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MSc. Thesis

MODELLING ASSESSMENT OF WATER QUALITY AND QUANTITY AT THE BASIN SCALE

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Abstract

This thesis aims to implement and evaluate Nature-Based Solutions (NBS) to improve water quality and assess the adequacy of available water resources at the watershed level. The studied watersheds are located on the island of Crete, specifically in the Chania region. The implementation and evaluation of NBS were carried out in the Koiliaris watershed, which covers an area of 210 km² and falls within the municipality of Apokoronas. Previous studies have indicated that the Koiliaris watershed suffers from severe soil degradation and the measurement of sediments in Ag. Georgios station is high. Utilizing the Karst-SWAT model, after updating the hydrological modeling of the area, three different NBS (terraces, riparian forests, and livestock management) were evaluated regarding their impact on water quality. The results of the Karst-SWAT model demonstrated that the combination of terraces and riparian forests resulted in a maximum reduction of soil erosion and sediment load by 83%. The adequacy of available water resources was assessed within a Chania prefecture region, encompassing the Keritis and Koiliaris watersheds. The Keritis watershed, covering an area of 130 km², is part of the Platanias municipality. These basins represent typical Mediterranean river systems characterized by complex hydrogeology and serve as crucial sources for meeting the water demands of the Chania prefecture. Following the update of the hydrological modeling of the area using the Karst-SWAT model, the WEAP model was selected to manage and distribute the availability of water resources for the period 2000-2020. Furthermore, climate scenarios RCP4.5 and RCP8.5 were applied for the period 2020-2100 to assess future water resource availability under projected rainfall conditions. The WEAP model results indicated no unmet water demand for the current period and for the periods under the applied scenarios. Based on the results of this study, the SWAT (Soil and Water Assessment Tool) model has proven to be a reliable tool for simulating Nature-Based Solutions (NBS) within watersheds, while the WEAP (Water Evaluation and Planning) model has demonstrated its reliability as a tool for water management, offering a comprehensive framework for evaluating water allocation, demand, and supply scenarios.

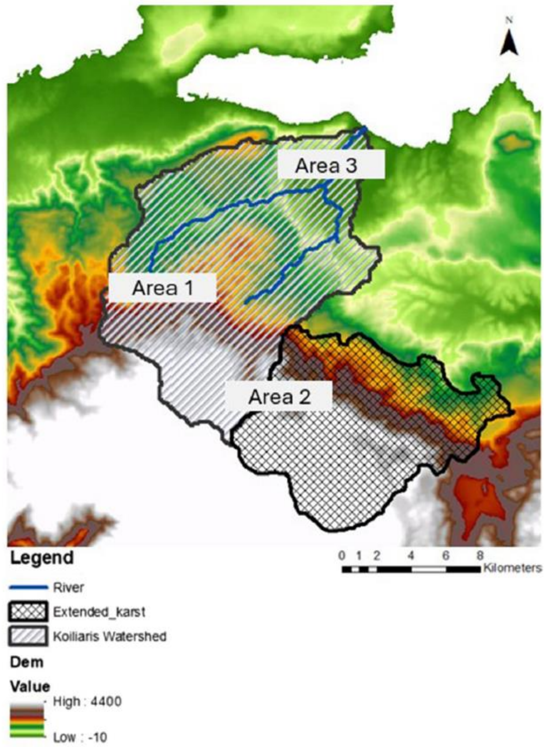
ΕΚΤΕΤΑΜΕΝΗ ΠΕΡΙΛΗΨΗ

Ένα από τα πλέον δυσκολότερα προβλήματα που αφορούν τους υδάτινους πόρους που καλείται η Ελλάδα να αντιμετωπίσει, είναι η διαθεσιμότητα και η διαχείριση αυτών. Τα τελευταία χρόνια, το φαινόμενο της κλιματικής αλλαγής έχει επηρεάσει αναμφισβήτητα τόσο την ποσότητα όσο και την ποιότητα των υδάτινων πόρων. Επομένως, η βελτίωση της ποιότητας τους καθώς και η βέλτιστη της διαχείρισης τους καθίστανται ένα από τα πρωτεύοντα ζητήματα διαχείρισης. Στο νησί της Κρήτης και πιο συγκεκριμένα στον Νομό Χανιών, συγκαταλέγονται οι δύο κυριότερες λεκάνες απορροής που είναι υπεύθυνες για την κάλυψη των υδάτινων αναγκών τόσο για ύδρευση όσο και για άρδευση του μεγαλύτερου μέρους του νομού. Οι λεκάνες απορροής αυτές, είναι η λεκάνη απορροής του Κοιλιάρη και η λεκάνη απορροής του Κερίτη.

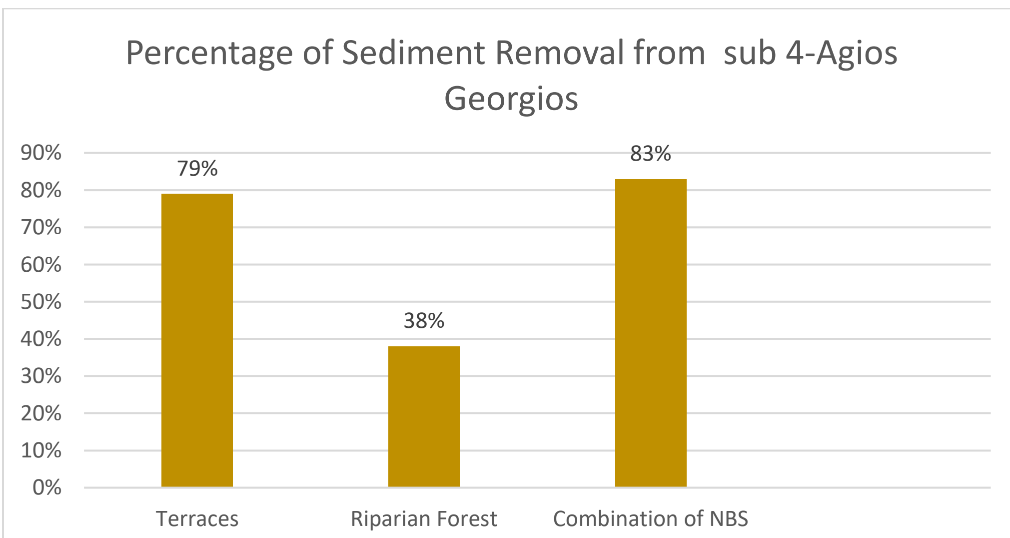
Σύμφωνα με πρόσφατες μελέτες στη λεκάνη απορροής του Κοιλιάρη, η οποία αποτελεί περιοχή εκτεταμένης έρευνας από το Πολυτεχνείο Κρήτης, έχει παρατηρηθεί η υποβάθμιση της ποιότητας των υδάτων που παρέχει, λόγω της ύπαρξης υψηλού φορτίου νιτρικών και ιζημάτων. Τα υψηλά αυτά φορτία, προέρχονται από την αλόγιστη και ανεξέλεγκτη βόσκηση ζώων καθώς και από τις λανθασμένες γεωργικές δραστηριότητες. Η Εικόνα 1, απεικονίζει τις περιοχές στις οποίες υφίστανται τα ανωτέρω προβλήματα. Η παρούσα διπλωματική, έχει ως στόχο την αξιολόγηση του αντίκτυπου στη μείωση των ιζημάτων και των νιτρικών που θα επιφέρει η εφαρμογή των Λύσεων Βασισμένων στη Φύση (NBS -Nature Based Solution) στις περιοχές 1 και 2 (Εικόνα 1).

Όσον αφορά την περιοχή 1 (Area 1), μέσω του μοντέλου SWAT προσομοιώθηκαν τρία διαφορετικά σενάρια. Το σενάριο 1, αφορά την εφαρμογή αναβαθμίδων στις υπολεκάνες που βρίσκεται ο ποταμός " Κεραμιανός" όπου από εκεί έχει καταγραφεί ότι προέρχονται αυξημένες ποσότητες ιζημάτων. Το σενάριο 2, αφορά την εφαρμογή παρόχθιου δάσους 20 μέτρων εκατέρωθεν του ποταμού και το σενάριο 3 αποτελεί τον συνδυασμό των δύο παραπάνω NBS. Τα αποτελέσματα της προσομοίωσης (Εικόνα 2), έδειξαν ότι ο συνδυασμός των δύο NBS θα επιφέρει τη μεγαλύτερη μείωση των ιζημάτων κατά 83%. Το ποσοστό απομάκρυνσης κατά την εφαρμογή των αναβαθμίδων ανέρχεται στο 79% ενώ κατά την εφαρμογή του παρόχθιου δάσους 38%.

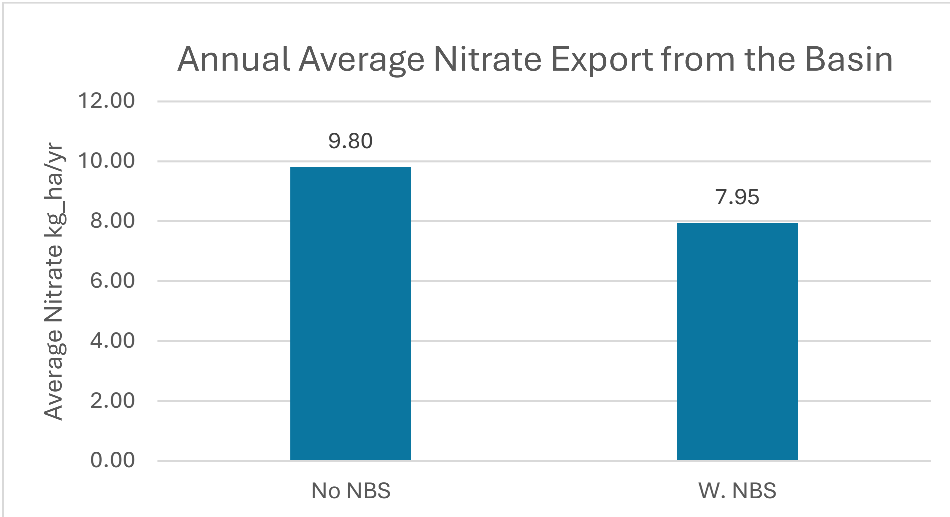
Όσον αφορά την περιοχή 2 (Area 2), στο μοντέλο του SWAT αφαιρέθηκαν όλες οι διεργασίες που σχετίζονται με τις δραστηριότητες λίπανσης από τα αιγοπρόβατα. Τα αποτελέσματα της προσομοίωσης έδειξαν ότι η απομάκρυνση αυτή, μειώνει περίπου κατά 19% (Εικόνα 3) την ύπαρξη των νιτρικών στην έξοδο της υπολεκάνης.



Εικόνα 1: Περιοχές στην λεκάνη απορροής του Κοιλιάρη με υφιστάμενα προβλήματα



Εικόνα 2: Ποσοστό απομάκρυνσης σωματιδίων στην υπολεκάνη του Αγίου Γεωργίου



Εικόνα 3: Μέση ετήσια έξοδος των Νιτρικών από τη λεκάνη απορροής.

Ο έλεγχος της επάρκειας της διαθεσιμότητας των υδάτινων πόρων, πραγματοποιήθηκε στην ευρύτερη περιοχή των Χανίων η οποία περιλαμβάνει τις δύο λεκάνες απορροής του Κερίτη και του Κοιλιάρη. Για τον έλεγχο αυτό, χρησιμοποιήθηκε το μοντέλο KARST-SWAT και το μοντέλο WEAP. Με τη χρήση του μοντέλου του KARTS-SWAT, υπολογίστηκαν οι παροχές εισροής σε κάθε ποτάμι και η συνεισφορά των καρστικών πηγών σε αυτό. Το μοντέλο WEAP, χρησιμοποιήθηκε στο κομμάτι της διαχείρισης και κατανομής των υδάτινων πόρων για την ενδιαφερόμενη περιοχή. Αρχικά, σε αυτό σχεδιάστηκε το δίκτυο κατανομής του νερού και στη συνέχεια αφαιρώντας τις αντλήσεις που πραγματοποιούνται για την ύδρευση και άρδευση της ευρύτερης περιοχής υπολογίστηκαν οι ανάγκες ύδατος που δεν έχουν ικανοποιηθεί για τα έτη 2010-2020 . Επιπλέον, εφαρμόστηκαν τα σενάρια κλιματικής αλλαγής RCP4.5 και RCP8.5 για την περίοδο 2020-2100, με σκοπό την αξιολόγηση της μελλοντικής διαθεσιμότητας υδάτινων πόρων. Τα αποτελέσματα του μοντέλου WEAP τόσο για την περίοδο 2010-2020 όσο και για την περίοδο 2020-2100 έδειξαν ότι δεν υπάρχει και δεν θα υπάρξει κάποια έλλειψη στη διαθεσιμότητα των υδάτινων πόρων.

Introduction

Climate change is an intricate and pressing global phenomenon that has garnered heightened attention and implications in recent decades across numerous sectors, particularly in water resources management. This phenomenon affects both the quantity and quality of water reserves. Climate change is already impacting Europe's ecosystems and is expected to pose further threats to biodiversity and ecosystem functioning in the future (Schröter et al. 2005, Grimm et al. 2008, Science for Environment Policy 2015). It also severely affects water scarcity, food scarcity (Hatfield et al., 2014) and numerous other sectors. Changes in temperature and precipitation patterns lead to more frequent and intense extreme events, such as droughts and floods, which affect freshwater availability, the health of wetlands and rivers, and ecosystem services (Knapp et al.,2010, McMichael et al., 2008). Flood events can mobilize substantial amounts of sediment from the land, which floodwaters then carry into water bodies. This sediment can obscure water clarity and impede light penetration (Georgakakos et al., 2014) For lakes and reservoirs, the most frequently reported changes are more intense eutrophication and algal blooms at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff (medium to robust evidence, high agreement). Increased runoff results in greater loads of salts, fecal coliforms, pathogens, and heavy metals (Pednekar et al., 2005; Paerl et al., 2006; Tibby and Tiller, 2007; Boxall et al., 2009). Changes in rainfall distribution cause some regions to experience prolonged dry spells, while others face intense and sporadic rainfall, complicating water management efforts (IPPC., 2007). Additionally, rising sea levels lead to saltwater intrusion into freshwater aquifers, further reducing the availability of potable water. These changes exacerbate existing water scarcity issues, particularly in arid and semi-arid regions, threatening agriculture, drinking water supplies, and overall ecosystem health. Significant changes have already been observed in the replenishment of groundwater reserves and the recharge of surface water bodies. Climate change accelerates the melting of glaciers and snowpacks, which are critical sources of freshwater. Increased evaporation rates reduce surface water levels in rivers, lakes, and reservoirs (Barker et al., 2016; Milly and Dunne, 2016; Lemordant et al., 2018; Berg et al., 2017).

Climate change profoundly affects every stage of the hydrological cycle, significantly influencing both the quantity and quality of water resources. These effects have become a significant concern for European emergency management authorities, leading policymakers to develop and implement innovative risk management strategies and solutions. To make informed decisions, it is essential to understand the system's dynamics and create frameworks that acknowledge the diverse benefits and co-benefits of nature-based solutions (NBS) for society.

Nature-based solutions (NBS), as defined by the IUCN, are actions inspired by, supported by, or modeled on natural processes and features. These solutions are resource-efficient and adaptable to various spatial contexts, effectively addressing societal challenges such as climate change, food and water security, and natural disasters. At the same time, they provide benefits for human well-being and biodiversity. NBS tackle global challenges by addressing social, environmental, and economic issues, leading to multiple benefits that strengthen ecosystem resilience. The European Union (EU) has embraced NBS as a strategy for promoting sustainable urbanization, restoring degraded ecosystems, adapting to and mitigating climate change, and enhancing risk management and resilience to extreme events.

According to Cohen-Shacham et al. (2016), several principles for Nature-based Solutions (NBS) are proposed. NBS should embrace nature conservation norms and policies, including measures or actions that address specific challenges. They can be implemented alone or integrated with other solutions to societal challenges, such as technological and engineering solutions. NBS are determined by site-specific natural and cultural contexts, incorporating traditional, local, and scientific knowledge. They should produce societal benefits in a fair and equitable manner, promoting transparency and broad participation. Additionally, NBS should maintain biological and cultural diversity and the ability of ecosystems to evolve over time. They should be applied at a landscape scale, recognizing and addressing trade-offs between producing a few immediate economic benefits for development and future options for producing a full range of ecosystem services. Finally, NBS should be an integral part of overall design.

Models that have already been used in the literature to simulate the impact of NBS implementation include Karst-SWAT, HEC-RAS, QUESTOR, and the XBeach hydro-morphological model (Unguendoli et al., 2023; Hutchins et al., 2024; Liao et al., 2024). Lilli et al. (2020b) used a combination of Karst-SWAT and HEC-RAS to design the restoration of a riparian forest and measures for flood protection for the Koilaris River Basin (Lilli et al., 2020b).

Before implementing NBS or any other structural measures, it is essential to conduct a hydrological study of the area under consideration to identify the actual pressures in the region. To achieve this, it is useful to apply models related to the management and allocation of available water resources, such as WEAP, MODSIM, and RIBASIM. The objective of the thesis is to illustrate how the hydrological model Karst-SWAT can be used for assessing ecosystem services provided by NBS in the Koiliaris River Basin of Crete, Greece, and to evaluate water management and distribution within the broader region of Chania Prefecture using the WEAP model.

The thesis contains two main chapters. The first chapter deals with the implementation and evaluation of Nature-Based Solutions (NBS) in the Koiliaris Watershed to improve water quality at the basin level. Specifically, it analyzes the description of the case study, the challenges faced, and the methodology applied in the SWAT model. Chapter 1 presents the published article in the Frontiers entitled: Optimizing the water-ecosystem-food nexus using nature-based solutions at the basin scale. The second chapter discusses the use of the WEAP model to describe and examine water resource management and assess the adequacy of water in the broader region. This chapter also analyzes the case study, the methodology used, and the scenarios applied.

Implementation and evaluation of Nature-Based Solutions (NBS) in Koiliaris Watershed to improve water quality at the basin level.

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1. Description of Case Study

Koiliaris Watershed

The Koiliaris River Basin is situated 15 km east of the city of Chania in Crete (Figure 1-1). The total watershed area covers 130 km2 with the primary water source originating in the White Mountains. Over the past two decades, from the last 20 years to the present day, the Koiliaris River watershed has undergone a comprehensive investigation (Lilli et al., 2020a; Lilli et al., 2020b; Giannakis et al., 2014; Vozinaki et al., 2015; Moraetis et al., 2015; Kourgialas et al., 2011; Nerantzaki et al., 2015; Nerantzaki and Nikolaidis, 2020; Morianou et al., 2017; Vozinaki et al., 2011; Sibetheros et al., 2013; Yu et al., 2019). The study area encompasses karst systems with a distinctive characteristic: a spring may receive contributions from karst formations extending beyond the boundaries of the watershed to which the spring belongs (Steiakakis et al., 2023; Steiakakis et al., 2018). Alternatively, the spring may also be supplied by stacked karst systems, each possessing unique hydraulic properties and transmissivities (Kourgialas et al., 2010). This characteristic underscore the significance of identifying the extended karstic area contributing to a spring's discharge. This identification is crucial for accurately assessing the hydrological and geochemical balances within the system. The karst system is distinguished by rapid infiltration and a direct connection to underlying conduits. Within this system, two primary groups of springs are discernible: the Stylos springs, situated at an elevation of +17 meters above mean sea level (a.m.s.l.), and the intermittent spring known as Anavreti, situated at an elevation of +24 meters a.m.s.l. Both springs ultimately contribute to the flow of the Koiliaris River. The combined recharge area for these springs extends beyond the boundaries of the Koiliaris River Basin, stretching southeastward from the watershed boundary. The geological composition of the region, coupled with a significant fault running in a northeast–southwest direction, directs water movement toward the springs within the Koiliaris River Basin.

The predominant soil type is Calcaric Regosol, covers most of the area. Euri-Lithic Leptosol appears in small, concentrated sections in the northern part of the region. The Calcaric-Lithic Leptosol, is primarily located in the western areas. In contrast, the Euric-Cambisol soil class, is found in a few specific patches in the southern part (FAO 2008). Additionally, Calcari Regosol, another form of regosol similar to Calcaric Regosol but distinct, is scattered across various parts of the map (Figure 1-2). Geologically, the area features consist of 71.8% Plattenkalk which is comprised mainly of dolomites, marbles, limestone, and re-crystallized limestone with cherts 9.5% calcaric marls in Neogene formations; 6.1% marls in Neogene formations 6.1% schists and 6.4% quaternary alluvial deposits (Figure 1-2). Land use (Figure 1-3) includes cropland and pasture (35%), olive and orange groves (32.1%), shrub and brush (32.3%), and mixed forest (0.6%). The total length of the river is 36 km. Koiliaris is joined by four tributaries, two of which are temporary rivers (Keramianos and Anavreti), and two are permanent ones. The basin incorporates three telemetric hydrometric stations and three telemetric meteorological stations (Nerantzaki et al., 2020). Furthermore, two hydrometric stations are positioned outside the basin, with one situated within the extended karstic area.

The main challenges in Koiliaris Watershed that we need to tackle according to Lilli et al. (2024) detected in Area 1: the western part of the basin presents intense soil degradation (Nerantzaki et al., 2015; Moraetis et al., 2015; Sibetheros et al., 2013)

Area 2: the southern part of the basin presents biodiversity degradation resulting from free-grazing livestock at the higher elevations of the basin. Area 3: the northeastern part of the basin presents land degradation due to unsustainable agricultural practices (Figure 1-4).

