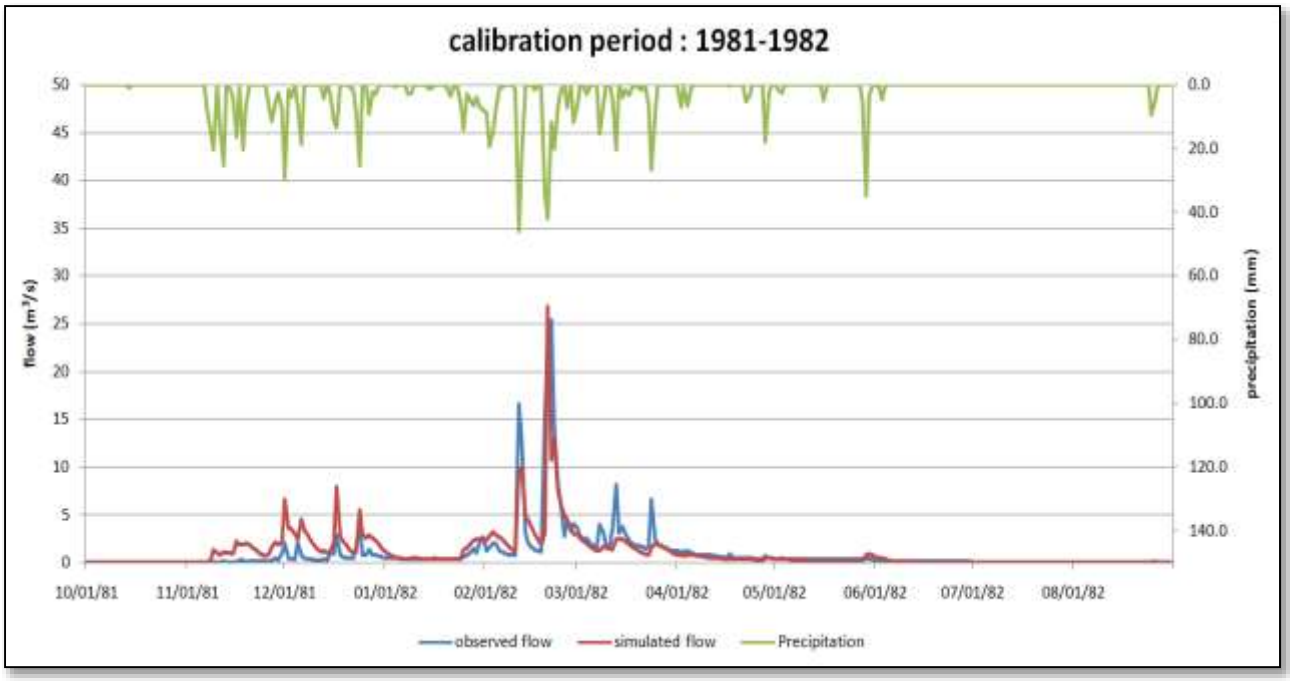

Figure 28.Simulated flow hydrograph of calibration period (1981-1982) Foinikia station.