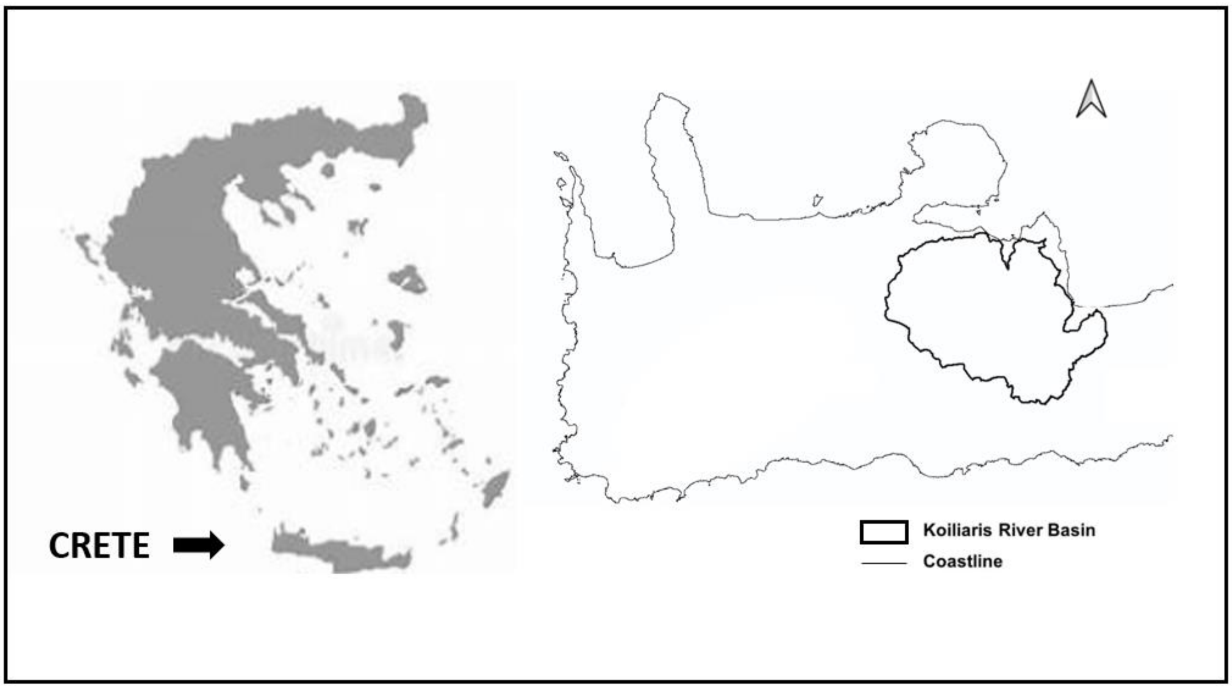

Figure 1-1: Location of Koiliaris Watershed

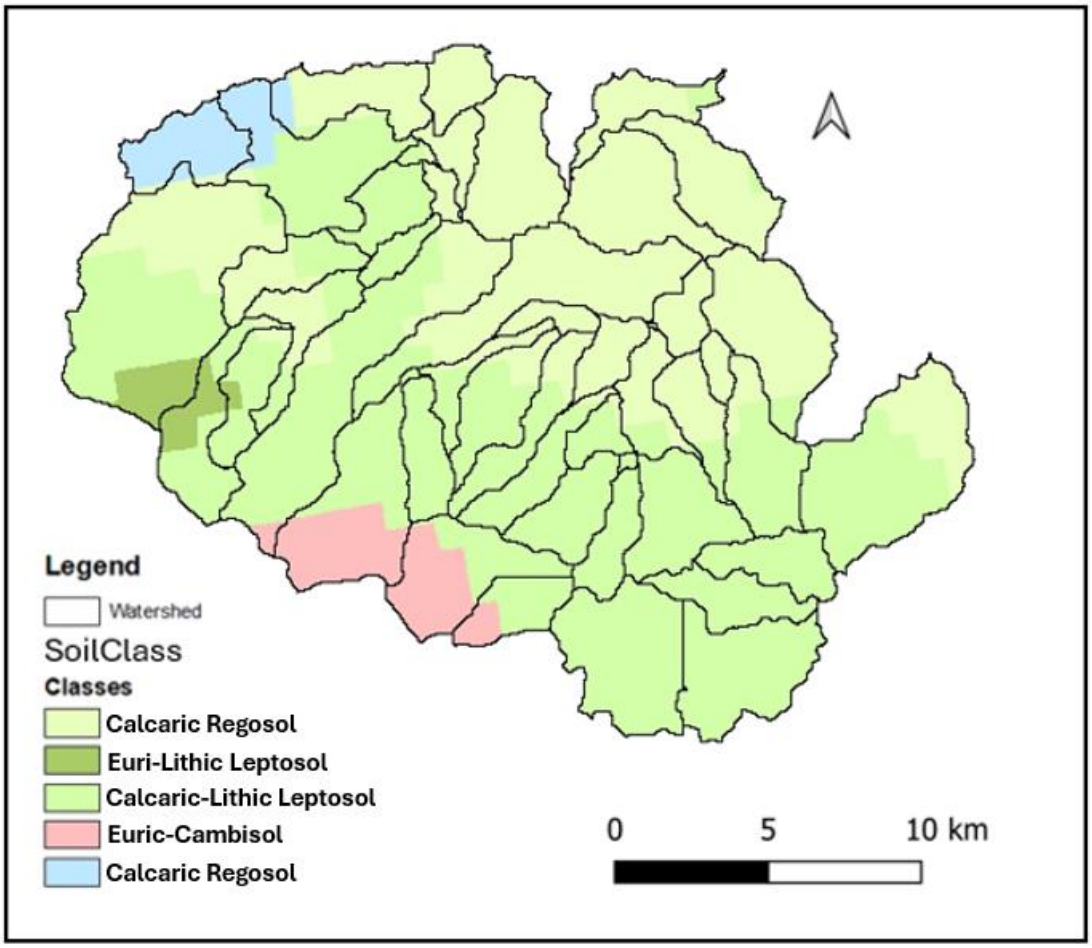

Figure 1-2: Type of Soils of Koiliaris Watershed

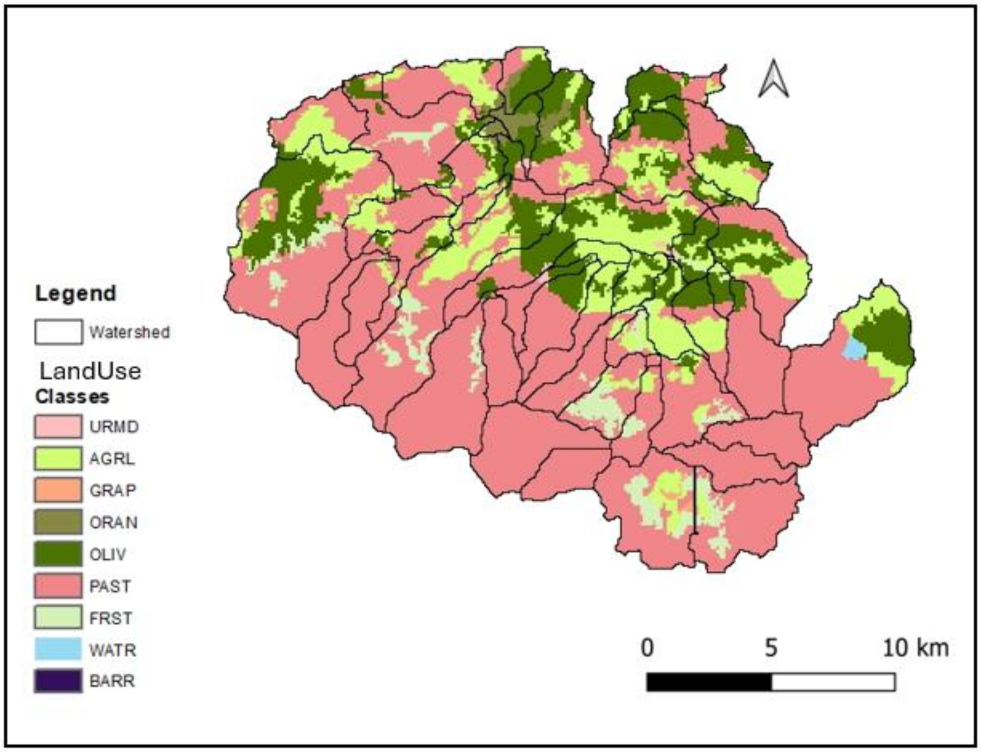

Figure 1-3: Type of Land use of Koiliaris Watershed

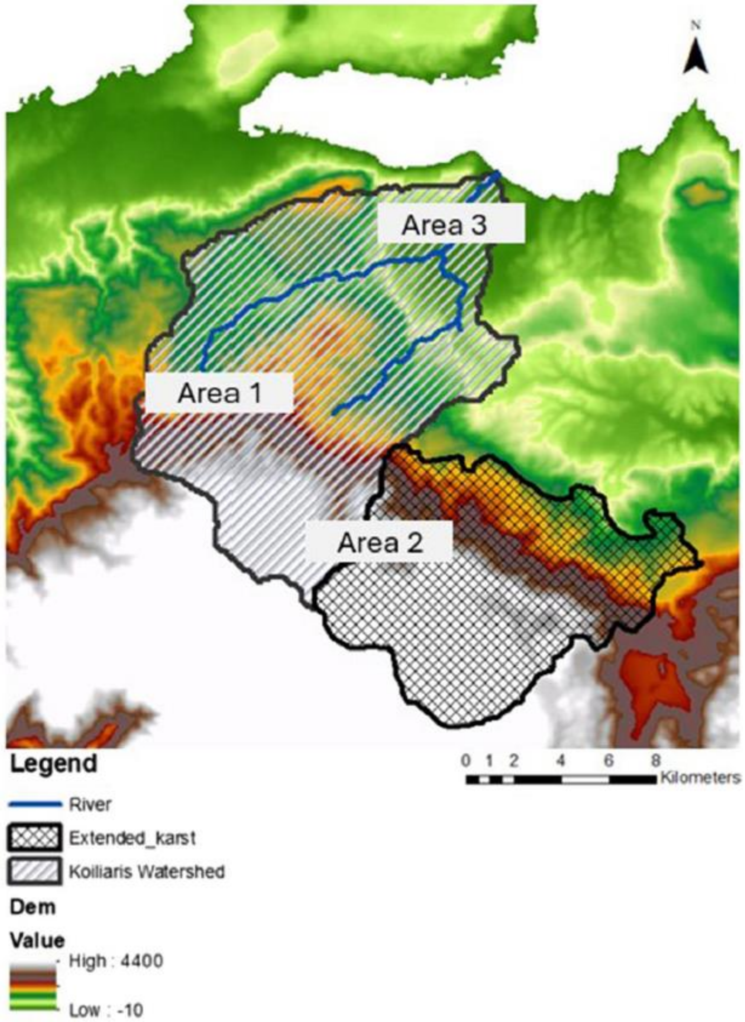

Figure 1-4: Approximate extent of the areas of the watershed related to the main challenges to be addressed at the Koiliaris River Basin.

2. Model Description

Karst-Swat model

The SWAT (Soil and Water Assessment Tool) model (Neitsch et al., 2011) is a widely utilized hydrological model designed to simulate and predict the impact of land management practices on water resources at the watershed scale. Developed by the United States Department of Agriculture (USDA), SWAT integrates various components, including hydrology, weather, soil, vegetation, and land use to simulate the complex interactions within a watershed (Figure 2-1). The model utilizes spatially distributed data on topography, soil properties, weather conditions, and land use to simulate processes such as water flow, sediment transport, nutrient cycling, etc. It's important to note that the SWAT model cannot simulate karst formation (Nikolaidis et al., 2013). This limitation arises from the assumption that water surpassing the deep aquifer is lost from the system. In karstic formations, water from the deep aquifer contributes to the main river flow through a pothole. To address this, the karstic model was introduced (Nikolaidis et al., 2013), retrieving water from the deep aquifer and directing it into two reservoirs, subsequently feeding the surface flow again. In the case study, specifically in the gorge of the watershed where karstic formations exist, the majority of the surface flow passes through a pothole and discharges downstream. Figure 2-2 illustrates the connection between the SWAT model and the karstic model.

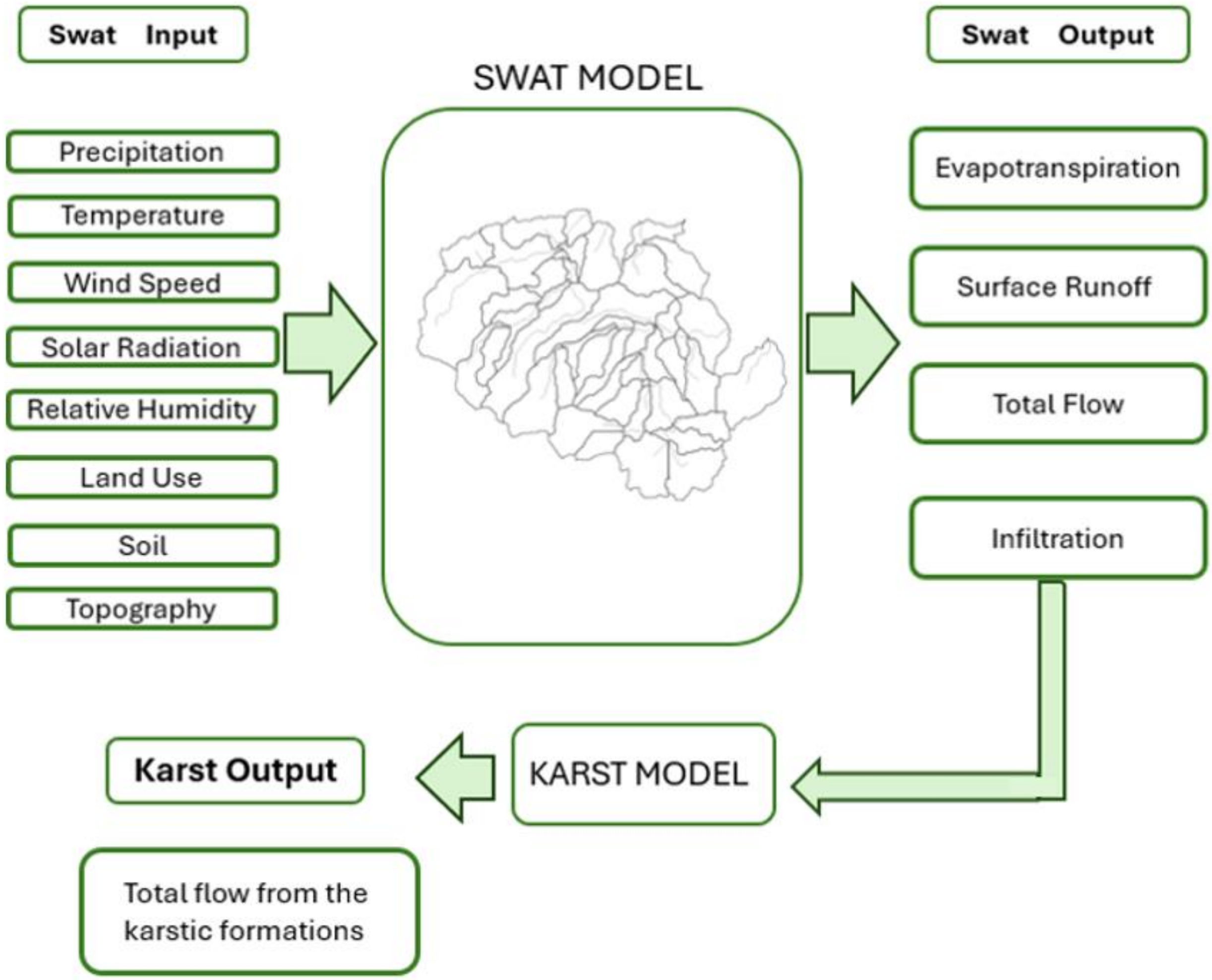

Figure 2-1: Input and Output data of SWAT and Karst-Swat model

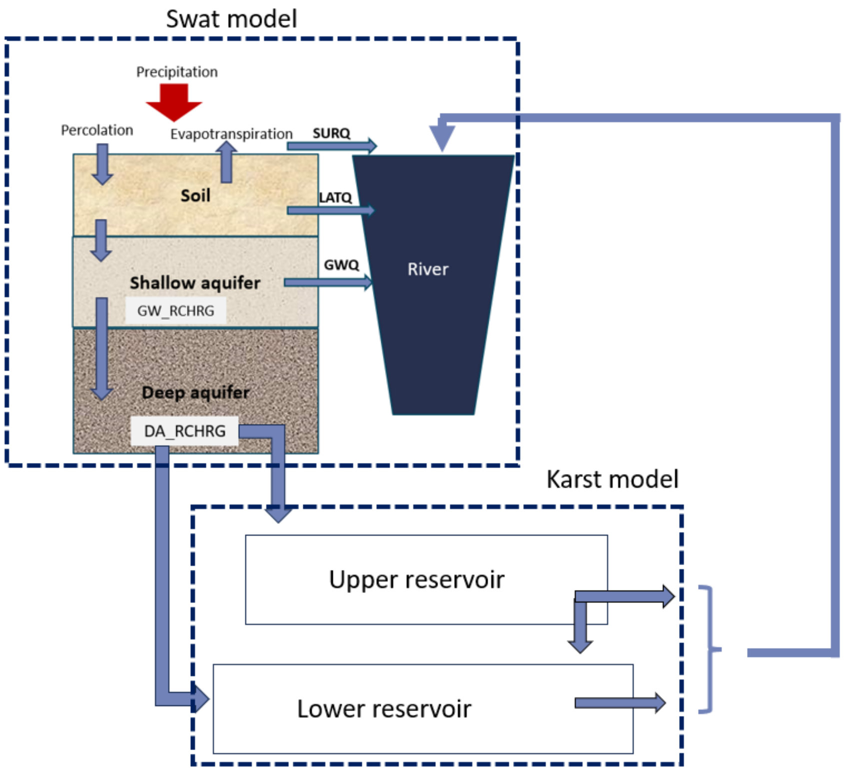

Figure 2-2: The connection between the SWAT model and the karstic model.

3. Methodology approach

As mentioned above, some of the pressures in the Koiliaris River basin that this thesis attempts to improve are those in areas 1 and 2. The methodology can be described in five stages (Figure 3-1).

Step 1: Identification of the pressures to be studied. The watershed pressures to be examined are intense soil degradation (Nerantzaki et al., 2015; Moraetis et al., 2015; Sibetheros et al., 2013) in "Area 1" and the degradation of biodiversity resulting from free-grazing livestock at higher elevations of the basin in "Area 2."

Step 2: Regarding Area 1, the NBS (Nature-Based Solutions) that were feasible to implement in the SWAT model and are "compatible" with the study area include the riparian forest and terraces. Three scenarios were examined:

- Scenario 1: Implementation of riparian forest

- Scenario 2: Implementation of terraces
- Scenario 3: Combination of NBS (terraces and riparian forest)

For Area 2, the strategy involved discontinuing the free grazing of livestock at high elevations and transitioning to organized caged livestock systems at lower elevations. This strategic shift aimed to alleviate the environmental pressures from livestock grazing in the highlands, thereby allowing the gradual restoration of biodiversity and facilitating the recycling of manure for agricultural reuse. To model this NBS within the calibrated SWAT, all model operations associated with manure fertilization from sheep and goats in the designated area were eliminated.

Step 3: For the implementation of NBS, it was necessary to update the calibration of the hydrology and chemistry of the watershed up to 2021.

Step 4: Evaluation of NBS results in water quality and final selection.

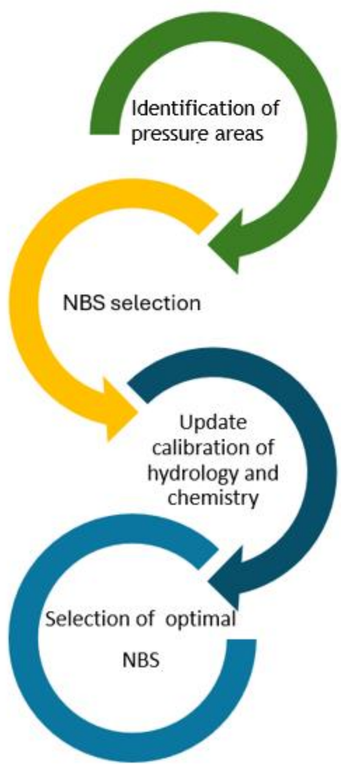

Figure 3-1: Methodology roadmap

Implementation NBS in Area 1

After completing the setup of the model, it emerged that the Koiliaris River Basin consists of 47 sub-basins for which the necessary calculations of the SWAT model are performed. Figure 3-2 displays the map with all the sub-basins in the study area. The sub-basins for which the results will be presented are sub-basins 4 (The point of intersection between Keramianos and Stylos Springs) and sub-basins 9 & 15, which make up the Keramianos and is the degraded area.

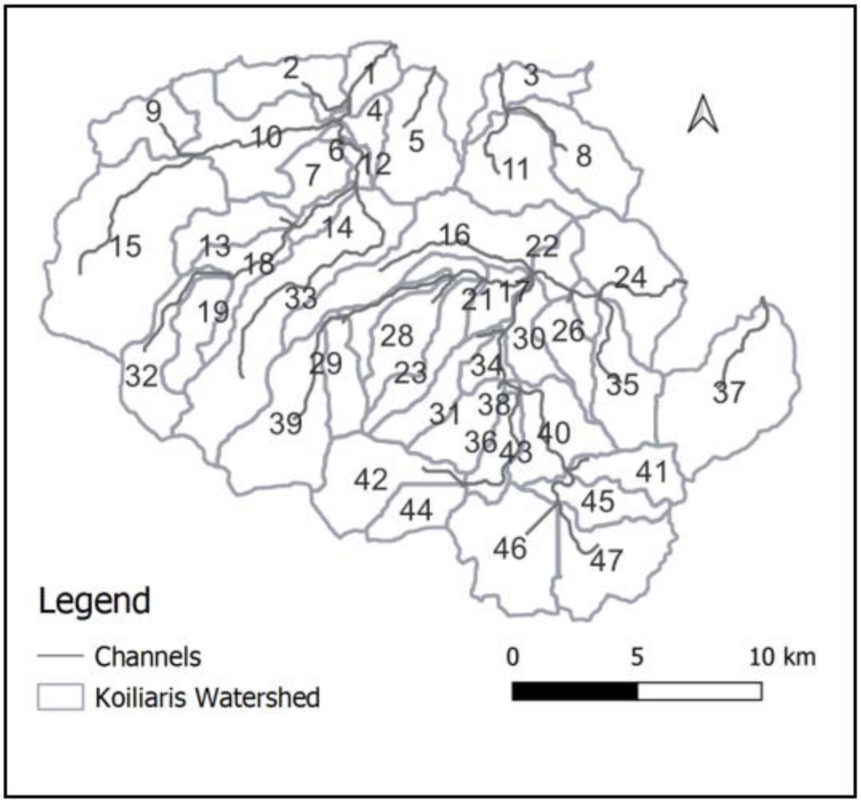

Figure 3-2: Sub-basins of Koiliaris Watershed.

The model was calibrated and verified for the KoiIlaris river basin regarding the hydrology, sediment transport, and nutrient concentrations (Nikolaidis et al., 2013; Nerantzaki et al., 2015). As part of this work, the SWAT model simulation was extended to 2020. Specifically, the 1973-2010 date was used to calibrate the model, whereas the 2010-2020 date was used for model validation. Figure 3-3 and 3-4, depict the simulated flows versus the observed data at Ag Georgios and Keramianos Tributary hydrologic stations. The simulation results suggest that the model can adequately describe the hydrology of the watershed. The goodness of fit of the calibration was tested against three statistical metrics proposed by Moriasi et al.: the Nash Sutcliffe Efficiency (NSE), Percent Bias (PBias), and RMSE Standard Deviation Error (RSR). A simulation is considered adequate if NSE<0.5, Pbias <25% and RSR<0.7. For the 2010-2020 validation period, the NSE was 0.82, Pbias 12.6% and RSR 0.42. The simulation characterized "Very good". Table 3-1 presents the maximum, mean and minimum flow for the years 2010-2020 at the two stations.

Table 3-1: Minimum, mean and maximum flow at the two stations.

Hydrometrics Stations	**Max Simul. Discharge m³/s**	**Mean Simul. Discharge m³/s**	**Min Simul. Discharge m³/s**
Ag.Georgios	36.04	2.65	0.12
Keramianos Tributary @ gorge entrance	10.66	1.33	0.01

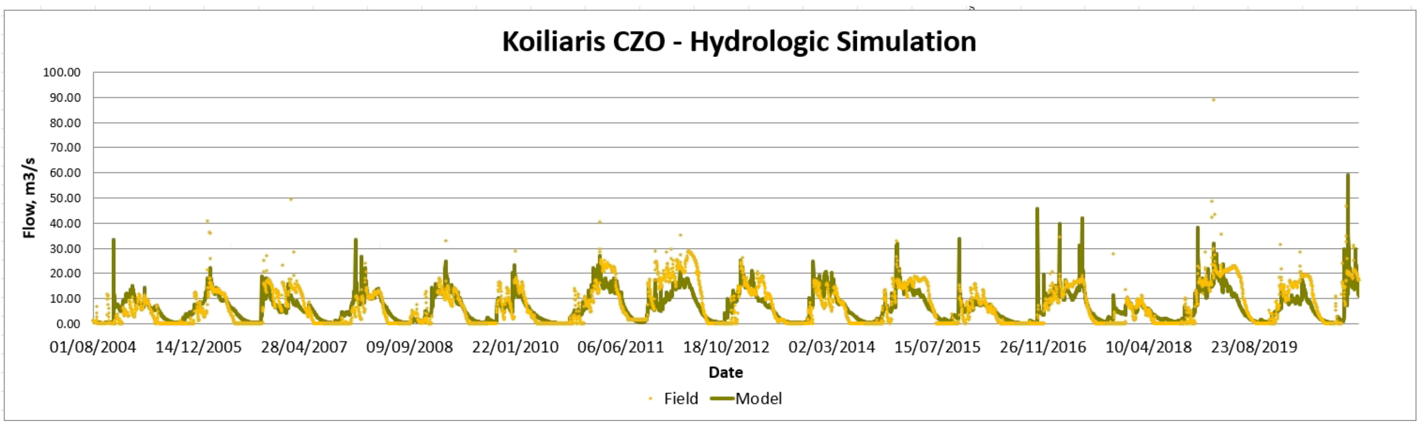

Figure 3-3: Hydrologic Simulation at St. Georgios station for the 2004-2021 period.