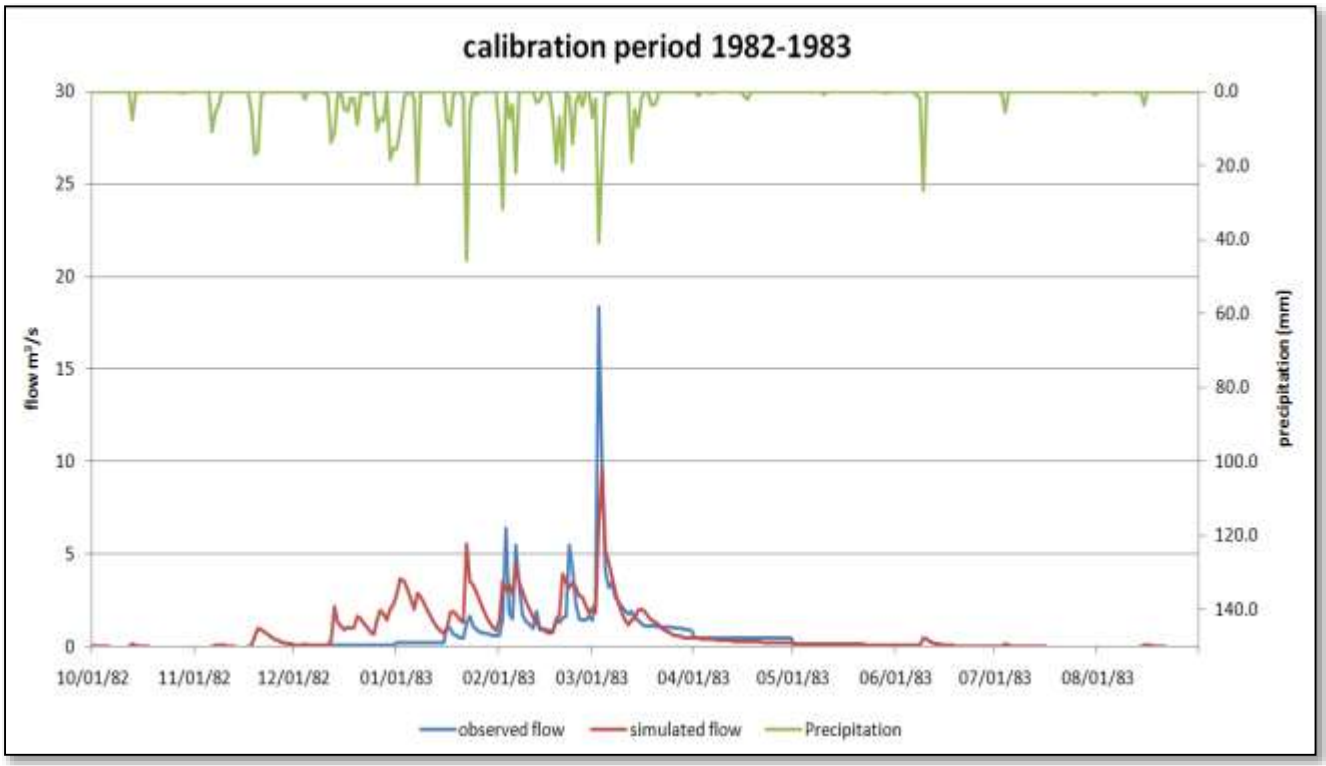

Figure 29. Simulated flow hydrograph of calibration period (1982-1983) Foinikia station.