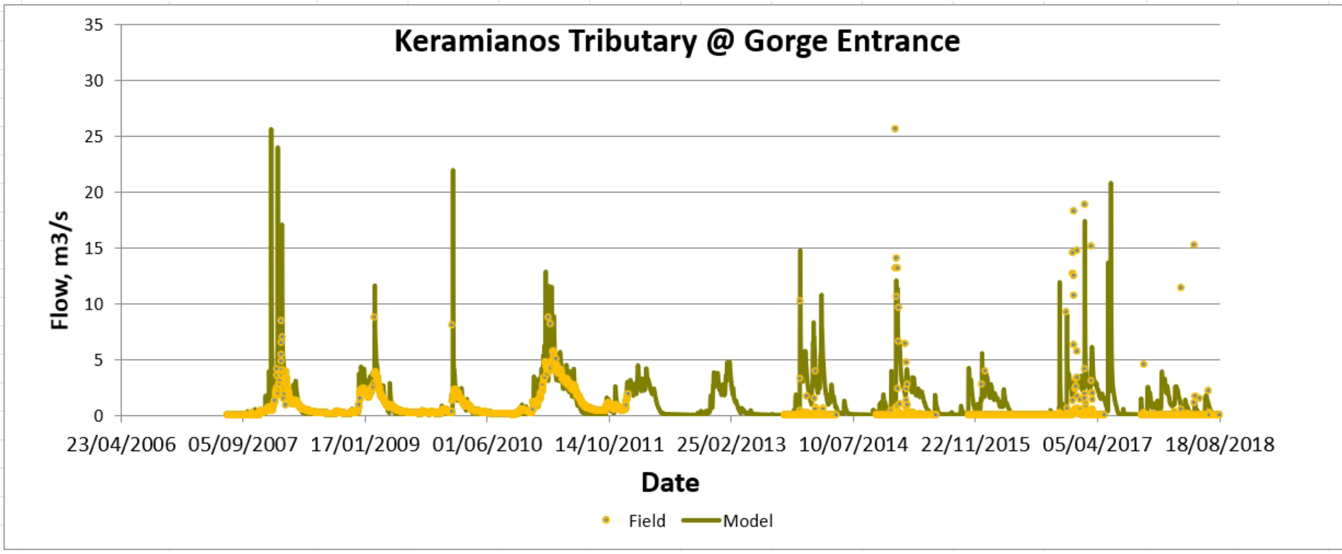

Figure 3-4: Hydrologic Simulation at St, Keramianos Gorge Entrance.

Suspended sediments were monitored at the Ag. Georgios hydrometric station during December 2011 and February 2013 using grab samples monthly. This data was used for the calibration of the model. The sampling point is located just downstream of the cross-section, where the Keramianos tributary, primarily responsible for the sediment transport, merges with the main river, the latter being fed by the karst springs. Based on field measurements it was assumed that the flow coming from the karst springs has a constant sediment concentration equal to 3 mg/L and that the variability was due to Keramianos loads.

Figure 3-5 presents the comparison between field measurements of suspended sediments and model simulation. There is good agreement between simulated and observed concentration values, considering that the available concentration data were limited to low concentration values and there were no data available during flood conditions. However, it is a fact that, almost twice a year, during flood conditions, Keramianos tributary transfers significant loads of suspended sediment, due to the high levels of erosion of the schist formations where the tributary flows over initially, before it enters a karstic gorge. The objective was to calibrate the sediment in such a way that high suspended sediment concentrations (originating from the subbasins with schist formations) would be simulated. The minimum, mean and maximum concentration of sediments according to the model for the years 2010-2020 were 0.29 mg/L, 2.41 mg/L and 22.45 mg/L.

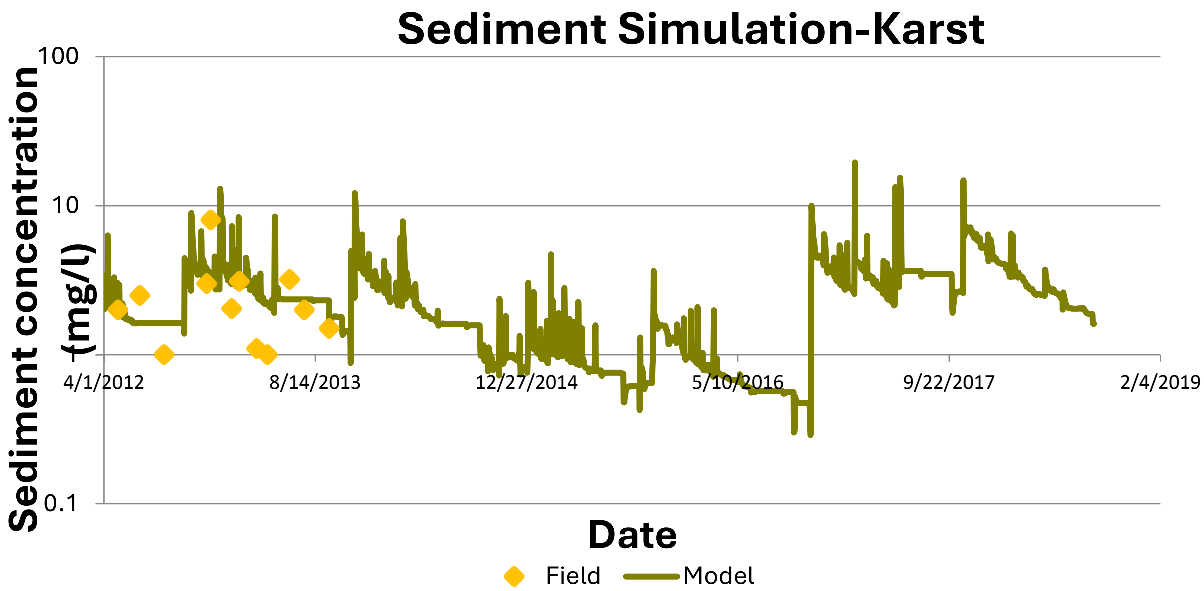

Figure 3-5: Sediment simulation at St. Georgios station for period 2011-2013 period.

Figure 3-6 presents the comparison between field measurements of suspended sediments and model simulation. Nutrient concentrations have been monitored at the Ag. Georgios hydrometric station, from May 2011 to February 2020 using grab samples monthly. This data was used for model calibration. There is good agreement between simulated and observed concentration values. The minimum, mean and maximum concentrations of NO3-N according to the model for the years 2010-2020 were 0.18 mg/L, 0.64 mg/L, and 3.38 mg/L.

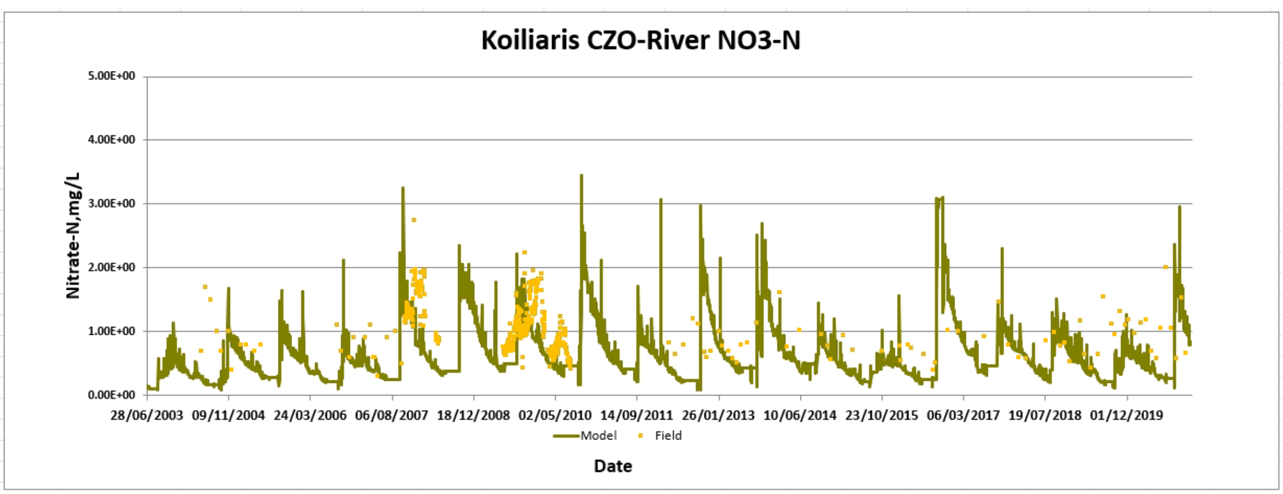

Figure 3-6: Nitrate Simulation at St. Georgios station for the 2004-2020 period.

The calibrated SWAT model was used to simulate NBS to mitigate the severe soil degradation in the Keramianos sub-basin and to limit the impacts of livestock activities.

Implementation NBS in Area 1

Soil degradation – Three scenarios of NBS were implemented to reduce soil erosion in the Keramianos sub-basin

- Terracing – Terraces were introduced in the model by defining the USLE practice factor (which depends on the slope of the selected terrace), average slope length (TERR_SL), and curve number (TERR_CN) for each HRU in the desired subbasins in which we want to create terraces.
- Riparian Forest – In the version of the SWAT model used, there was no operation that models simulate riparian forest. That's why we simulated riparian forests using filter strips at the HRU level on both sides of the river. More specifically, on both sides of the river, in subbasin 9, there are AGRL and PAST land uses, while in subbasin 15, there are AGRL and OLIV land uses. The filter strip was applied to these HRUs. The defined parameters included the ratio of field area to filter strip area (VFSRATIO), the fraction of the Hydrologic Response Unit (HRU) that drains to the most concentrated ten percent of the filter strip area (VFSCON), and the fraction of flow within the most concentrated ten percent of the filter strip that is fully channelized (VFSCH). In subbasin 9, for the AGRL land use, the average ratio of field area to filter strip area was 2%, and for the PAST land use, it was 1%. In subbasin 15, for the OLIV land use, the ratio of field area to filter strip area was 2.5, and for the PAST land use, it was 0.5.

Implementation NBS in Area 2

- Livestock activities – To implement this NBS, in calibrated SWAT model, all operations related to fertilization from sheep/goats (Sheep-Fresh Manure) in mountainous and pasture areas were removed. More specifically, as presented in Figure 3-7, the operation declaring the presence of sheep was removed from subbasins 9, 13, 15, 18, 19, 28, 29, 32, 33, 39, 40, 41, 42, 43, 44, 45, 46 and 47. The implementation of this NBS has several advantages. Some of them include the reduction of soil erosion caused by animal grazing, which will result in an improvement in water quality and an increase in biodiversity.

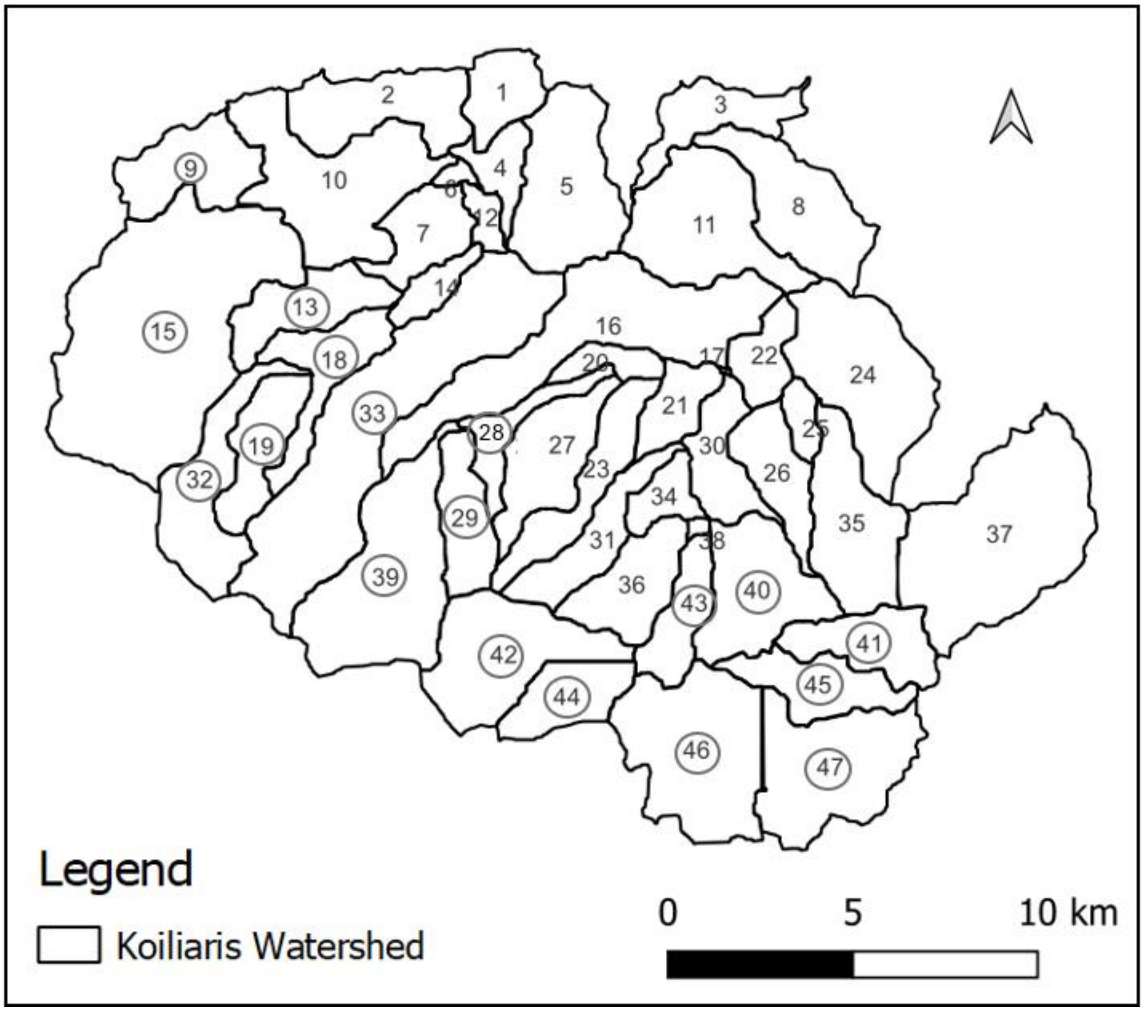

Figure 3-7: Subbasins in which removed fertilization from sheep/goats

4. Results

Area 1

Three different scenarios were tested to reduce soil erosion in this area. Scenario 1 involves the application of terraces in areas with high slopes. Scenario 2 involves the implementation of riparian forests, and scenario 3 combines the first two scenarios.

To understand how SWAT simulates terraces, we performed a sensitivity analysis on the key model parameters. These are the Curve Number of the terraces (TERR_CN), the average slope length (TERR_SL) and the USLE practice factor. The curve number value tested ranged from 40 to 45. The upper value, 45, was the one obtained after completing the hydrological calibration, while the lower value was based on literature for terraces. The range of values tested for the average slope length (TERR_SL), considering the soil morphology, was 3-15 meters. Figures 4-1 and 4-2 present the results of the calculated SYLD from the model by varying the slope length in the subbasins 9 and 15 where terracing was applied.

According to Neitsch et al. (2011), the parameter USLE practice factor also depends on the slope range. The slope range selected for testing is 0-25%, and correspondingly, the tested values of Pfactor ranged from 0.12 to 0.18. Figures 4-3 and 4-4 present the results of SYLD calculated from the model by varying the USLE practice factor in the same subbasins.

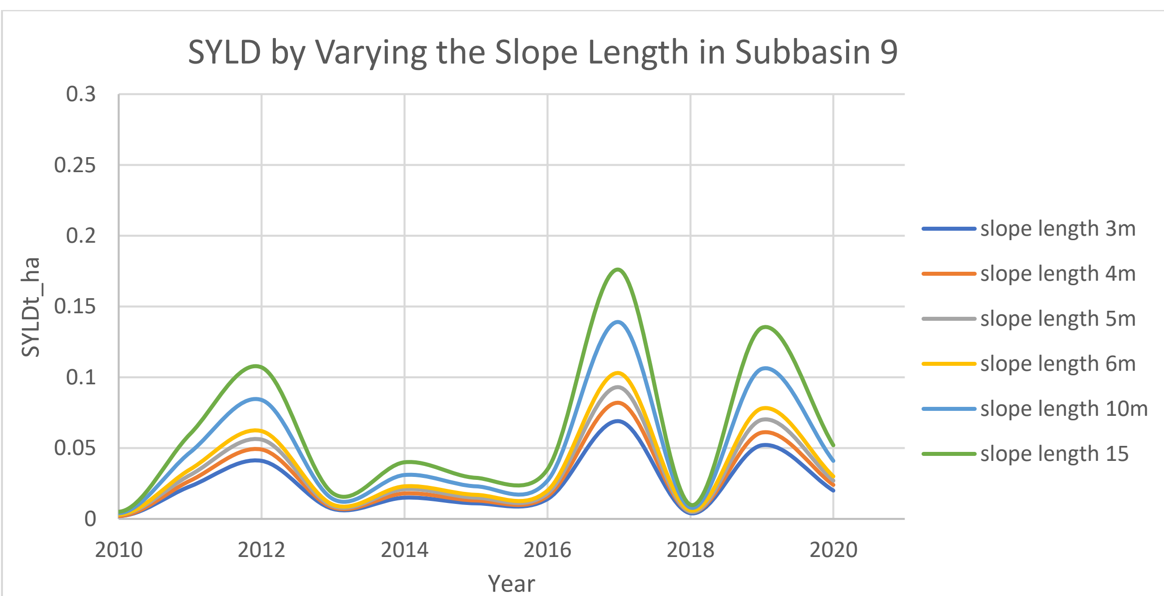

Figure 4-1: Result of SYLD by varying the slope length in subbasin 9.

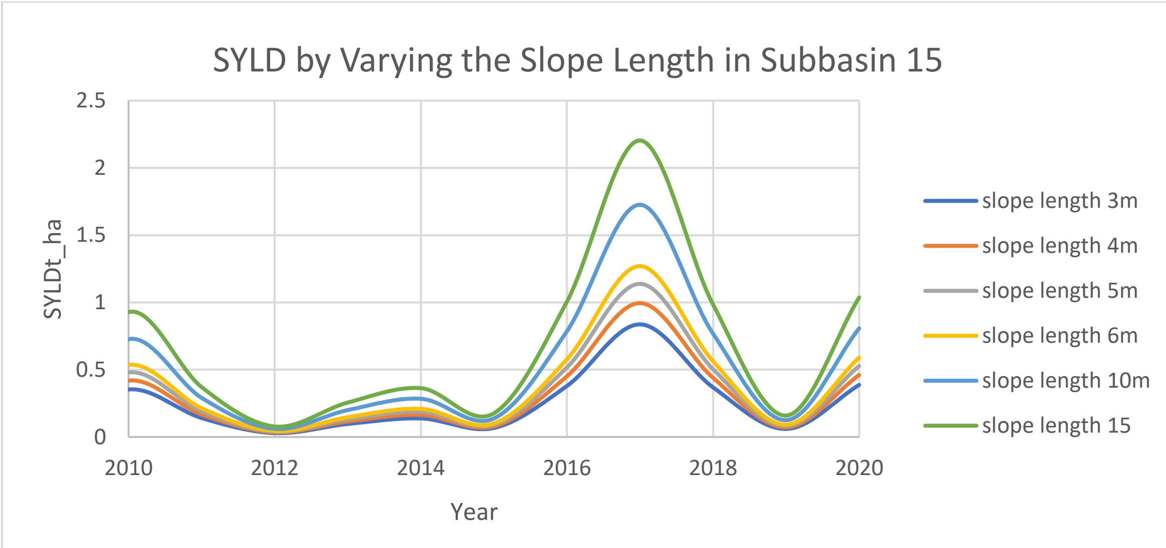

Figure 4-2: Result of SYLD by varying the slope length in subbasin 15.

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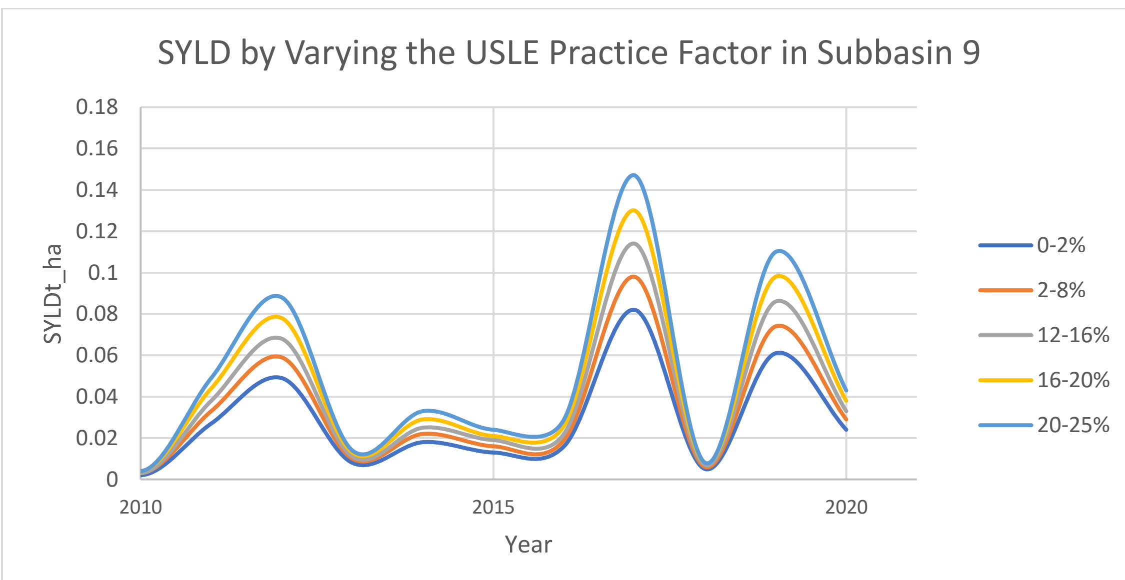

Figure 4-3: Result of SYLD by varying the USLE practice factor in subbasin 9.

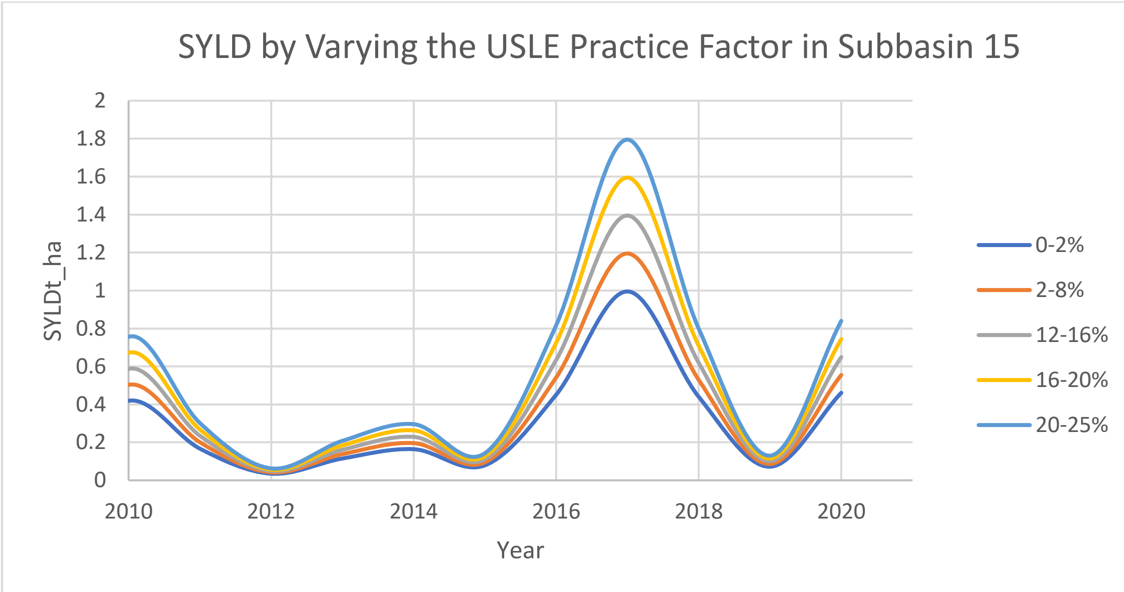

Figure 4-4: Result of SYLD by varying the USLE practice factor in subbasin 15.