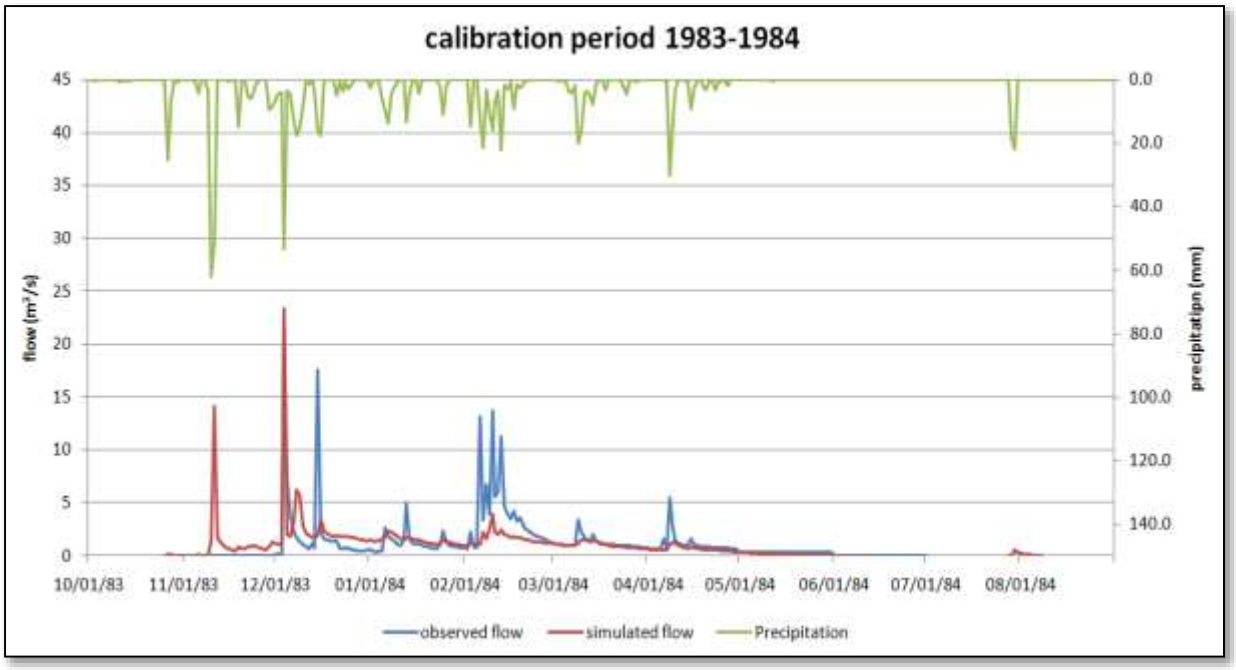

Figure 30Simulated flow hydrograph of calibration period (1983-1984) Foinikia station.

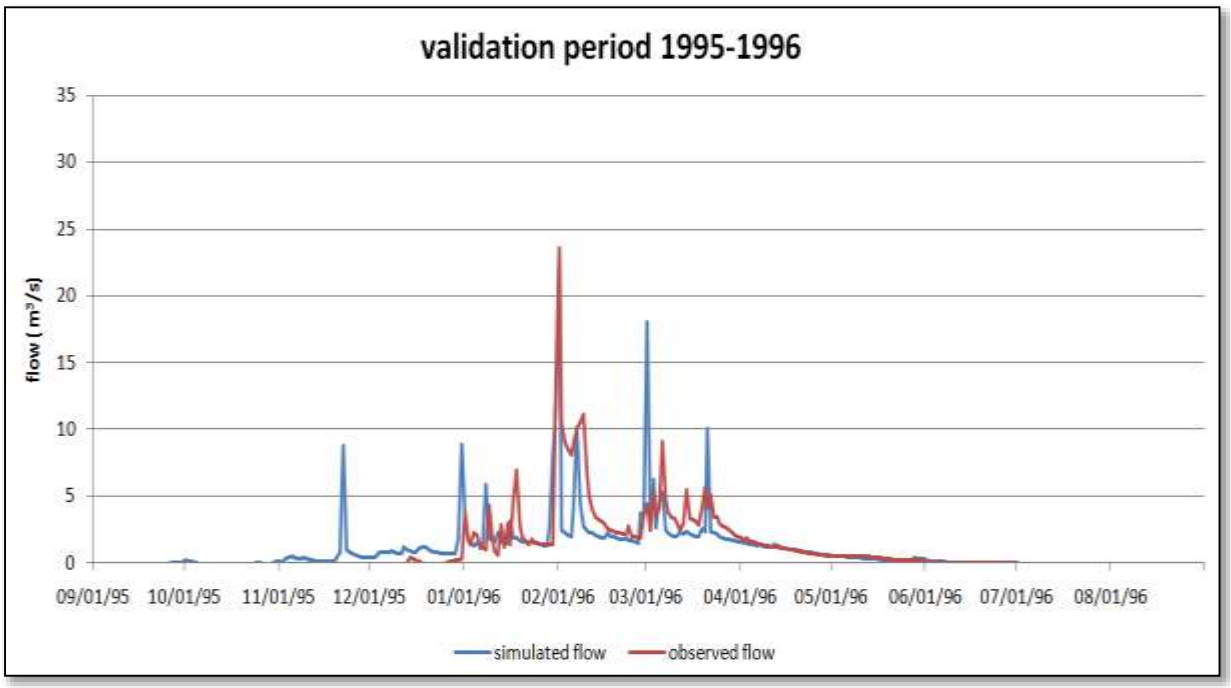

Figure 31Simulated flow hydrograph of validation period (1982-1983) Foinikia station.