Upon the conclusion of the experiments, the ultimate values of the chosen parameters are presented in Table 4-1.

Table 4-1: Selected parameters for the implementation of terraces.

Name of Parameter	TERR_P	TERR_CN	TERR_SL
Value of parameter	0.10	45	4

The values that were defined for the implementation of the filter strip in specific HRUs were calculated under the assumption that the width of the riparian forest on both sides of the channel is 40 meters. Table 4-2 depicts the values that were eventually used for the simulation of the filter strip.

Table 4-2: Selected parameters for the implementation of Filter strip.

Hru	Soil	L.U	Slope Class	VFSI	VFSRATIO	VFSCOIN	VFSCH
Hru 53	S9340	AGR	5-15	1	6	0.5	0
Hru 58	S9340	PAST	15-9999	1	3	0.5	0
Hru 59	S9340	PAST	5-15	1	3	0.5	0
Hru 105	S9320	OLIV	15-999	1	9	0.5	0
Hru 106	S9322	OLIV	15-9999	1	6	0.5	0
Hru 103	S9320	AGR	15-9999	1	1.2	0.5	0
Hru 102	S9320	AGR	5-15	1	1.5	0.5	0
Hru 104	S9322	AGR	15-9999	1	0.6	0.5	0

The annual average sediment load export from the subbasins due to various NBS implementations is shown in Figures 4-5, 4-7, and 4-9. Figures 4-6, 4-8, and 4-10 present the results as percentage reductions. Tables 4-3, 4-4, and 4-5 display the minimum, mean, and maximum values of subbasins.

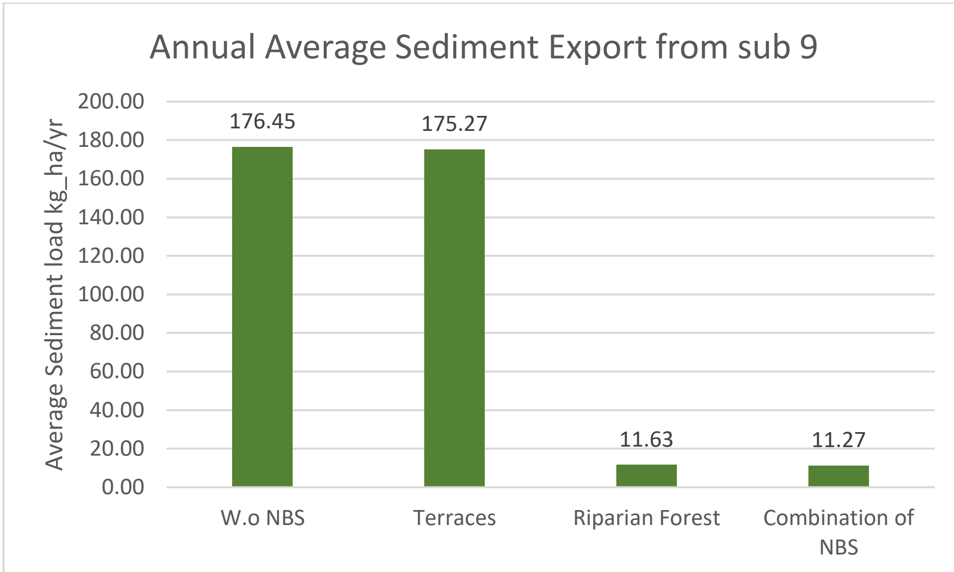

Figure 4-5: Annual Average Sediment Export from sub 9.

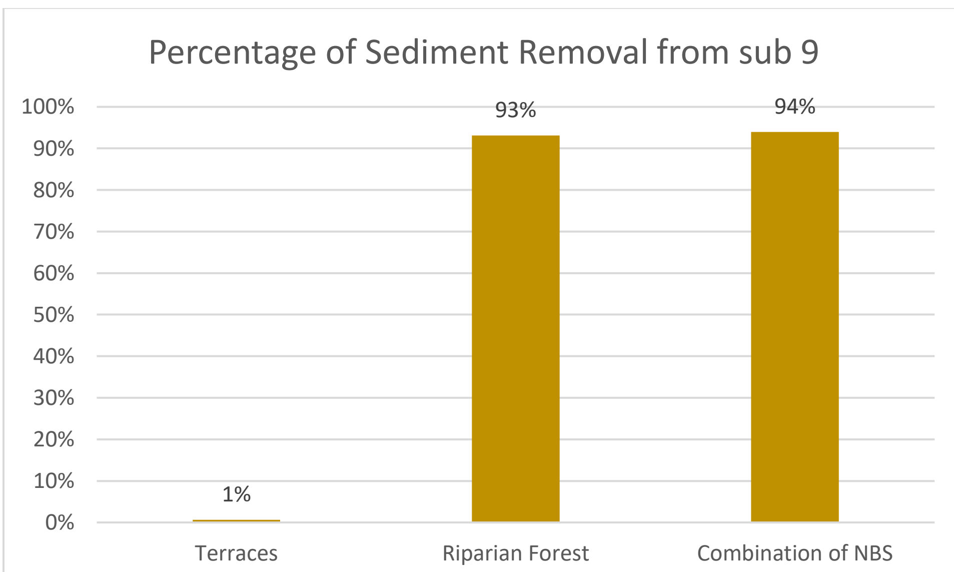

Figure 4-6: Percentage of Sediment Removal from sub-9.

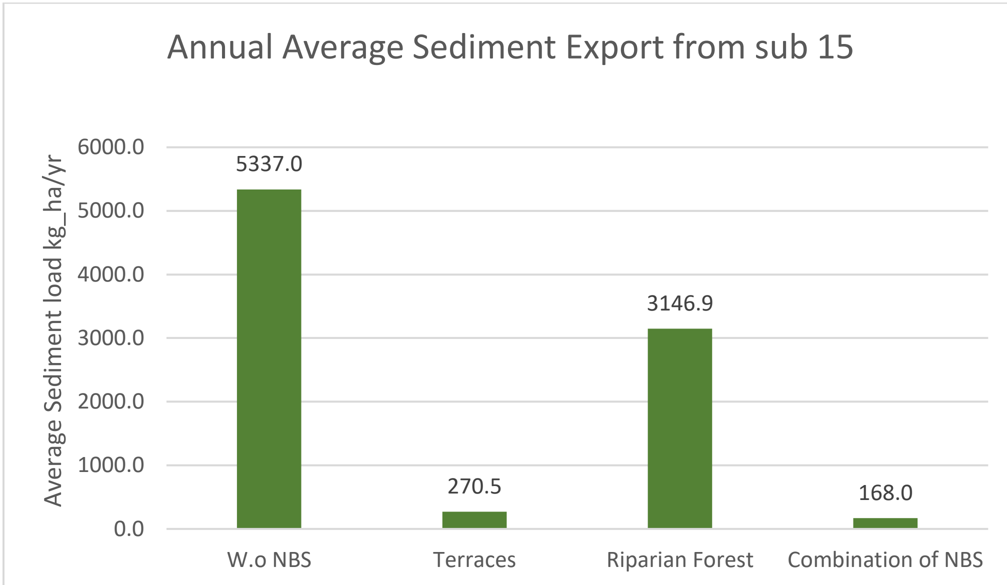

Figure 4-7: Annual Average Sediment Export from sub-15.

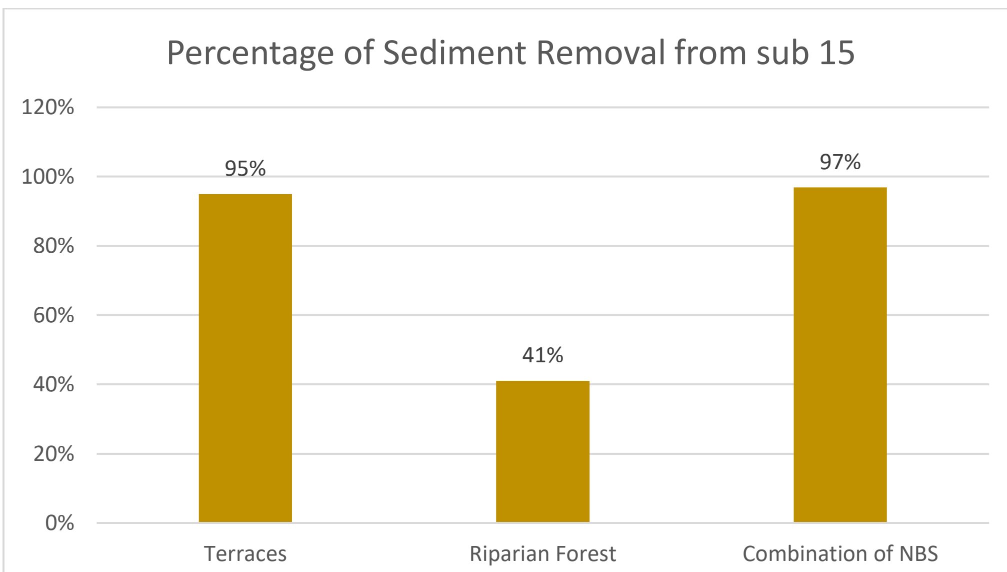

Figure 4-8: Percentage of Sediment Removal from sub-15.

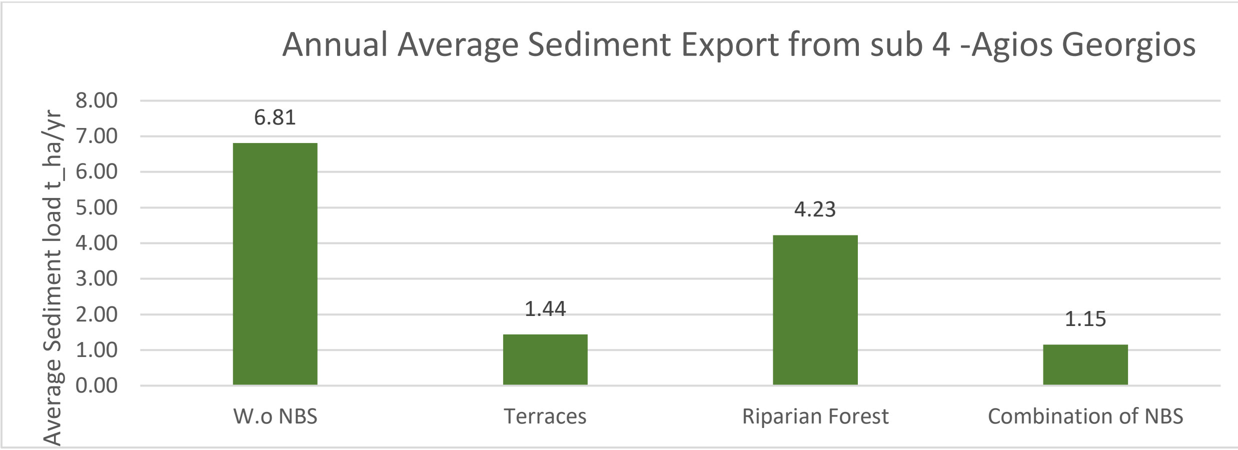

Figure 4-9: Annual Average Sediment Export from sub 4.

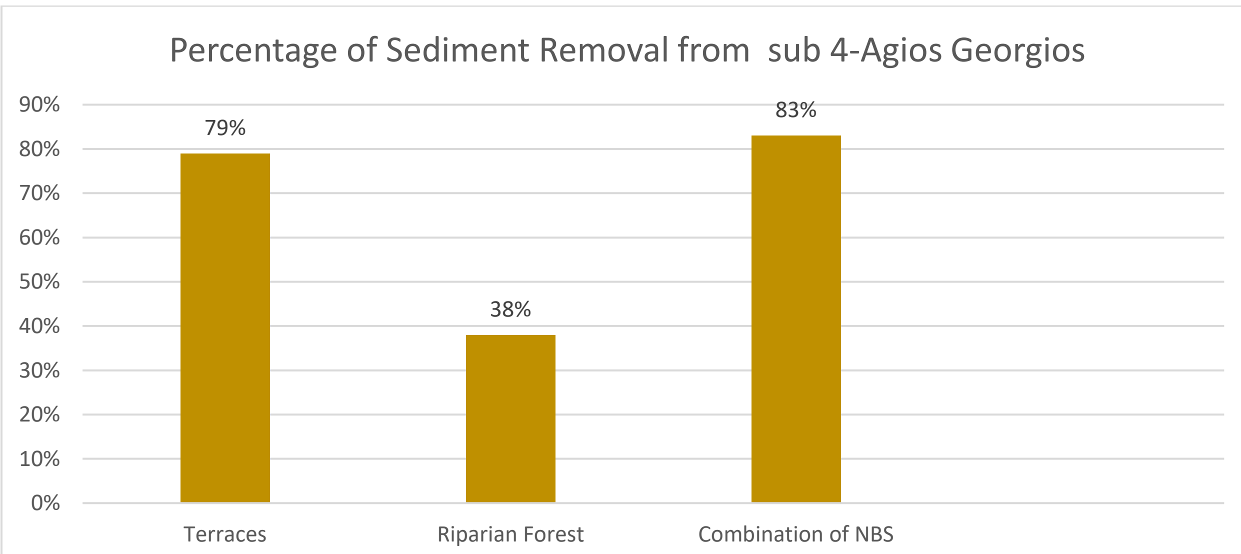

Figure 4-10: Percentage of Sediment Removal from sub 4.

Table 4-3: Minimum, mean and maximum values of Sediment Load in sub 9 for the years 2010-2020.

Sub 9

Scenarios	Min Sediment load t_ha	Mean Sediment load t_ha	Max Sediment load t_ha
wo NBS	0.022	0.176	0.806
Terraces	0.021	0.175	0.810
Riparian Forest	0.000	0.012	0.058
Combination of NBS	0.000	0.011	0.057

Table 4-4: Minimum, mean and maximum values of Sediment Load in sub15 for the years 2010-2020.

Sub 15

Scenarios	Min Sediment load t_ha	Mean Sediment load t_ha	Max Sediment load t_ha
wo NBS	0.446	5.337	24.250
Terraces	0.024	0.270	1.258
Riparian Forest	0.081	3.147	16.102
Combination of NBS	0.005	0.168	0.868

Table 4-5: Minimum, mean and maximum values of Sediment Load in sub 4 for the years 2010-2020.

Sub 4

Scenarios	Min Sediment load t_ha	Mean Sediment load t_ha	Max Sediment load t_ha
wo NBS	1.137	6.814	16.952
Terraces	0.361	1.441	2.863
Riparian Forest	0.529	4.228	11.365
Combination of NBS	0.344	1.155	2.346

According to the above diagrams, it is observed that in sub-basin 9, the most efficient NBS is the implementation of a riparian forest. With this option, there will be a reduction of approximately 93% in the sub-basin and 38% in Agios Georgios. In sub-basin 15, the most efficient NBS (Nature-Based Solution) is the creation of terraces, and with this choice, there will be a reduction of 95% in the sub-basin and 79% at the Agios Georgios station. If both NBS are applied, then the combined effect would be higher sediment removal.

Area 2

The removal of livestock from the upland pasture areas was simulated by eliminating the manure input in these HRUs. The results of this action are presented in Table 4-6 and Figures 4-11 and 4-12. Figure 4-11 shows the annual average nitrate export from the Koiliaris River Basin. The export was reduced from 9.80 kg/ha/yr to 7.95 kg/ha/yr or a reduction of about 19%. Figure 4-12 presents the annual average nitrate concentration before and after the NBS implementation. The summary of these results is presented in Table 4-6. The annual average nitrate-N concentration decreased from 0.64 mg/L to 0.79 mg/L with the removal of manure. Similarly, the range of annual values changed from 0.18-0.20 mg/L to 3.35-4.36 mg/L. The results illustrate the impact of livestock activities on water quality.

Table 4-6: Minimum, mean and maximum values of NO3-N for the years 2010-2020.

Scenarios	Minimum NO_3-N mg/L	Mean NO_3-N mg/L	Maximum NO_3-N mg/L
Livestock activity	0.20	0.79	4.36
w.o Livestock activity	0.18	0.64	3.35

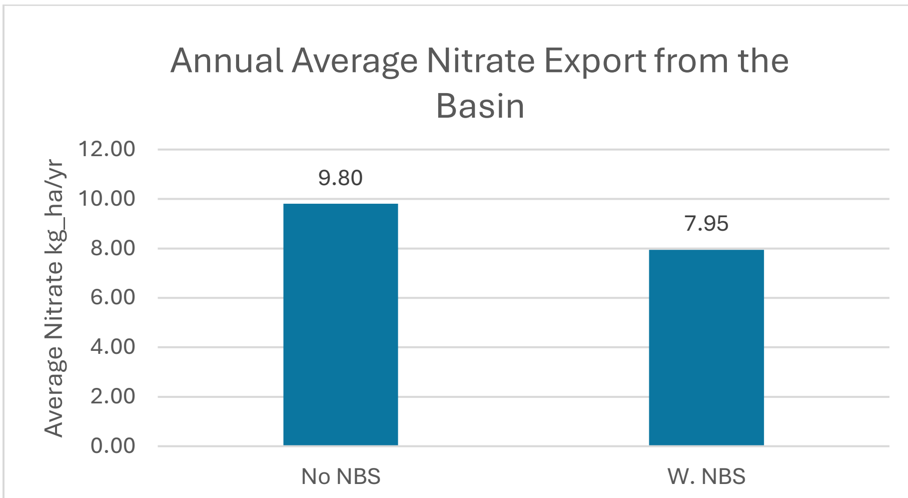

Figure 4-11: Annual Average Nitrate Export from the Basin.

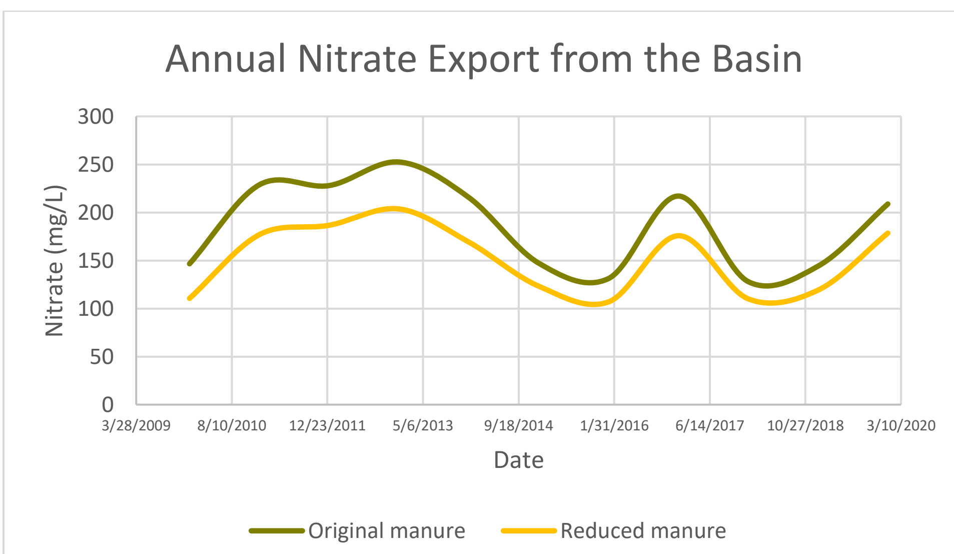

Figure 4-12: Annual Nitrate Export from the Basin of each scenario.

5. Conclusion

This research evaluated three distinct Nature-Based Solutions (NBS)—terraces, riparian forests, and livestock management—for their impact on water quality in the Ag. Georgios River, where high concentrations of nitrates are observed. Each of these NBS can directly or indirectly enhance soil ecosystem functions and mitigate soil threats. Terraces and Riparian forests significantly reduce soil erosion: terraces can reduce sediment load by up to 79%, riparian forests by up to 38% but the combination of both can achieve up to a 83% reduction. Livestock management is also crucial for improving soil and water quality, as it reduces nitrate levels by approximately 19%.

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Yu, X., Moraetis, D., Nikolaidis, N. P., Li, B., Duffy, C., Liu, B., 2019. A coupled surface-subsurface hydrologic model to assess groundwater flood risk spatially and temporally, Environ. Model. Softw. 114, 129-139. https://doi.org/10.1016/J.ENVSOFT.2019.01.008

Modeling assessment of water quantity at the basin level.

1. Description of Case Study

Keritis Watershed

The Keritis River Basin is one of the two main drainage basins in the Chania region. It is located in the north-central part of the Chania region, 12 kilometers west of the city (Figure 1-1). It is situated between the geographic coordinates of 35°15' - 35°32' north latitude and 23°45' - 23°55' east longitude. The hydrological basin covers an area of 210 km², with an average elevation of 734 meters, and falls within the jurisdiction of the Platanias Municipality. The hydrographic network begins in the southern and higher part of the basin (approximately 2000 meters) in the White Mountains and flows north of the village of Platanias. This basin is one of the most important hydrological basins in the region due to its abundant water resources. The annual rainfall for the Chania region is estimated to be 665 mm (Chartzoulakis et al., 2001). Numerous boreholes (Nikolaidis N, Karatzas, 2006) and wells serving the wider area's water supply and irrigation purposes are located in this drainage basin. The geological formations of the Keritis-Therisou basin (Figure 1-2) exhibit different hydrogeological and hydraulic behaviors due to their

lithological and tectonic characteristics (IGME 1969; Fassoulas 2001; Fassoulas et al., 2000; Perleros and Vozinakis 2002; Papanikolaou and Vassilakis 2008), thereby determining the hydrological regime of the study area. The study area is characterized by the presence of two main deep hydrogeological systems (Perleros, C., and Vozinakis, K., 2002; Nikolaidis N, Karatzas G 2010) and one secondary surface system. The deeper system is represented by permeable carbonate formations and is located in the southeastern part of the drainage basin. Underground springs mainly originate from the southwestern sector, where the carbonate formations of the White Mountains recharge primarily from the carbonates of the area. In the northern part, the carbonate rock formation is interrupted by a northeast-southwest fault, which leads to the formation of karst springs in the Agia region (Kourgialas et al.,2010; Nikolaidis et al.,2013; Steiakakis et al.,2023). The second major hydrogeological system is an impermeable system of marls and clay deposits, extending in the central part of the drainage basin (Soupios P et al., 2007; Fytrolakis N, 1980). The rich hydrographic network in this area prevents rainfall from infiltrating the soil, resulting in intense surface runoff and the formation of numerous streams that feed the main flow of the Keritis River. The sources of Meskla are fed by carbonates and surface runoff from the marl of the Keritis, located southwest of the village of Meskla. The secondary hydrogeological system consists of Quaternary deposits, extending north of the marls in the central part of the Keritis drainage basin. It is fed by surface runoff from the marls as well as by underground lateral flows to the east of the basin.The main geological formations found in the drainage basin are Quaternary formations, Neogene formations, phyllites-quartzites, and carbonate rocks (Fassoulas C 2000; IGME 2006, 1969) (Figure 1-2).Figure 1-3 is a map illustrating the land use classification in watershed. Some of the land use categories include:

- URMD: Urban Medium Density (cyan)
- UTRN: Urban Transportation (red)
- UIDU: Urban Industrial (magenta)
- APPL: Apple Orchards (light brown)
- OLIV: Olive Groves (green)
- SPAS: Sparse Vegetation (yellow)
- FRSB: Forest Deciduous (light green)
- FRSE: Forest Evergreen (dark green)
- GRAP: Vineyards (purple)
- DWHT: Winter Wheat (beige)
- BARL: Barley (yellow)

The map indicates that large portions of the watershed are covered by olive groves (green), urban medium density areas (cyan), and forested regions (light and dark green). Sparse vegetation (yellow) and other agricultural uses, such as vineyards (purple) and winter wheat (beige), are also depicted.

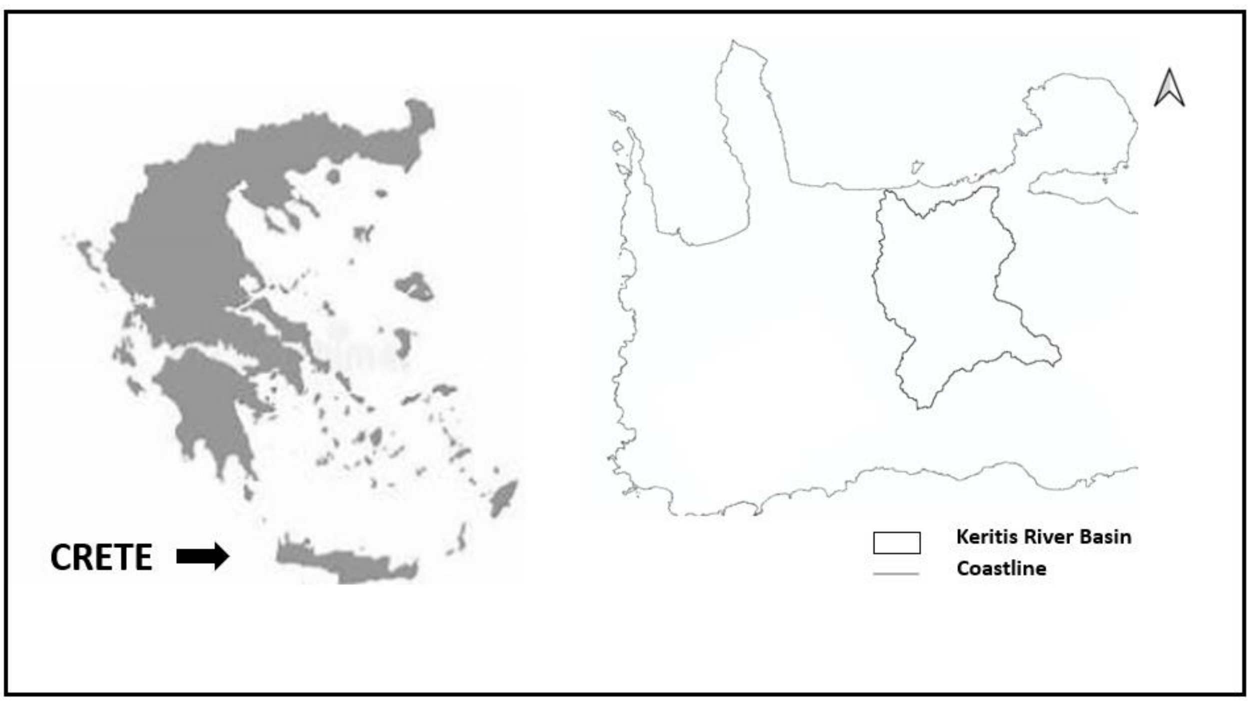

Figure 1-1: Location of Keritis Watershed

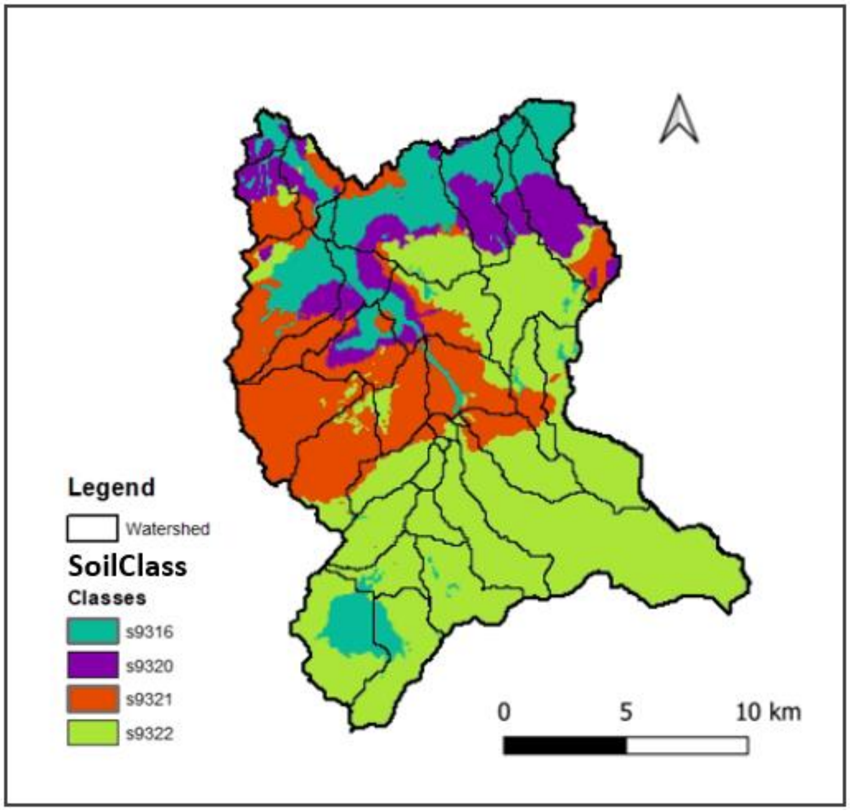

Figure 1-2: Type of Soils of Keritis Watershed

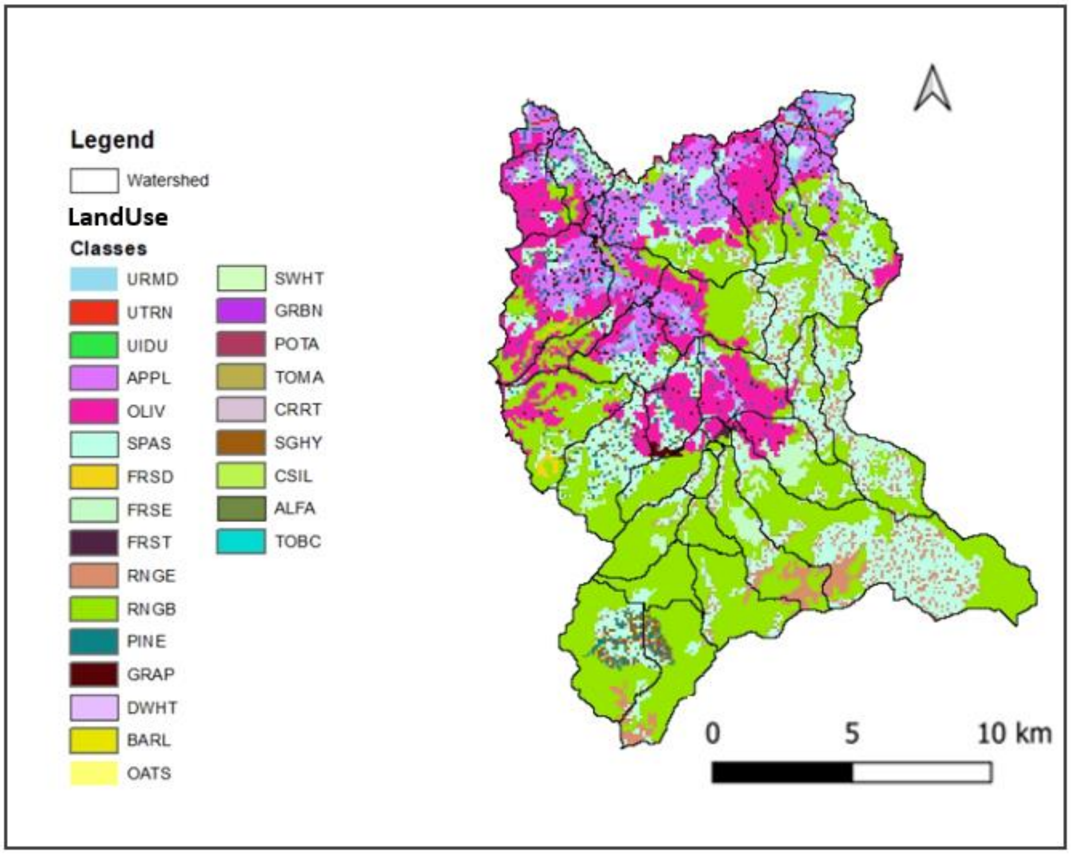

Figure 1-3: Type of Land use of Keritis Watershed

2. Model Description

WEAP model

The WEAP model, which stands for "Water Evaluation and Planning," is a sophisticated and versatile tool designed for the comprehensive management and planning of water resources. Developed by the Stockholm Environment Institute (SEI), this integrated decision support system aids policymakers, water resource managers, and researchers in conducting thorough assessments and planning for water allocation. Embracing a holistic approach to water resource management, the model considers various factors and provides valuable insights.

WEAP encompasses several key components. Initially, it incorporates hydrological modeling to simulate water movement within a watershed or river basin, taking into account factors like precipitation, evaporation, infiltration, and runoff. Users can define and allocate water demands for agriculture, industry, municipalities, and environmental conservation, with the flexibility to adjust allocations under different scenarios, exploring the impacts of climate change, population growth, and other variables on water availability (Yanga et al.,2018).

The model also features provisions for assessing water quality, facilitating the evaluation of not only the quantity but also the health of water bodies and ecosystems. WEAP's multi-objective optimization capabilities assist users in finding balanced solutions that accommodate competing water management goals, such as minimizing water scarcity, maximizing economic benefits, and preserving ecological integrity.

Moreover, the model integrates Geographic Information System (GIS) data, providing spatial context and enhancing modeling accuracy. With a user-friendly interface, it simplifies the process of building and visualizing water resource management models, while its decision support features present results in an accessible format.

In summary, the WEAP model is an indispensable tool in water resource management. Its adaptability and comprehensiveness make it invaluable for addressing diverse water-related challenges and supporting well-informed decision-making. Whether assessing current water systems, planning for the future, or evaluating the impact of environmental changes, WEAP offers a powerful and flexible platform to guide sustainable water allocation and management efforts.

The WEAP model consists of 5 main sections, as depicted in Figure 2-1: Schematic, Data, Results, Overviews, and Notes. These five perspectives are detailed below.

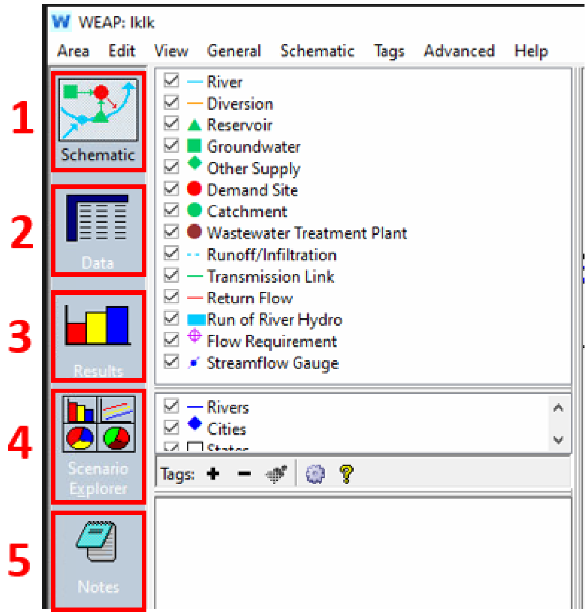

Figure 2-1: Main sections of WEAP model.

In the schematic section, the user creates the network, defining demand and supply nodes, existing rivers, etc. For the creation of the network, 14 elements are available, which are described in Table 2-1.

Table 2-1: Symbols and description

Symbol	Name	Description
	River	Surface water
	Diversion	The way to allocate water to the demand site is used when you want to build a distribution network
	Reservoir	Reservoir, type of reservoir On-Stream, Off-Stream
	Groundwater	Groundwater
	Other Supply	Any water source that is not being modeled and represents
	Demand Site	Demand site (agricultural, livestock)
	Catchment	The entire area of the basin
	Wastewater Treatment Plant	Wastewater Treatment Plant
	Runoff/Infiltration	The element that connects links from the catchment to the river
	Transmission Link	The way to allocate water to the demand site

	Return Flow	The water that is not consumed at the demand site
	Run of River Hydro	
	Streamflow Gauge	Points to evaluate the model performance
	Flow requirement	This element tries to force the model to meet the flow rate assigned to it, considering demand priority.

The "Data" section allows the user to define data. For example, the user can input the inflow and outflow of the river, the monthly consumption of demand nodes, annual water use, etc. This section provides the capability to create variables and relationships, input assumptions and predictions using mathematical expressions, and dynamically link to Excel.

The "Results" section enables a comprehensive and adaptable presentation of all model outputs, both in charts and tables, as well as on the Schematic.

In the "Scenario Explorer" section, users can highlight essential data and results in their system, facilitating swift and easy viewing.

The "Notes" section offers a space to record your data and assumptions.

3. Methodology approach

For the setup of the WEAP model, data exported from the Karst-SWAT model were used. This required updating the hydrology of the watersheds included in the case study, specifically the Koiliaris and Keritis Watersheds. The results of the Koiliaris calibration are shown above. For the Keritis River Basin, and more specifically for the Meskla springs, monthly data are available from 1978 to 2004, while for the Agyia springs, data are available from 1978 to 1985. Data for the Keritis River are available for 2012-2013 and 2014-2015. Figure 3-2 until 3-5 present the result of calibration.

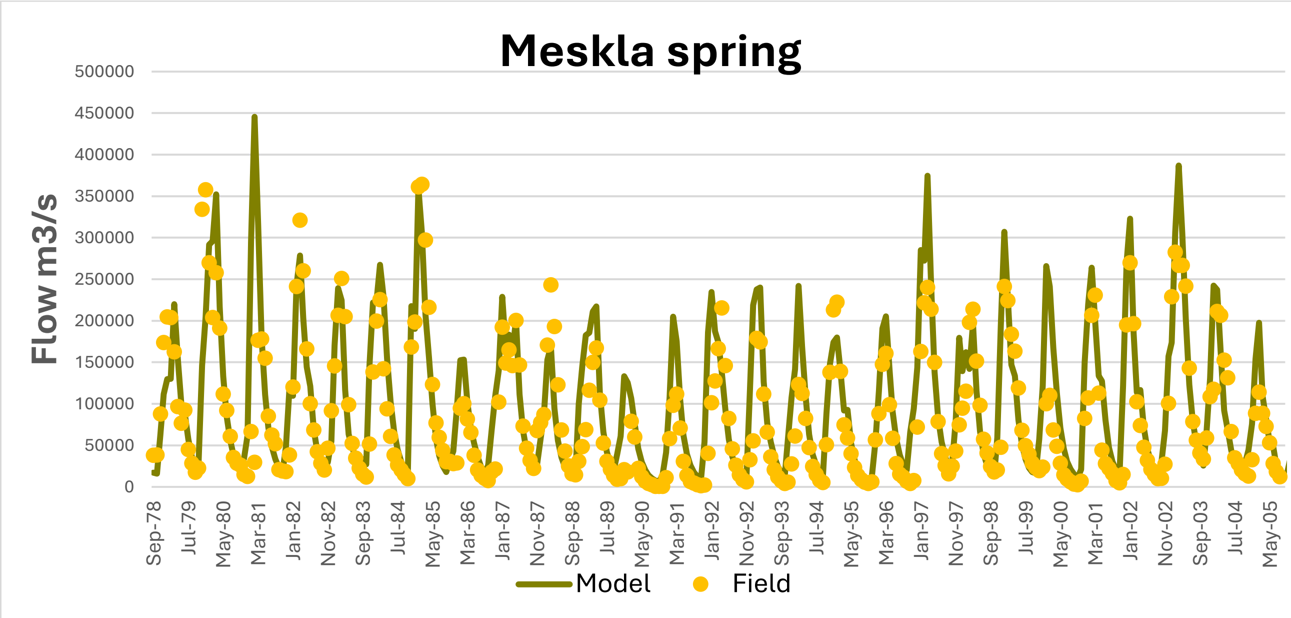

Figure 3-1: Hydrologic Simulation at Meskla Springs for the 1978-2005 period

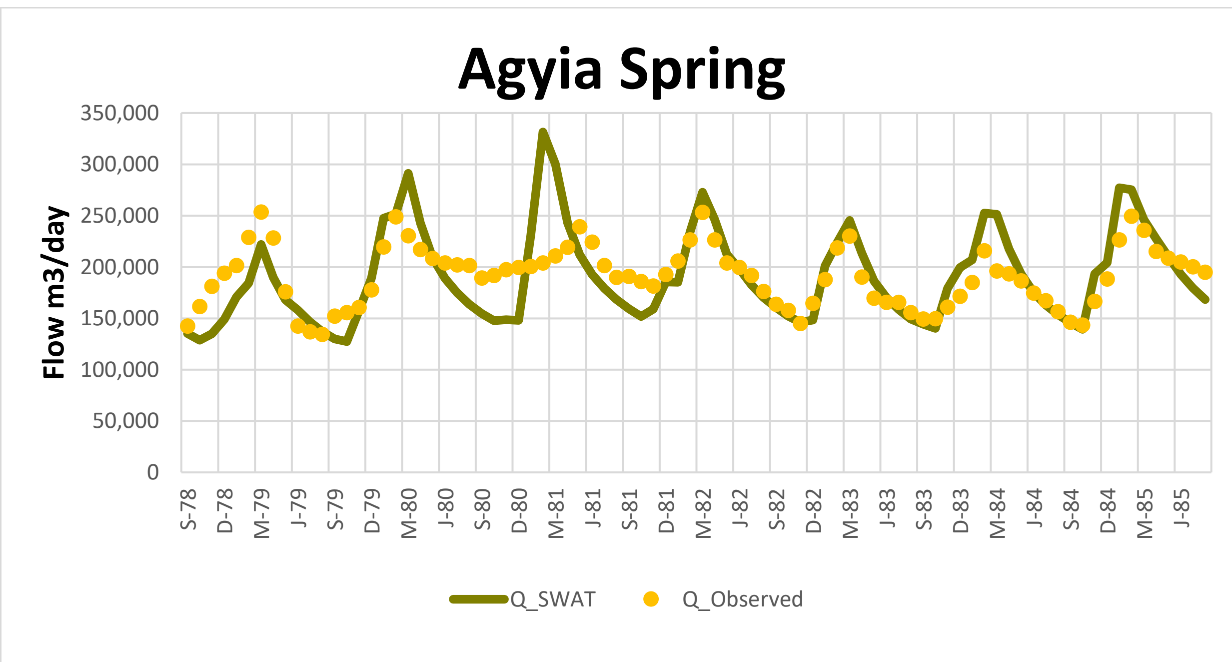

Figure 3-2: Hydrologic Simulation at Agia springs for the 1978-1985 period

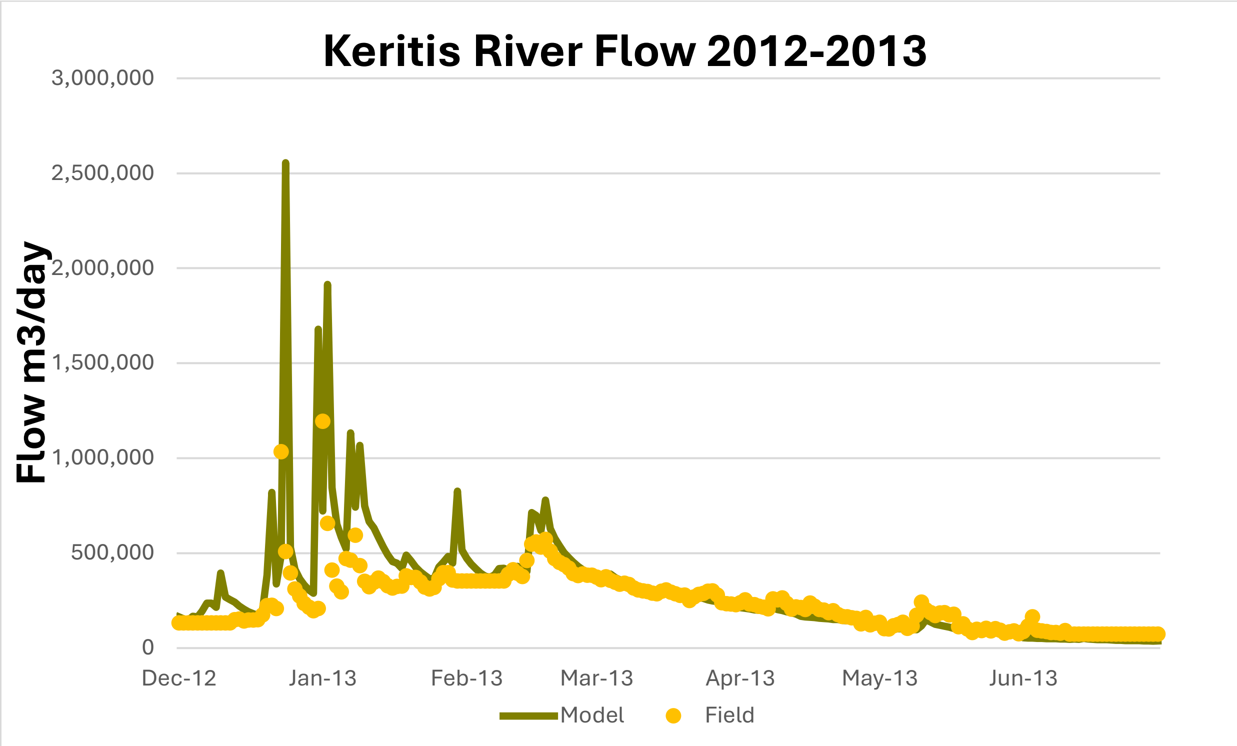

Figure 3-3: Hydrologic Simulation at Keritis river for the 2012-2013 period

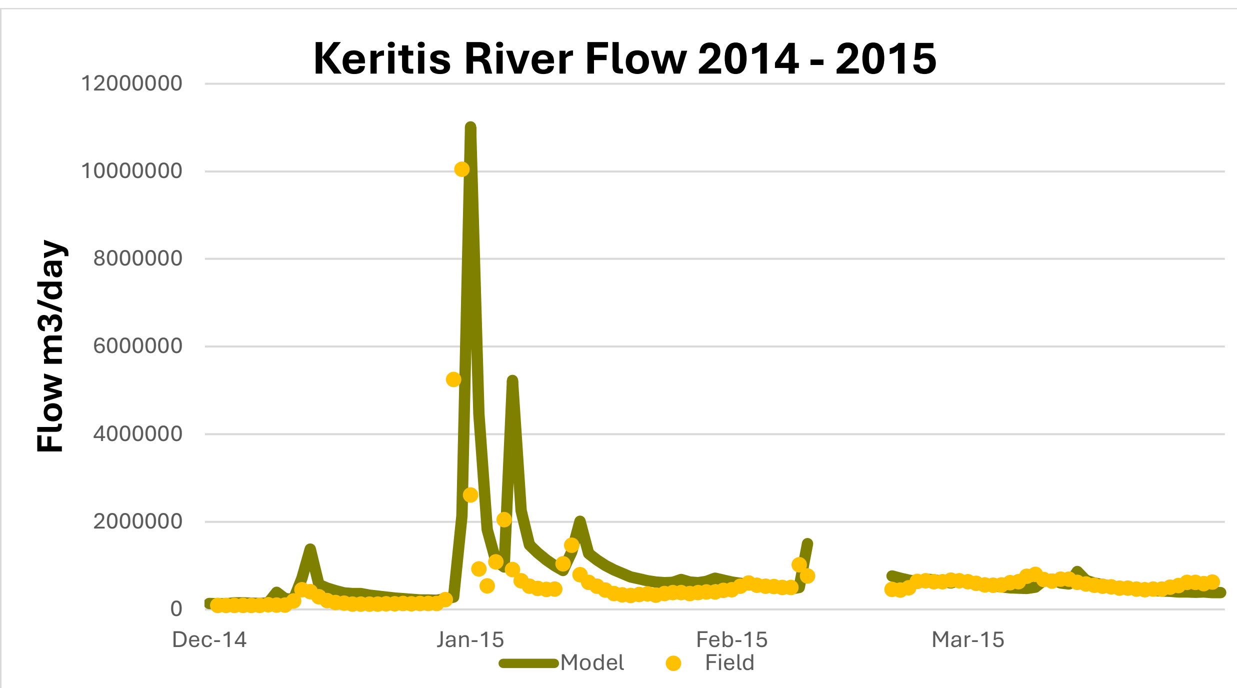

Figure 3-4: Hydrologic Simulation at Keritis River for the 2014-2015 period.