3 Flood frequency analysis:

The objective of frequency analysis is to relate the magnitude of events to their frequency of occurrence through probability distribution. In order to do the flood frequency analysis for Xerapotamos, the simulated flow is used from the calibration of the model for the period of 1960-2011, from subbasin number 8, which is the closest to the outlet of the basin (figure 19). Then each year's maximum flow from the same calibration period is integrated in an excel file, where the formula for Gumbel distribution type I and log Pearson III are calculated using the method of moments.

The following graphs show the results of the Gumbel and log pearson III distributions represent the discharge in each return period with a confidence interval of 95%.

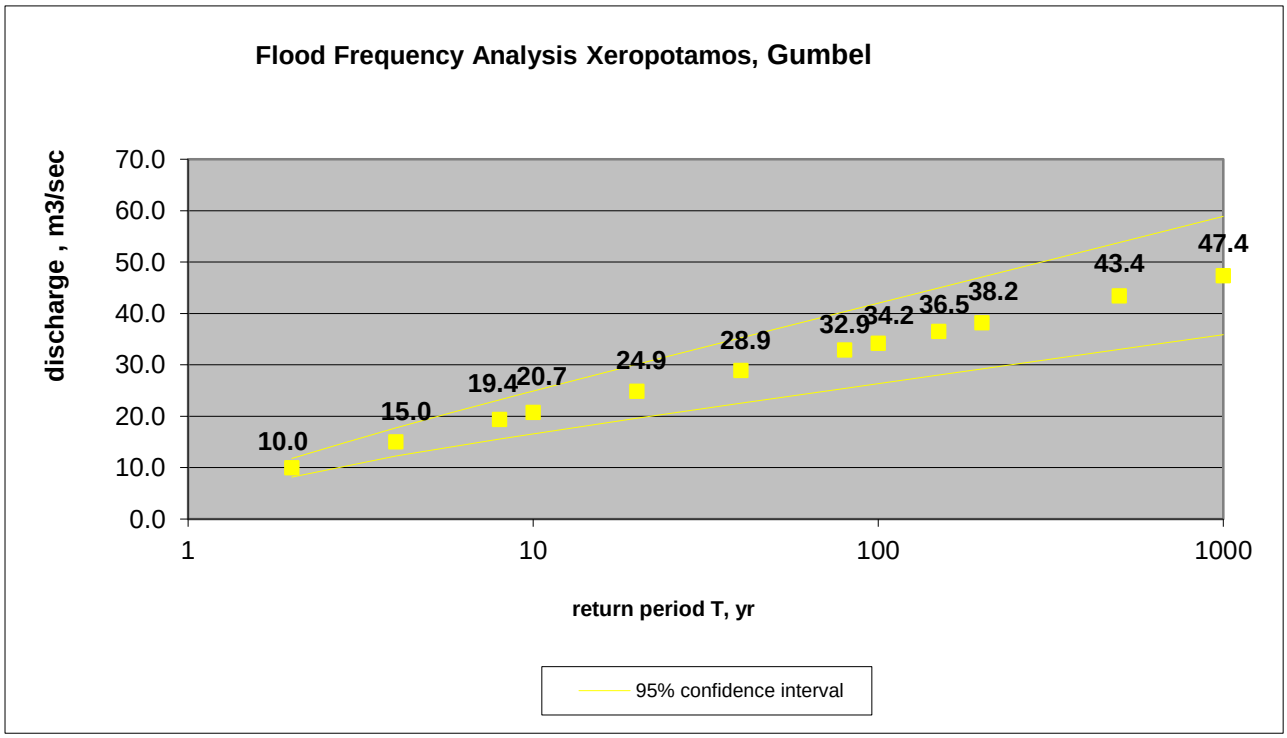

Figure 32. Flood frequency analysis Gumbel, for Xeropotamos estuary with modeled data of the period 1960-2011