3.1. Model set up

Initially, for the creation of the water distribution network, it was necessary to map the main rivers that supply the areas. Then, the demand sites were defined, and finally, the necessary data were introduced to complete the model. Some of this data included river flows, the population of each demand site related to water supply, the area under irrigated crops, and so on.

3.1.1. River element

In the study area, we have identified four rivers (Figure 3-5). The river "Keritis" and the river "Tributary" belong to the Keritis River Basin, while the river "Keramianos" and "Agios Georgios" belong to the Koiliaris River Basin. For the aforementioned rivers, we obtained the monthly surface water discharge data in cubic meters per second (cms) from the SWAT model. Four rivers and the monthly variation of flows are depicted in Figure 3-6.

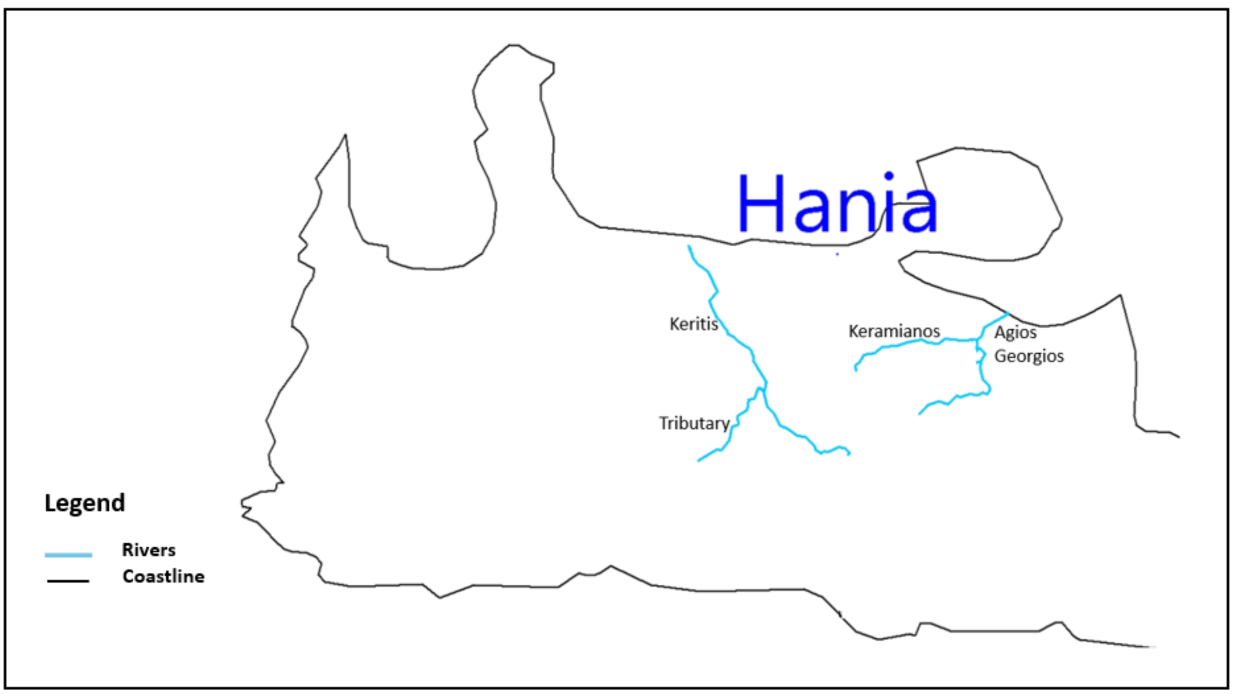

Figure 3-5: Rivers of study area

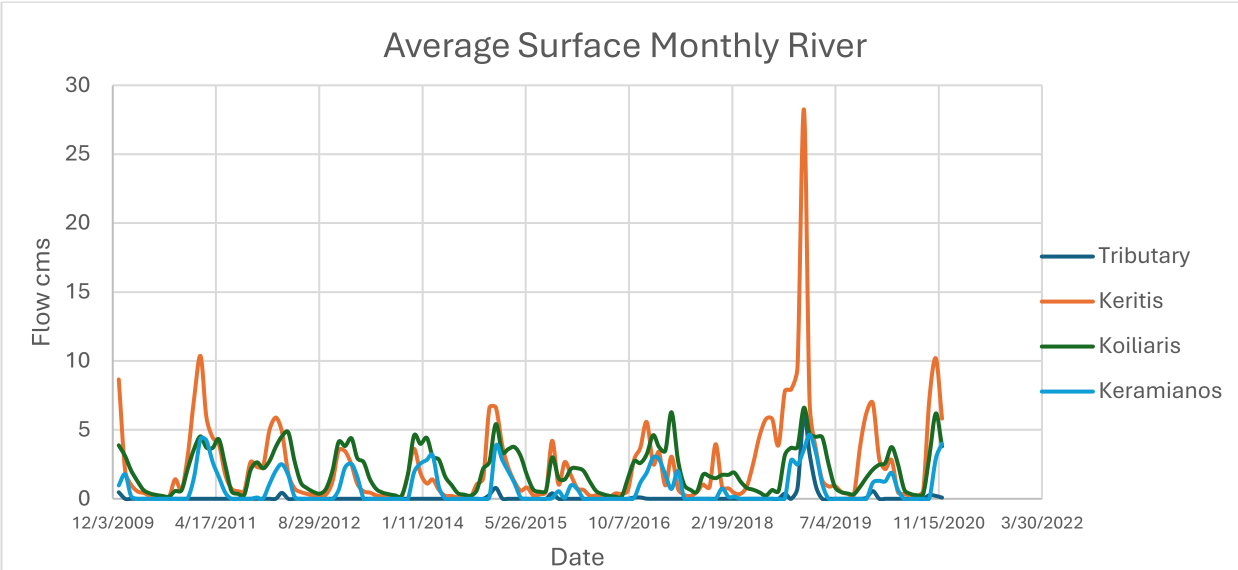

Figure 3-6: Surface flow of the case study rivers

3.1.2. Demand Site

In the broader area, there are 9 demand sites (Figure 3-7). Four of these sites are related to areas that require water for irrigation, while the remaining areas require water to meet their drinking water needs. The areas that need water for irrigation are the 'Irrigation of Keritis Valley,' 'Irrigation of Akrotiri,' 'Irrigation of Chania,' and 'Irrigation of Koiliaris Valley.' The demand sites 'Water Drink of Platanias ', 'Water Drink of Chania Town', 'Water Drink of Akrotiri ', 'Water Drink Industrial Villages' and 'Water Drink Vamos Kalyves' use the water for drinking purposes. For the demand sites that serve a drinking water purpose, it is necessary to define the population, annual water use rate, monthly variation, and consumption. For the sites that serve irrigation purposes, define the irrigated area (in hectares), annual water use rate, monthly variation, and consumption.

The 'Water drink_industrial_village' site includes the municipality of Apokoronas. According to demographic data, in 1991, the population was 11,827; in 2001, it was 12,441, and in 2011, it reached 12,807. Based on Figure 3-8, the population follows a linear increase with the equation y = 49x - 85,691. Using this equation, it was calculated that the population in 2021 was 13,338. For the model, the assumption was made that the population increase of 531 individuals per decade remained consistent every year. The results for the years 2010-2020 are presented in Table 3-1.

The same methodology was followed for the calculation of "Water drink Vamos_Kalives" (Table 3-2) . In this case, the population exhibited a declining linear trend. For the remaining four demand sites, demographic data was available from the Hellenic Statistical Authority of Greece for the years 2010 and 2021. In this case as well, it was assumed that the population increase each year was constant. For example, the population of the city of Chania was 53,910 in 2011 and increased to 54,559 in 2021. Therefore, the population was increasing by 65 individuals every year. Using this method, the population for each year was ultimately calculated. Population for each demand site present in Table 3-3 until 3-5.

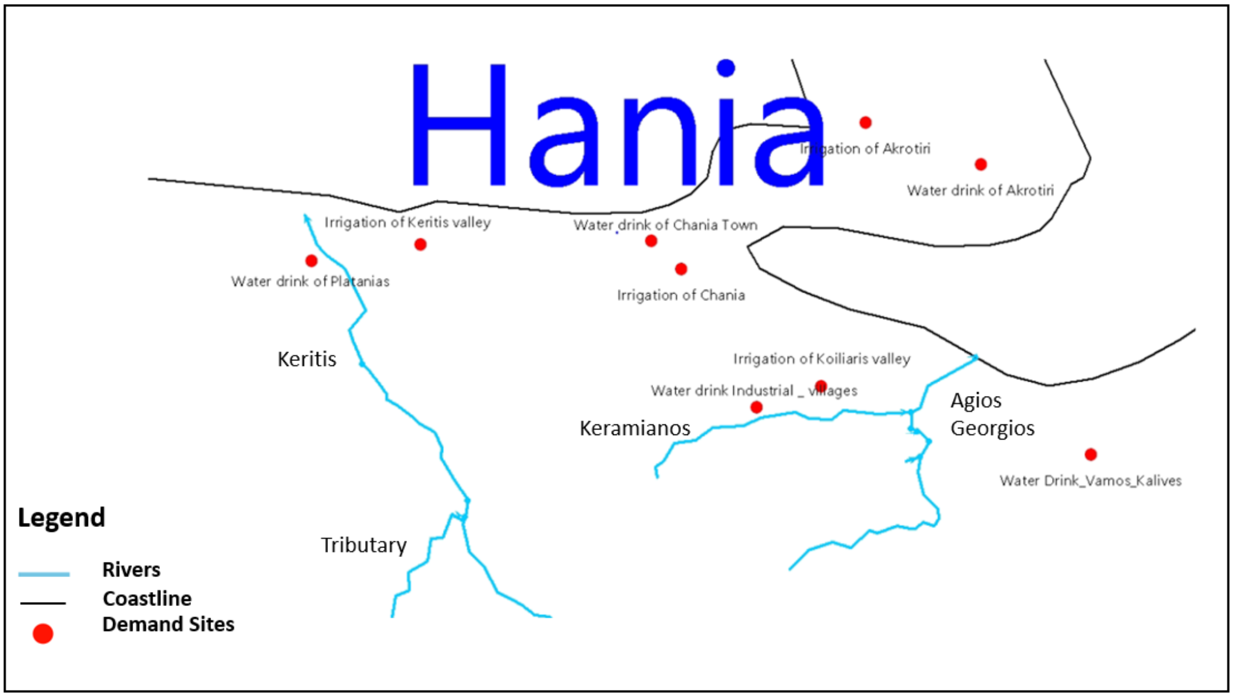

Figure 3-7: Demand sites of case study

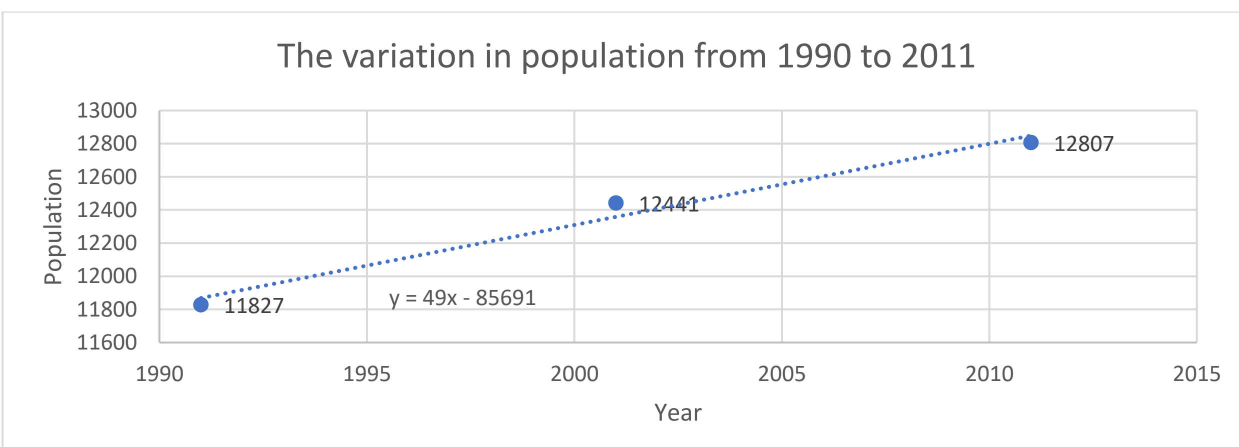

Figure 3-8: The variation in the population of demand site " Water drink_industrial_villages" from 1990 to 2011

Table 3-1: Annual variation in the population of demand site "Water drink_industrial_villages"

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Population	1407	1377	1356	1326	1296	1266	1236	1206	1176	1146	1116

Table 3-2: Annual variation in the population of demand site "Water drink Vamos_Kalives"

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Population	12770	12807	12860	12913	12966	13019	13073	13126	13179	13232	13285

Table 3-3: Annual variation in the population of demand site "Water drink of Akrotiri"

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Population	13000	13100	13193	13295	13397	13499	13601	13703	13805	13907	14009

Table 3-4: Annual variation in the population of demand site "Water drink of Platanias"

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Population	18081	18157	18233	18309	18385	18461	18537	18613	18689	18765	18841

Table 3-5: Annual variation in the population of demand site "Water drink of Chania"

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Population	53845	53910	53975	54040	54105	54170	54235	54300	54365	54430	54495

As per ‘Metcalf & Eddy' the annual water consumption per individual is 80.3 m3, and this value is considered constant for all demand sites and in the subsequent years.

The monthly variation, considering the demand for water from the water management authorities of the area for all demand sites and in the subsequent years, was estimated as shown in Table 3-6.

Table 3-6: Percentage of the monthly consumption variation for the demand sites that use water for water supply.

Month	Variation (%)
Jan	9
Feb	8.9
Mar	9.2
Apr	9.9
May	10.4
Jun	8.8

Jul	8.9
Aug	7.6
Sep	6.7
Oct	6.4
Nov	8
Dec9	6.2

The area of the demand sites that need water for irrigation is known from the ODWC (1990) and ODWC (2007) The irrigated area for the Irrigation of Keritis Valley is 4200 ha, for the Irrigation of Akrotiri 1200 ha, for the Irrigation of Chania 500 ha, and the Irrigation of Koiliaris Valley 1300 ha. According to ODWC (2007) the recommended irrigation quantity per hectare per year is 4000 cubic meters. This value is considered constant for all demand sites and in the subsequent years. The monthly variation, considering the demand for water from the water management authorities of the area for all demand sites and in the subsequent years, was estimated as shown in Table 3-7.

Table 3-7: Percentages of the monthly consumption variation for the demand sites that use water for irrigation.

Month	Irrigation of Keritis valley (%)	Irrigation of Chania (%)	Irrigation of Koiliaris valley (%)	Irrigation of Akrotiri(%)
Jan	3.77	3.02	5.51	3.02
Feb	2.94	2.86	4.94	2.86
Mar	3.19	3.52	5.19	3.52
Apr	4.87	6.21	6.56	6.21
May	7.64	9.06	8.55	9.06
Jun	10.35	11.63	9.83	11.63
Jul	13.35	15.07	11.85	15.07
Aug	14.75	14.43	12.36	14.43
Sep	13.96	13.48	11.53	13.48
Oct	11.85	10.21	10.04	10.21
Nov	8.09	5.98	8.05	5.98
Dec9	5.25	4.53	5.60	4.53

3.1.3. Other Supply

This option is used to represent any water source that is not being modeled (Figure 3-9), in this case, the springs. In the Keritis River Basin, there are the springs "Meskla " and "Agia." The springs "Stylos," "Armenoi," "Anavreti," and "Zourbos" belong to the Koiliaris River Basin. For these sources, the data extracted from the SWAT model after completing the calibration and validation were used. The average flow per second in a monthly time step for the years 2010-2020 is presented in Figure 3-10.

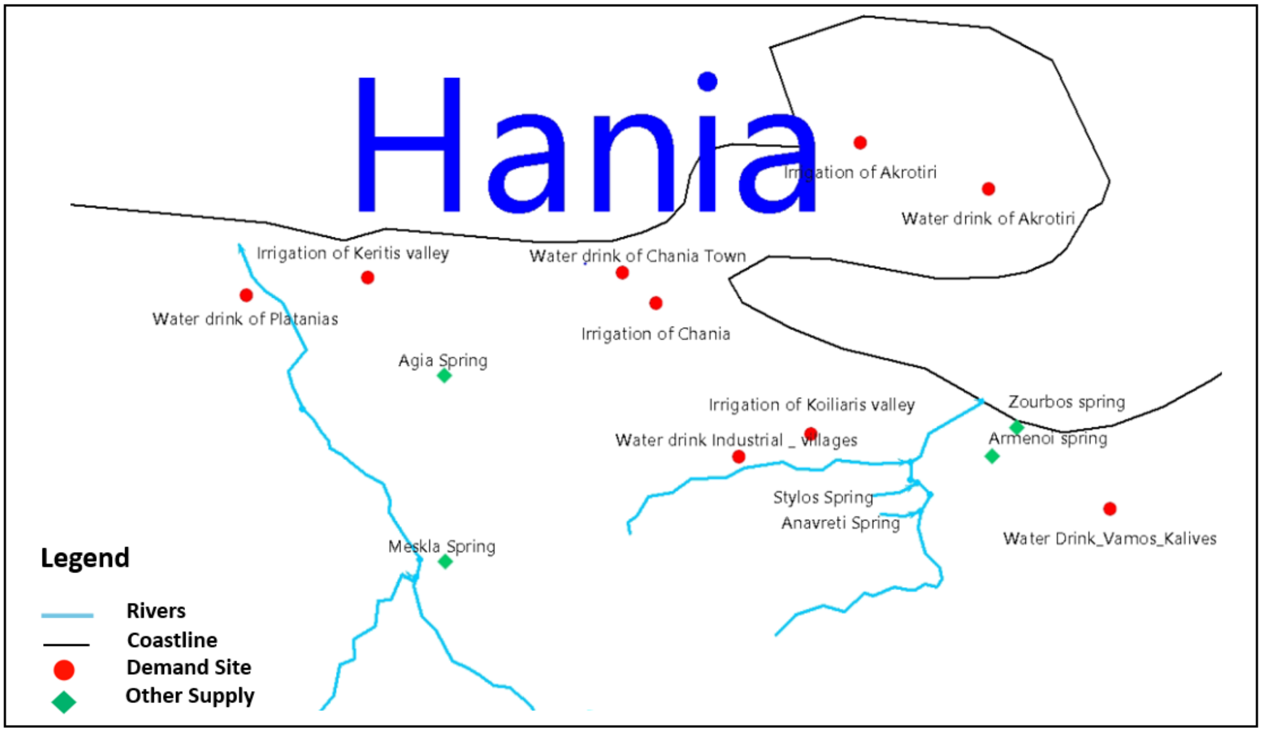

Figure 3-9: Other supply of Case study

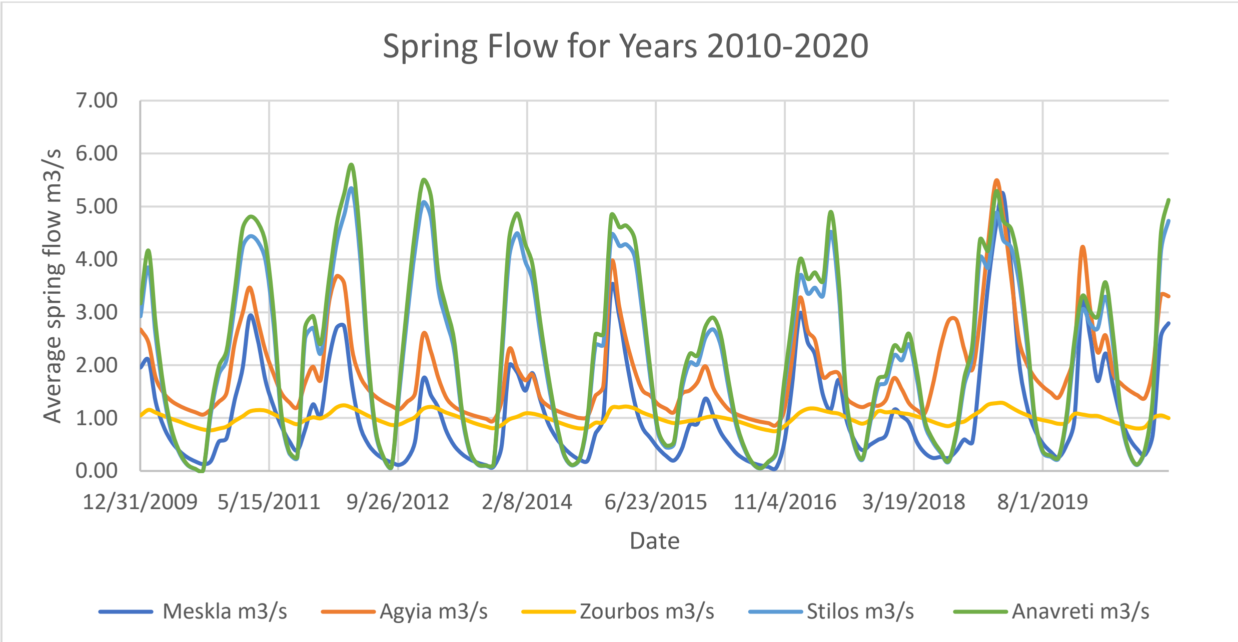

Figure 3-10: Average Spring flow (cms)

3.1.4. Reservoir

In the Keritis River Basin, three organizations pump and manage the distribution of water to meet both drinking and irrigation needs. For a more realistic representation of the water distribution network in this area, we depicted these organizations as small-capacity reservoirs since the aforementioned organizations do not have the ability to store water (Figure 3-11). The average flow per second in a monthly time step that each organization pumps for the years 2010-2020 is presented in Figure 3-12. Furthermore, in the study area, there is a reservoir known as "Valsamiotis." This reservoir receives an amount of water from the ODWC to sustain the functionality of the dam and the flora and fauna that have been established there.