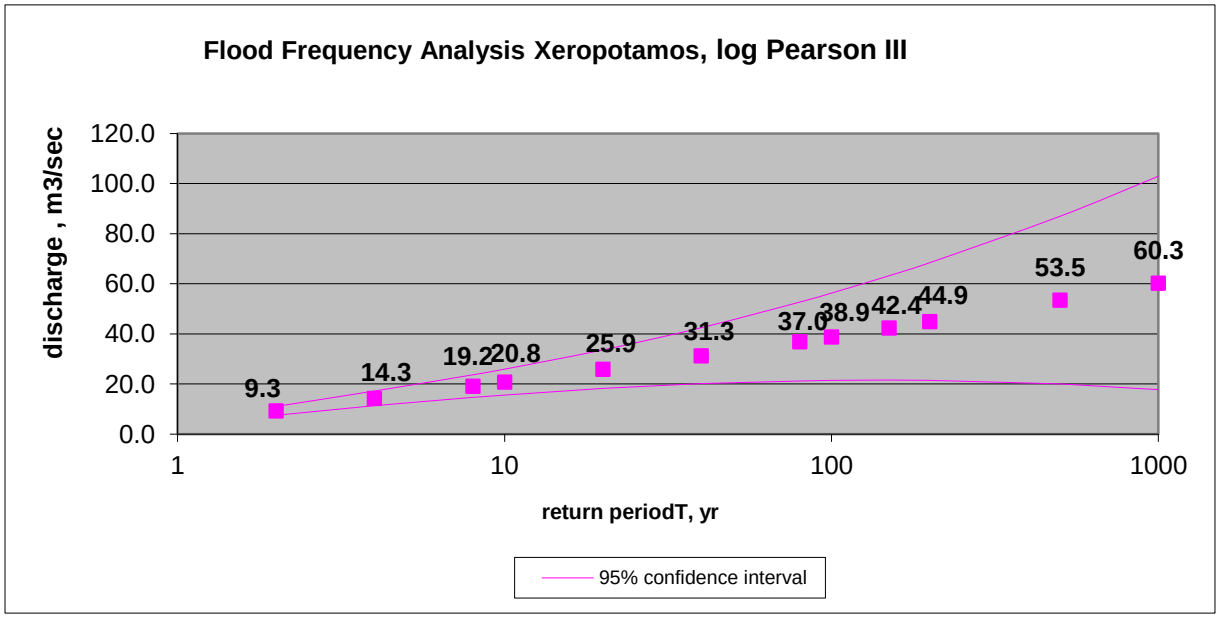

Figure 33. Flood frequency analysis log Pearson III, for Xeropotamos estuary with modeled data of the period 1960-2011

Comparing the Gumbel distribution and log Pearson III distribution, the interval of uncertainty is wider in log Pearson III than Gumbel. That indicates a better prediction for floods.

The log Pearson III predicts higher floods in a long return period, unlike the Gumbel. For example, for the return period of 100, it predicted a flood of 38.9 m^3/s.

Due to the lack of validation and historical data, the average predicted floods of both methods for each return period is suggested, in order to predict flood with high return period.

The Hyfran program is used in order to confirm the validity of the two graphs, the results (figure 34,35) are similar to the method of the moments used in Excel.

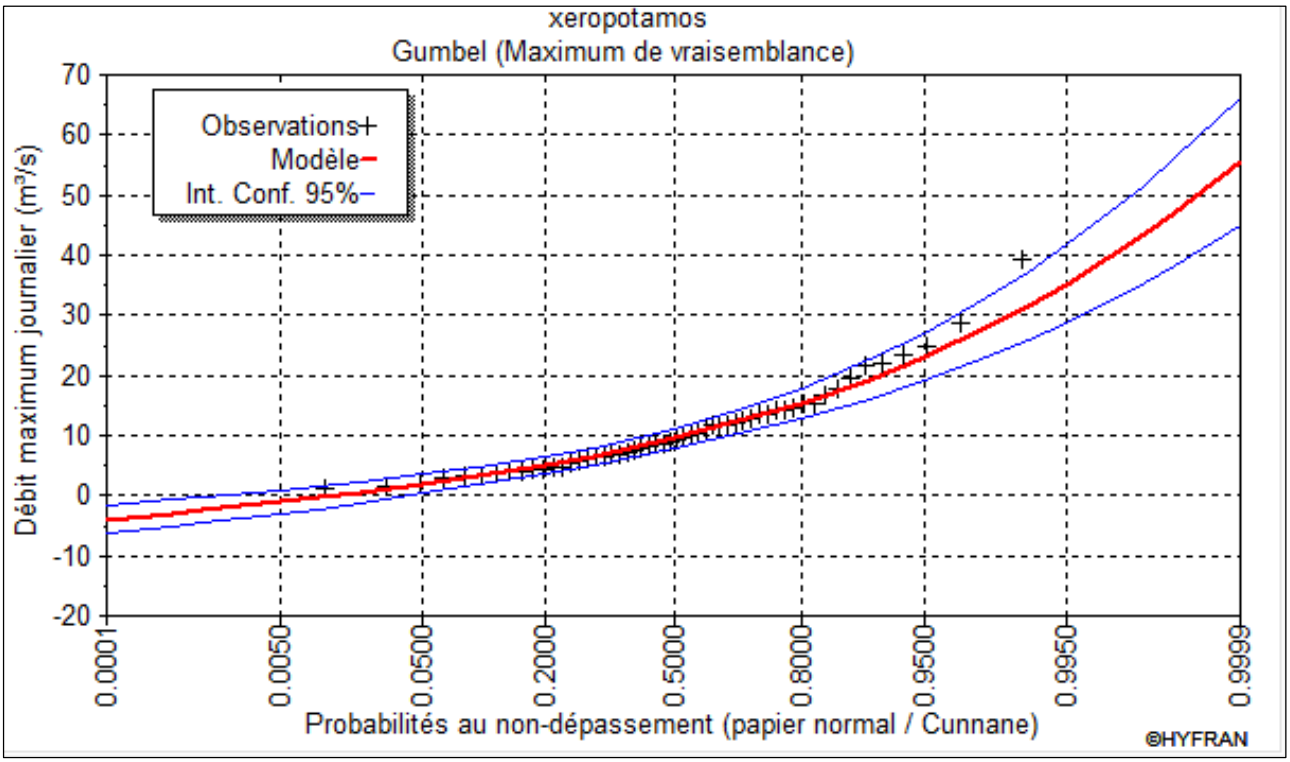

Figure 34. Flood frequency analysis Gumbel for Xerapotamos estuary with modeled data the period 1960-2011 using Hyfran