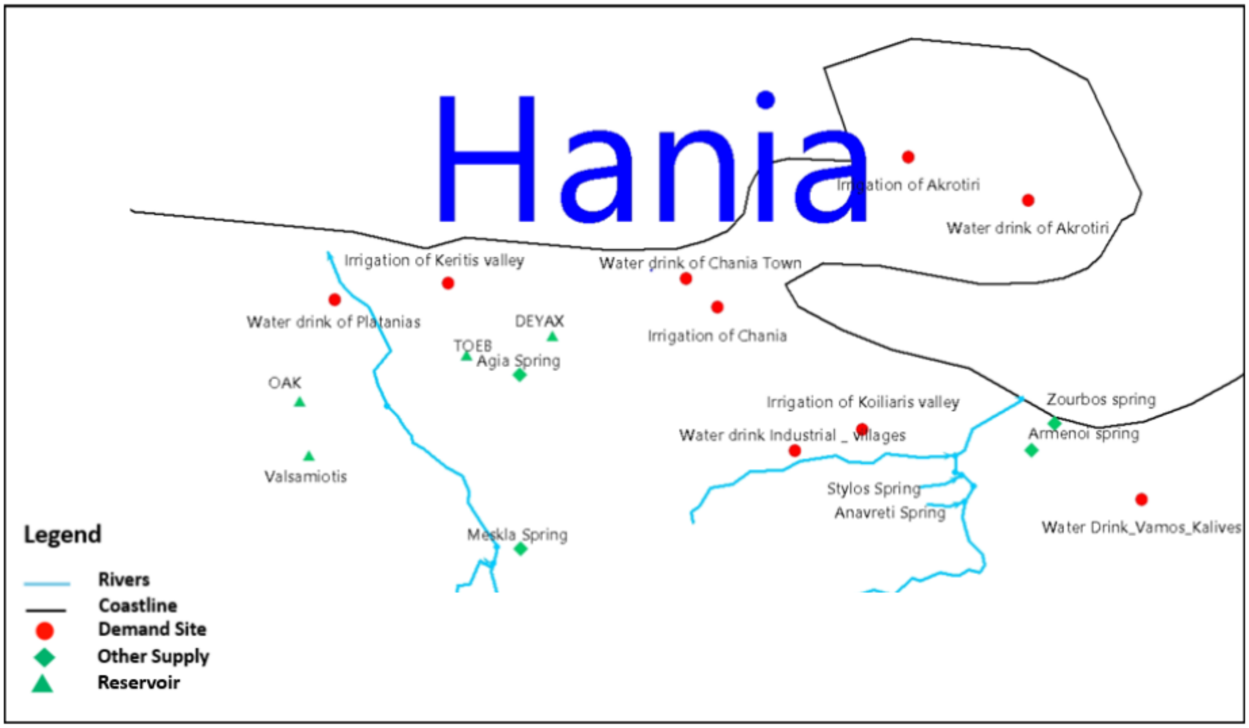

Figure 3-11: Reservoirs of Case study

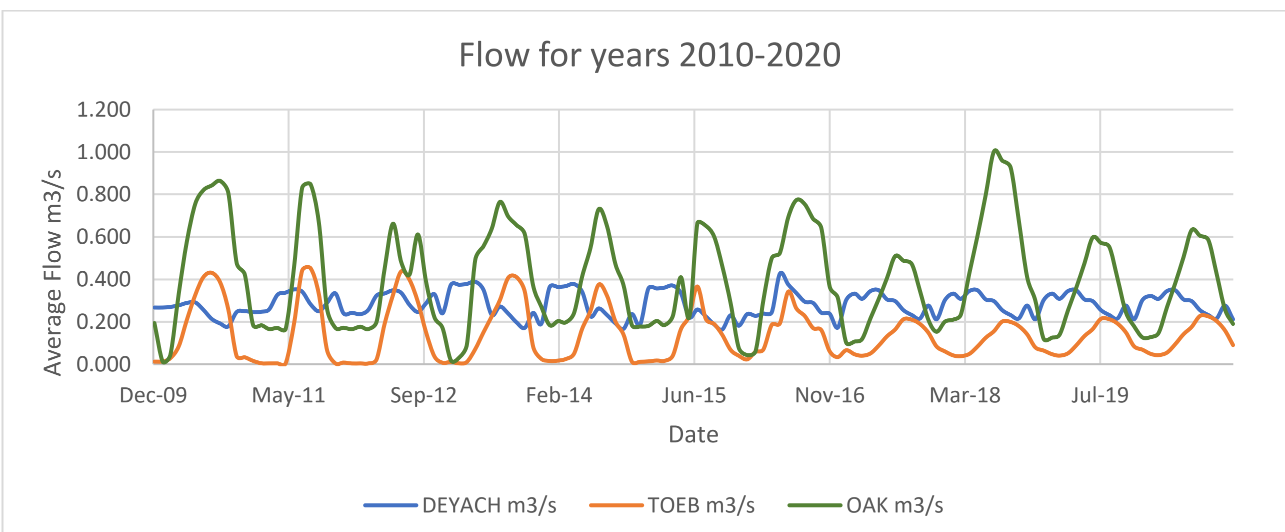

Figure 3-12: Average Flow (cms) that organizations pump

3.1.5. Groundwater

In the case study a main groundwater point pump water, “Myloniana gw” with storage 1.7 cubic meters (Figure 3-13).

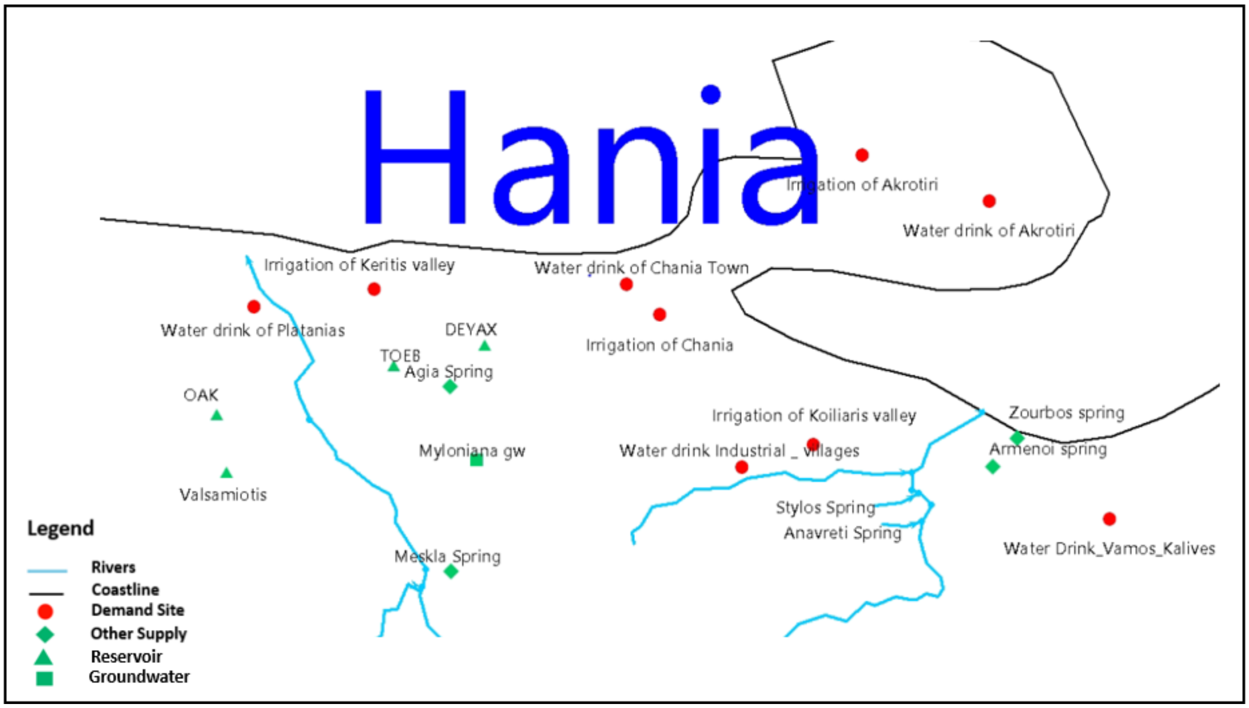

Figure 3-13: Groundwater of case study

3.1.6. Transmission Link/Return Flow

After inserting all points, it was necessary to establish correlations with a Transmission Link between the available resources and the demand sites (Figure 3-14). For each demand site, it is essential to account for return flow (water lost from the system). In the case study, water is indeed lost from the system. However, the model lacks the capability to simulate this scenario. Consequently, the return flow is directed to the ends of rivers. These points were chosen because they do not affect the overall simulation.

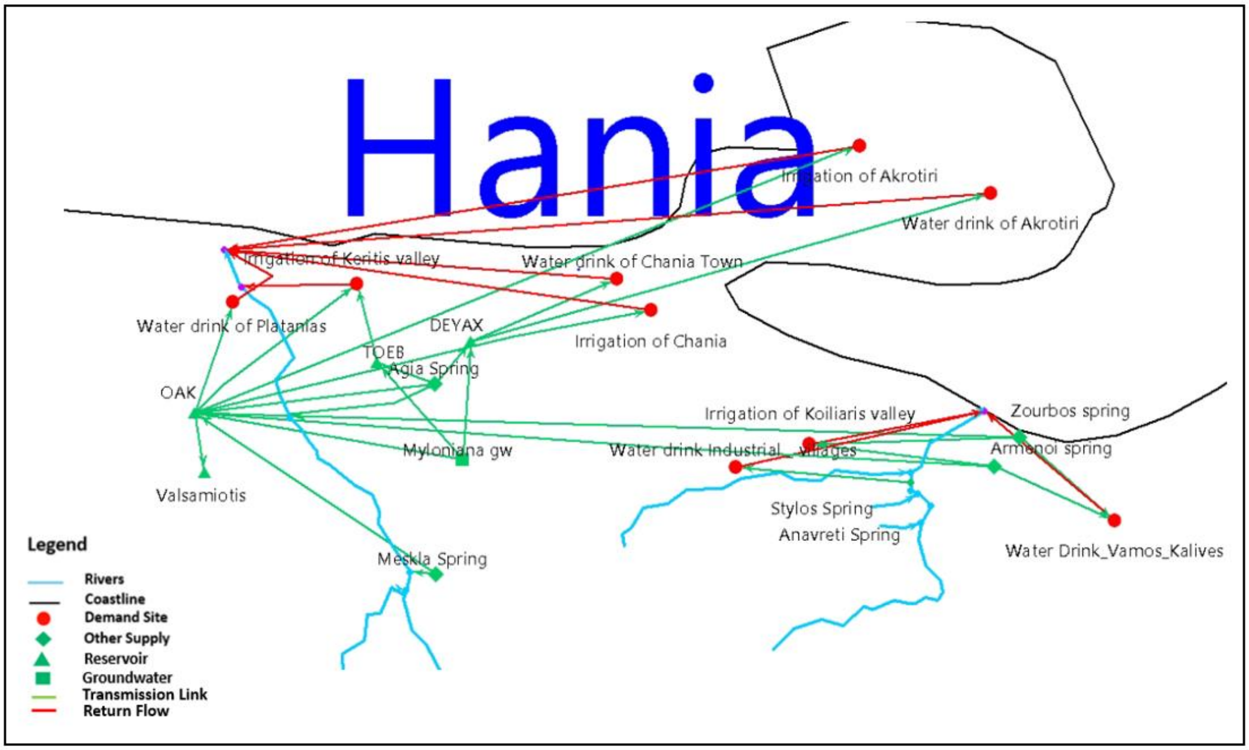

Figure 3-14: Transmission Link & Return Flow of Case study

3.1.7. Streamflow Gauge

In this step, it was necessary to input points that would correspond to field data to validate the model's reliability. Due to a lack of field data, we utilized the calibrated total discharge output by the SWAT-Karst model before the river's outflow into the sea. More specifically, this discharge includes both the river's surface flow and the flow entering from the karstic spring system. The average streamflow data are presented in Figure 3-15.

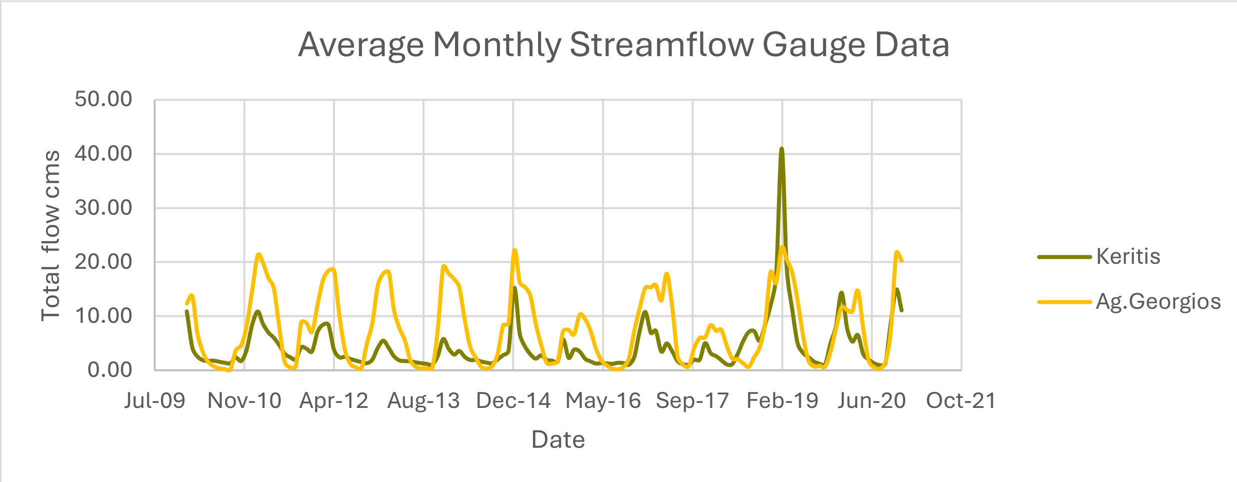

Figure 3-15: Flows that are used for the evaluation of the model.

3.1.8. Climate change Scenarios

Climate projections are generated using two types of models: Global Climate Models (GCMs), which simulate the climate globally, and Regional Climate Models (RCMs), designed to simulate the climate for specific regions (Jonathan M. E.,2014). GCMs typically operate at a spatial resolution ranging from 50 to 250 km and demand significant computational power and time. RCMs were primarily developed to refine climate data produced by coarse-resolution GCMs, offering detailed information at finer, sub-GCM grid scales more suitable for studying regional phenomena and conducting climate risk assessments. The disparities between the results of RCMs and GCMs arise from the former depicting global circulation, considering large-scale factors like greenhouse gases (GHGs) or solar radiation fluctuations. In contrast, the latter enhances this information both spatially and temporally, incorporating finer-scale details such as topography, coastlines, inland water bodies, land cover, or mid-range dynamic processes (Giorgi, 2019).

The spatial resolution of GCM simulations is deemed appropriate for climate analysis on a larger geographic scale (European, Mediterranean, etc.) but not at the local level. This limitation arises because the average climatic conditions in broader areas significantly differ from those specific to smaller regions. Consequently, a thorough analysis at the local scale was deemed necessary, employing RCM simulations based on the RCPs. Among the four RCPs outlined by the IPCC (2013), RCP4.5 and RCP8.5 were chosen. The former serves to examine a more realistic mitigation scenario as an intermediate option according to emissions, while the latter represents a scenario capturing GHG emissions in the absence of mitigation measures (IPCC, 2013). Specifically, RCP4.5 envisions the stabilization of radiative forcing at 4.5 W/m² by the year 2100 without surpassing that value (Thomson et al., 2011), whereas RCP8.5 anticipates that radiative forcing will exceed 8.5 W/m² by 2100 and continue to rise for a certain duration (Riahi et al., 2011).

In our case study, we utilized the new scenario data (precipitation, temperature) from 2023-2100 to configure the SWAT-Karst model. This has resulted in the calculation of new flows for rivers and springs, which are then incorporated into the WEAP model. The meteorological stations used to set up the model it was for the period 2010-2020 are Alikianos, Meskla, Askifou, Kalives, Samonas, Psichro Pigadi, and Agrokipio.

Before using precipitation and temperature data for 2023-2100 RCP4.5 and RCP8.5, it was necessary to examine the reliability of them. From the scenarios selected and compared the period 2010-2020 in which observed data are available from local meteorological stations. As depicted in the Figures 3-16 and 3-17 below, we have concluded that the RCM data does not align well with the observed values of the case study. Consequently, the application of bias correction became necessary.

Firstly, we calculated the average monthly precipitation/temperature for 1971-2000 for both scenarios and the local stations. Subsequently, we determined their respective ratios, which were applied to the daily data. The ratios for each station, regarding precipitation and temperature, are depicted in Tables 3-8 and 3-9.

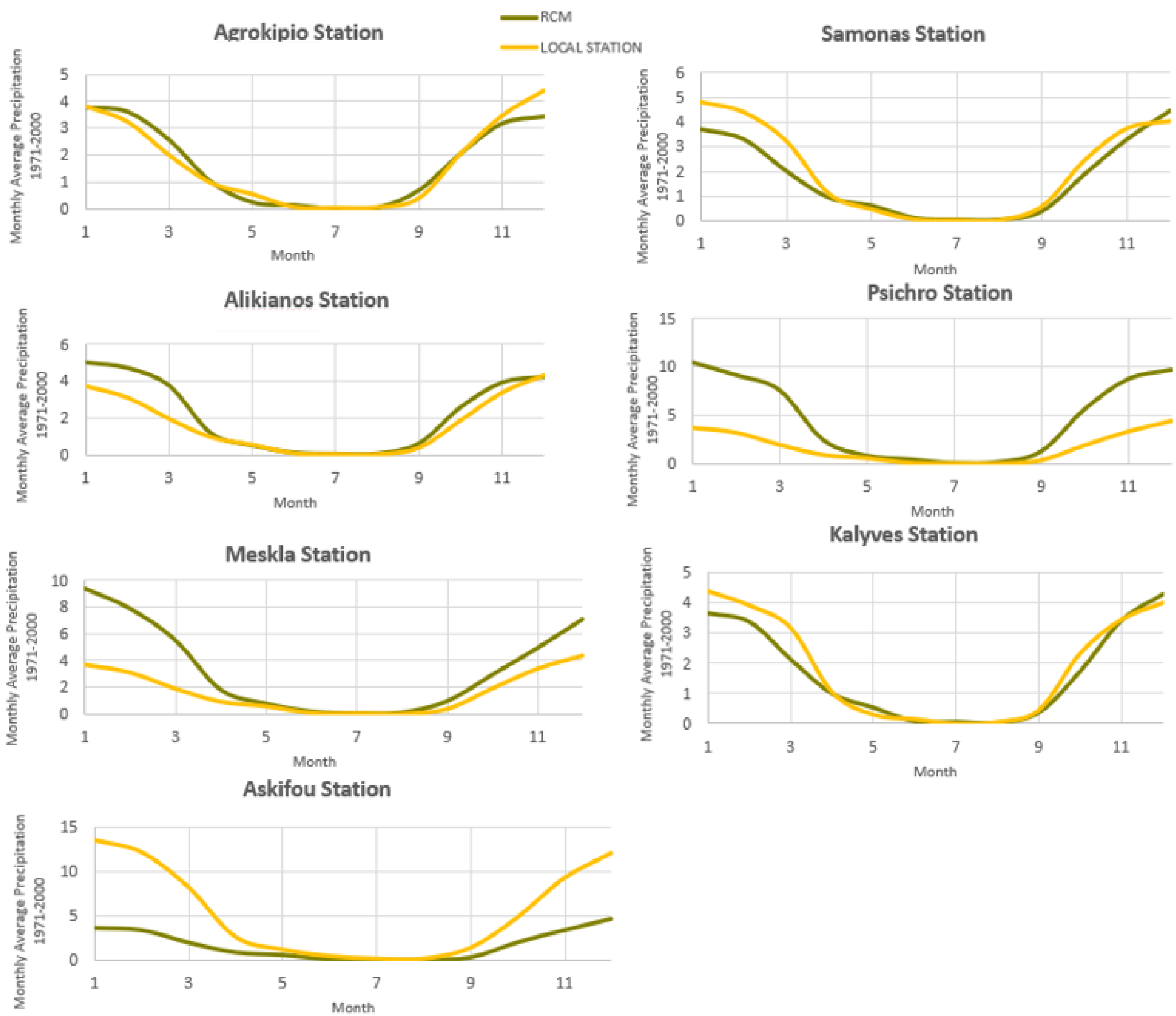

Figure 3-16: Comparison of precipitation data from the model with local weather stations.

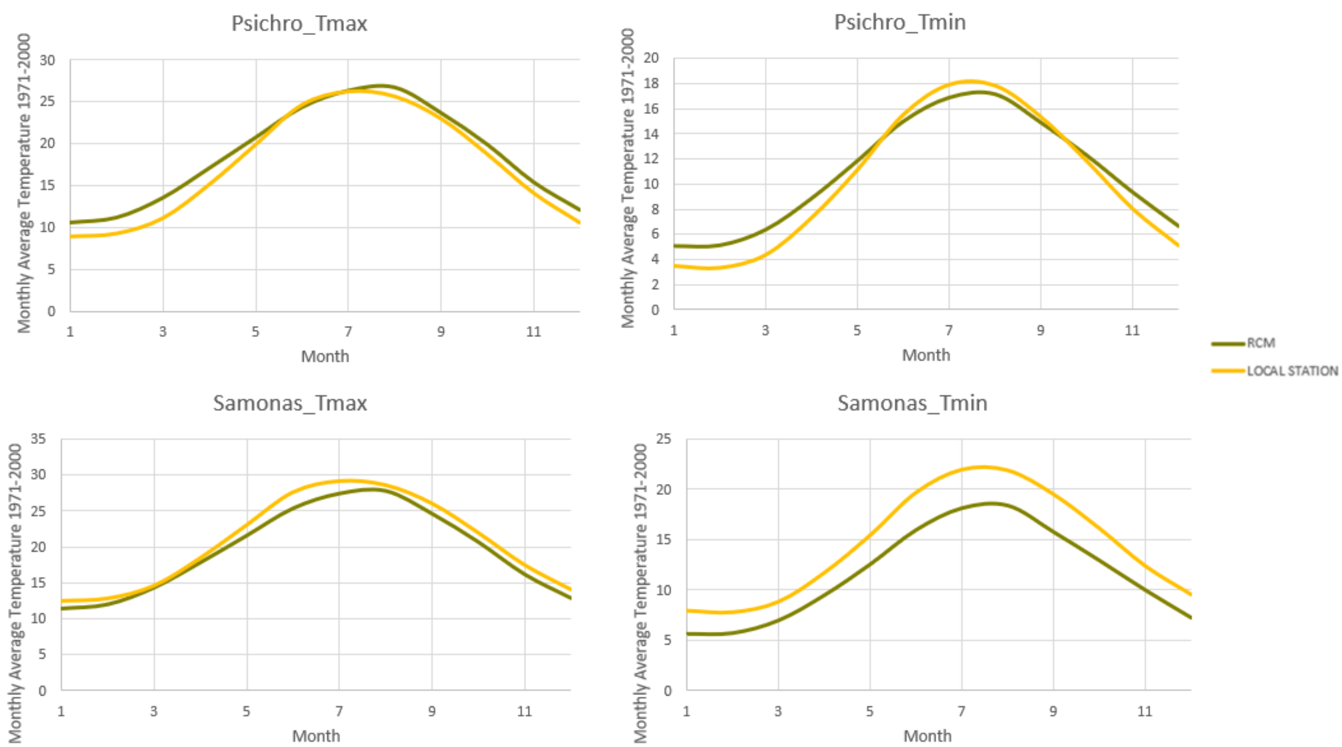

Figure 3-17: Comparison of temperature data from the model with local weather stations.

Table 3-8: Correction factor for each station for precipitation.

Month	Agrokipio	Alikianos	Meskla	Psichro	Samwnas	Kalyves	Askifou
Jan	1.01	0.75	0.40	0.35	1.30	1.20	3.74
Feb	0.89	0.67	0.40	0.35	1.34	1.17	3.61
Mar	0.78	0.53	0.35	0.26	1.62	1.50	4.19
Apr	0.95	0.84	0.51	0.38	1.20	1.05	3.01
May	2.15	1.13	0.76	0.77	0.81	0.57	2.02
Jun	0.47	0.94	0.50	0.28	0.81	1.85	4.50
Jul	5.01	1.17	0.91	4.20	1.07	0.10	7.01
Aug	1.04	0.86	0.34	0.40	1.30	1.50	4.43
Sep	0.57	0.66	0.40	0.31	1.58	1.21	4.66
Oct	0.99	0.74	0.65	0.34	1.31	1.34	2.41
Nov	1.09	0.87	0.69	0.38	1.13	1.01	2.74
Dec	1.28	1.03	0.62	0.45	0.91	0.94	2.59

Table 3-9: Correction factor for each station for temperature.

Month	Psichro_Tmax	Psichro_Tmin	Samonas_Tmax	Samonas_Tmin
Jan	0.84	0.69	1.09	1.41
Feb	0.83	0.66	1.07	1.36
Mar	0.82	0.69	1.02	1.27
Apr	0.88	0.83	1.03	1.23
May	0.96	0.94	1.07	1.23
Jun	1.01	1.03	1.09	1.23
Jul	1.00	1.06	1.06	1.21
Aug	0.96	1.03	1.03	1.19
Sep	0.97	1.03	1.05	1.23
Oct	0.94	0.96	1.06	1.24
Nov	0.91	0.86	1.08	1.24
Dec	0.87	0.77	1.09	1.32

4. Results

The results of the WEAP model indicate that the simulation of Keritis River was characterized as "satisfactory" according to statistical indicators NSE and RSR that calculated 0.58 and 0.65 (Figure 4-1). In Ag.Georgios River, the simulation characterized as " Very Good". The NSE calculated 0.92 and RSR 0.28 (Figure 4-2). The conclusion of the calculations above present us that the setup of the model and the data that has been used are reliable to describe the case study.

Moreover, for the period that model was calculated and for the scenarios RCP4.5 & RCP8.5 conclude that there is not and will not appear unmet demand in case study.