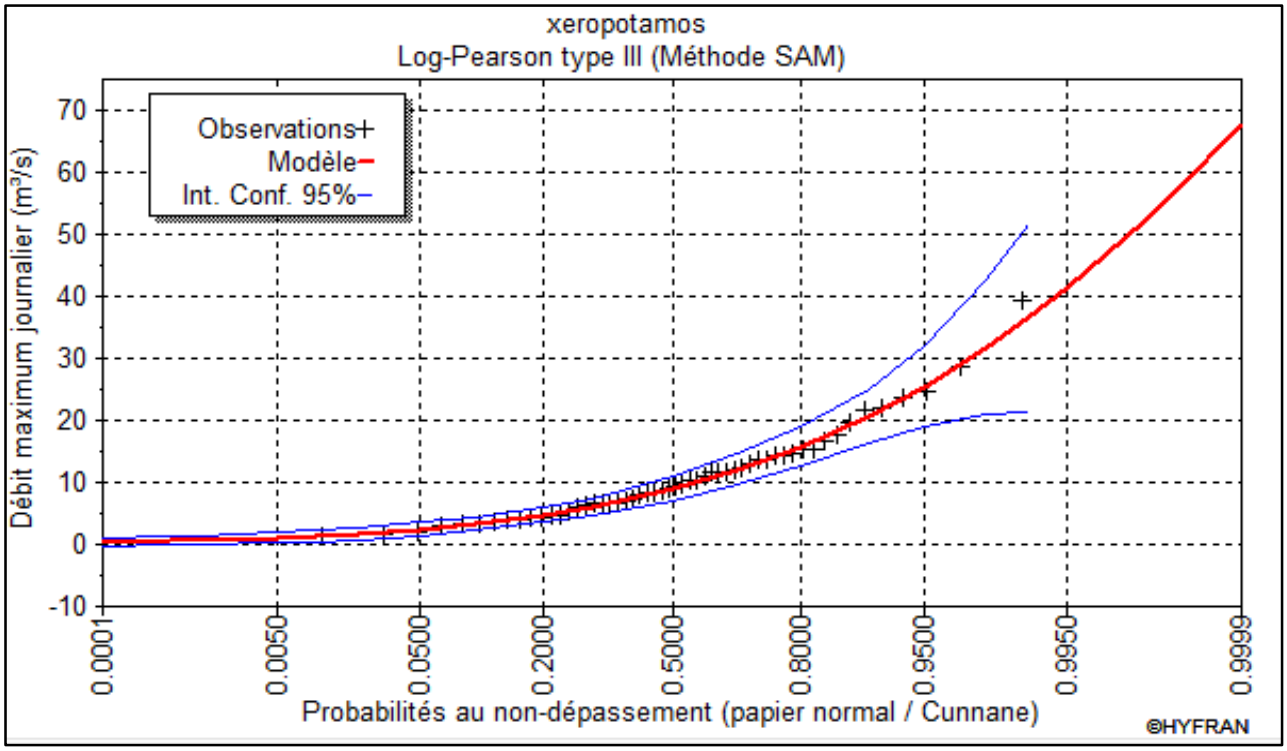

Figure 35Flood frequency analysis log Pearson III, for Xeropotamos estuary with modeled data of the period 1960-2011 using Hyfran

Conclusions

At the end of this work, the main conclusion is that SWAT (Soil and water assessments tool) model managed to simulate adequately the ungauged watershed Xeropotamos based on the juxtaposed watershed of Giofyros that have similar characteristics and data. The predicted values showed a quite good agreement with the observed data, based on qualitative criteria.

The calibration process needs a long time to provide as many cases as possible to reach the best scenario that satisfy both qualitative and statistical criteria. This was not the case for our study. We managed to satisfy only the qualitative criteria.

One of the problems of SWAT model is not considering the division of groundwater different subbasins, for this reason that the study area is divided into two parts depending on the altitude and soil characteristics. This technique is used to catch the late spring picks observed in the calibration hydrograph.

Another problem for SWAT model is not being able to simulate the single events and reach the high peaks of flow during dry period. These high peaks affect the values of nash-sutcliff and RSR for a value of 0.1 or more. According to this, we can conclude that we cannot always rely on quantitative criteria for evaluation of the calibration.

In another hand, Xerapotamos is an intermittent Mediterranean river that discharges into the beach of Amoudara, This area is one of the most important touristic areas of north Crete. The extreme flood events have a high probability of occurrence in this kind of rivers. In this case Swat can provide us with flow data to precede flood frequency analysis methods for watershed that we can only have meteorological data. The data provided by SWAT and flood frequency analysis can be used by engineering for flood protection the constructions against floods and for the design of flood risk maps.

For this work, Gumbel and log Pearson III distribution were used to predict the return period of extreme events. The average of these two methods is proposed based on the available data. Further study can be done on the validation of the hydrologic simulation of the watershed and further more on the sediment transport simulation for the estimation of the inland erosion contribution to the beach sand budget.

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