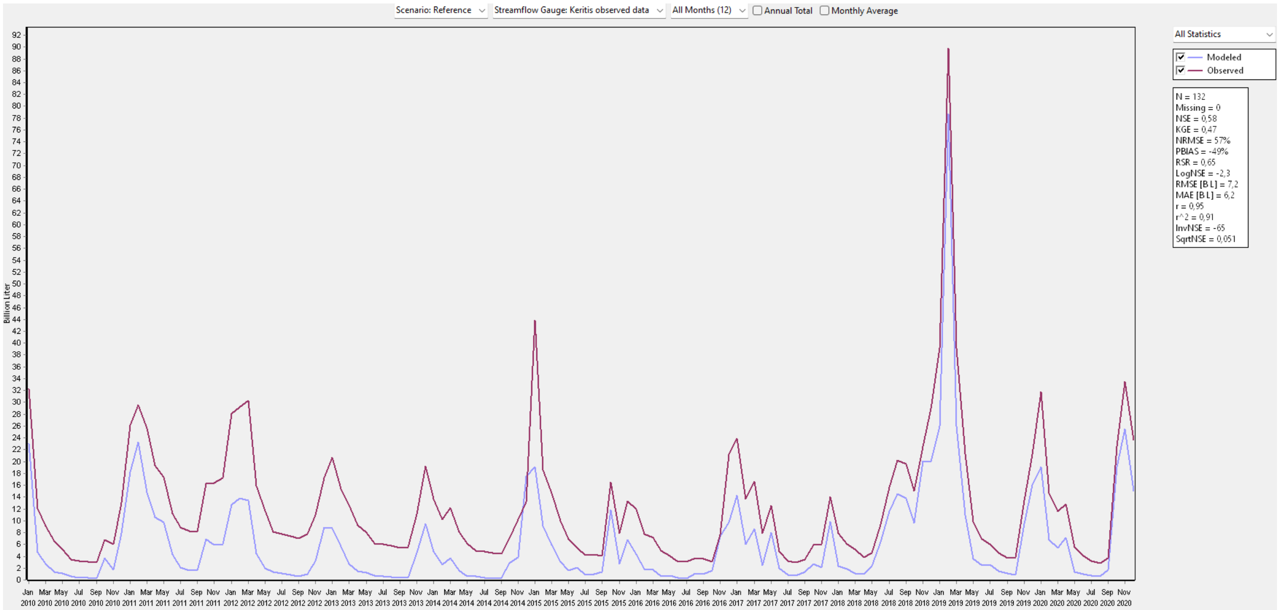

Figure 4-1: Comparison in Keritis River Basin

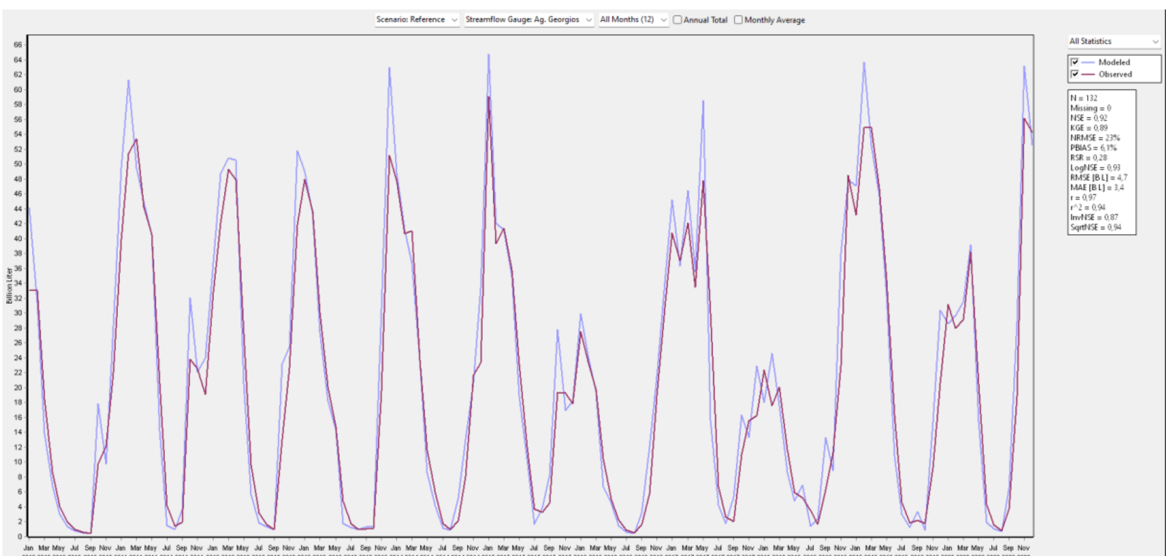

Figure 4-2: Comparison in Koiliaris River Basin

The monthly average surface flow in cubic meters per second (cms) of the two main rivers, 'Koiliaris' and 'Keritis,' under two scenarios (RCP4.5, RCP8.5) for the years 2022-2100, is depicted in Figure 4-3 and Figure 4-4. Tables 4-1 and 4-2 present the statistical properties of the river Basins.

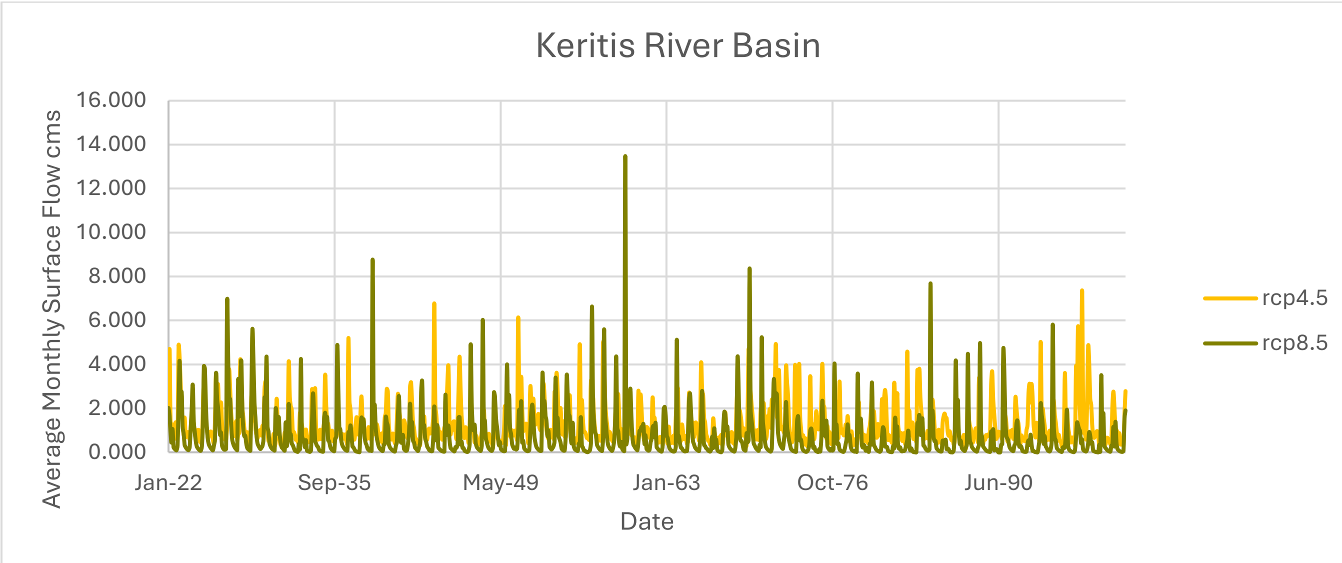

Figure 4-3: Surface flow of Keritis river for each scenario

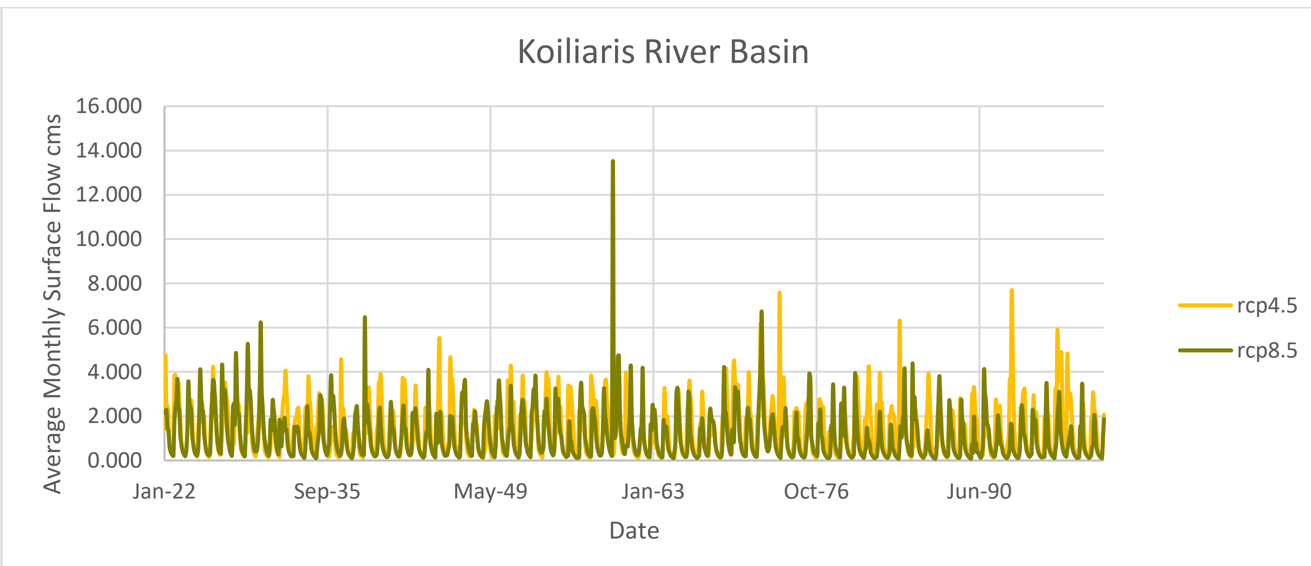

Figure 4-4: Surface flow of Koiliaris river for each scenario

Table 4-1: Statistical properties of climate change outcomes in Keritis River Basin

Keritis River Basin	Reference Period		RCP4.5		RCP 8.5	
	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.
	1.99	6.32	1.27	0.96	0.75	1.16

Table 4-2:Statistical properties of climate change outcomes in Koiliaris River Basin

Koiliaris River Basin	Reference Period		RCP4.5		RCP 8.5	
	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.
	2.04	2.02	1.38	1.17	1.10	1.11

5. Conclusion

This research evaluated the existing available water resources in the broader area of Chania and examined unmet demand about temperature and precipitation variability. The combination of the hydrologic Karst-SWAT model and the management WEAP model serves as a reliable tool for assessing current conditions, making predictions, and managing challenges related to climate change.

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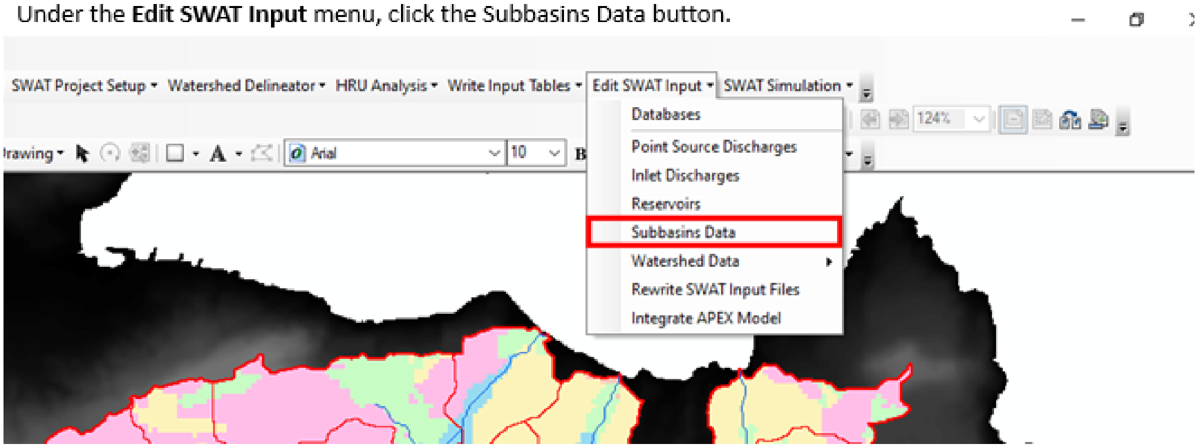
7. Appendix

After completing the modeling of hydrology and nitrates, which is described in the paper" Sediment Transport in the Koiliaris River of Crete" the application of Nature-Based Solutions (NBS) follows. The process of implementing NBS is described below.

01 EDIT SWAT INPUT MENU

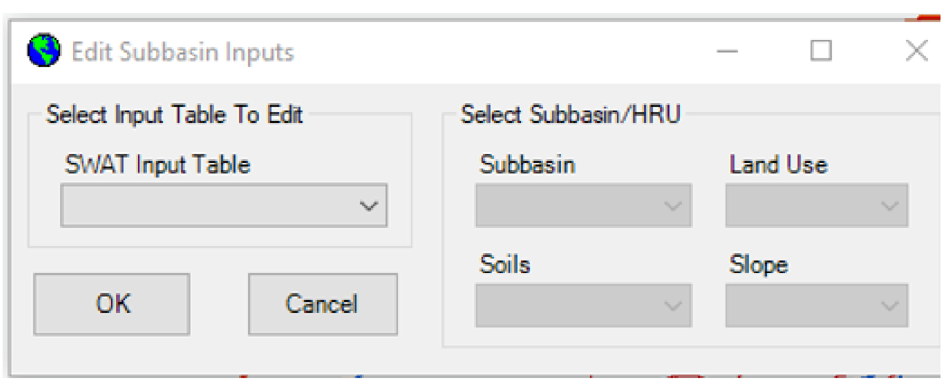
Under the **Edit SWAT Input** menu, click the Subbasins Data button.



02 EDIT SWAT INPUT WINDOW

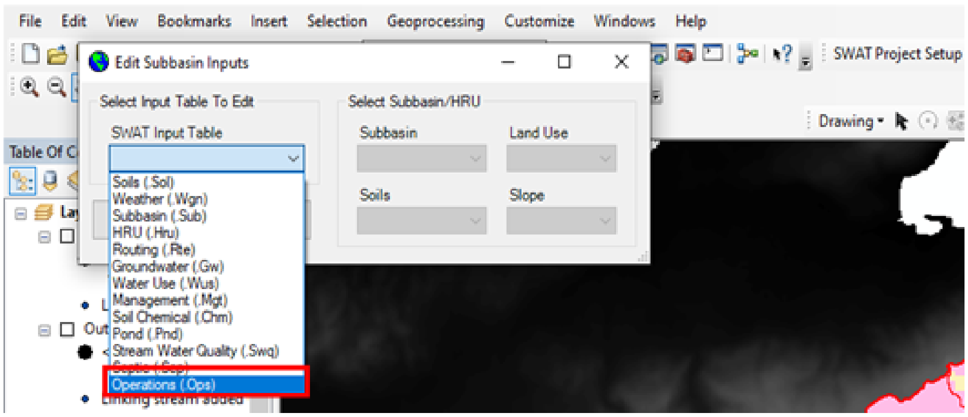
The **Edit SWAT Input** window will appear. This tool is divided into the following sections:

- Select Input Table To Edit
- Select Subbasin/HRU



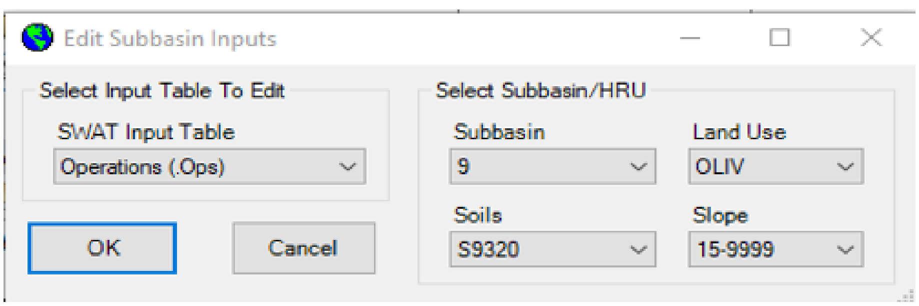
03 SELECT INPUT TABLE TO EDIT WINDOW

In the Select Input Table To Edit section, the user must select the appropriate SWAT Input Table. The appropriate table concerning the implementation of NBS is the "operations (Ops)" table.



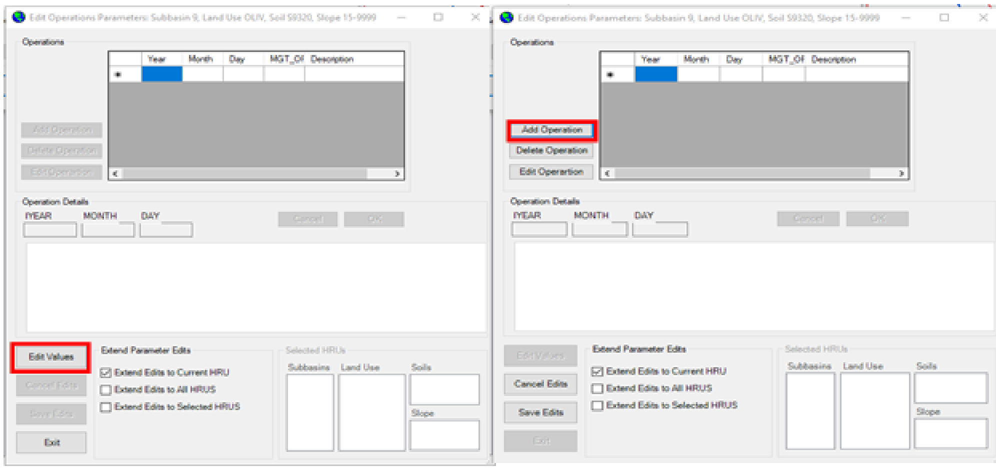
04 SELECT SUBBASIN/HRU WINDOW

In the Select Subbasin/HRU section, the user needs to select the HRU in which want to implement NBS. The HRU will be determined by choosing the Subbasin, Land Use, Soils and Slope.



05 INPUT OPERATION

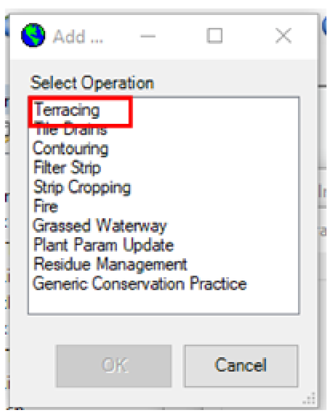
A new window will pop up. To input an operation, first click on the "Edit Values" button and then select "Add operation."



06 SELECT OPERATION

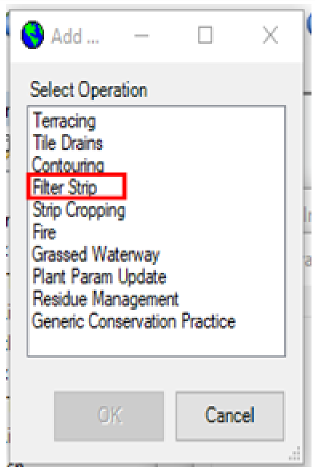
B. Terracing

In this step we are going to select the operation we want. In this case "Terracing" is selected.



A. Riparian Forest

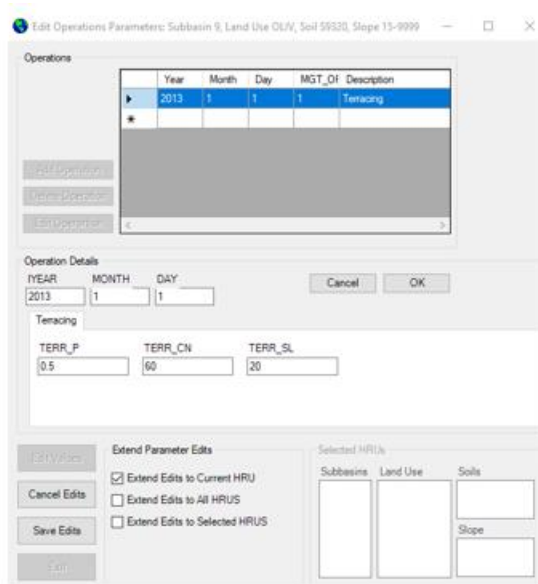
To create riparian forest, we are going to select the "Filter Strip."



07 OPERATION DETAILS

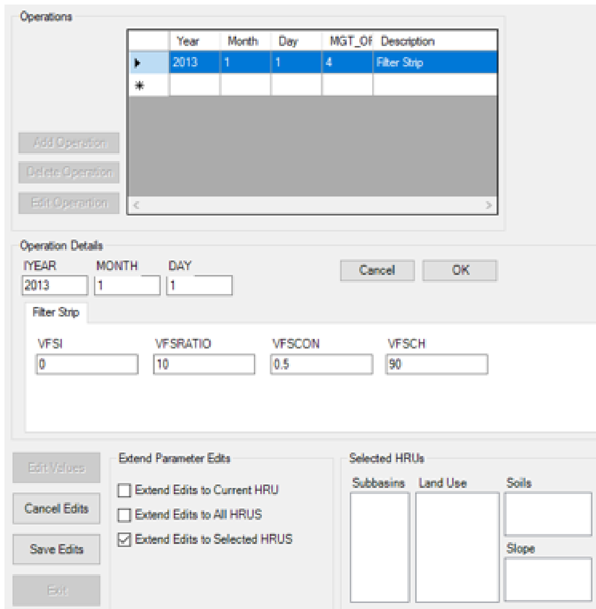
A. Terracing

In this window, we input the characteristics of Terracing. More details about the values are described in the Theoretical documentation (version 2009) of Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2011) in the Soil and Water Assessment Tool.



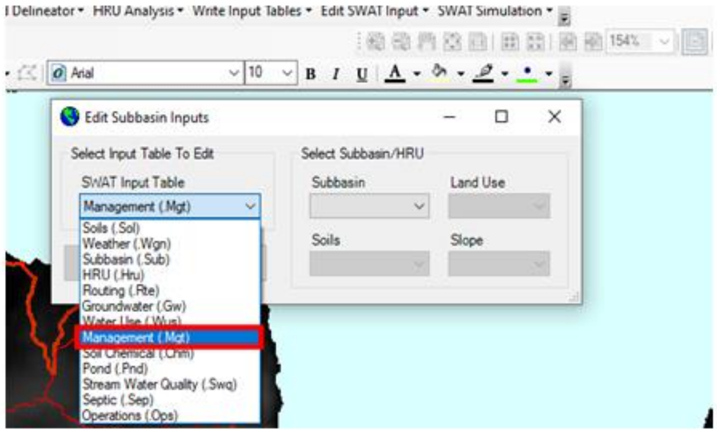
B. Riparian Forest

In this window, we input the characteristics of Filter Strip. More details about the values are described in the Theoretical documentation (version 2009) of Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2011) in the Soil and Water Assessment Tool.



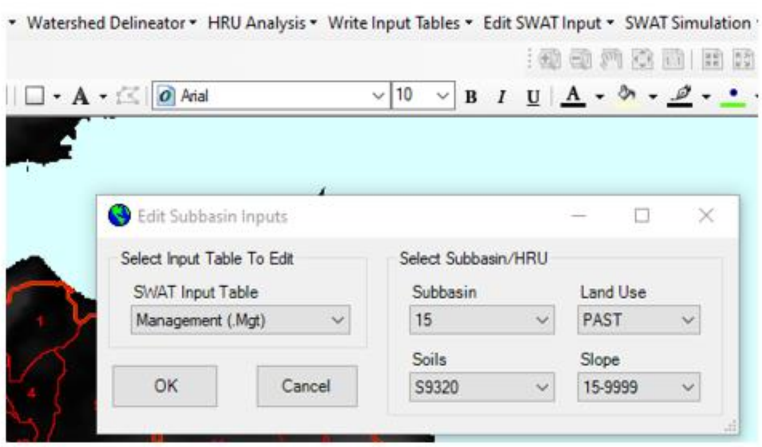
To implement established livestock farming, that is, to remove the presence of sheep/goats from grazing areas in mountainous regions, we will go back to step 3 and choose the "Management (.Mgt) table" as shown below.

08 SELECT INPUT TABLE TO EDIT



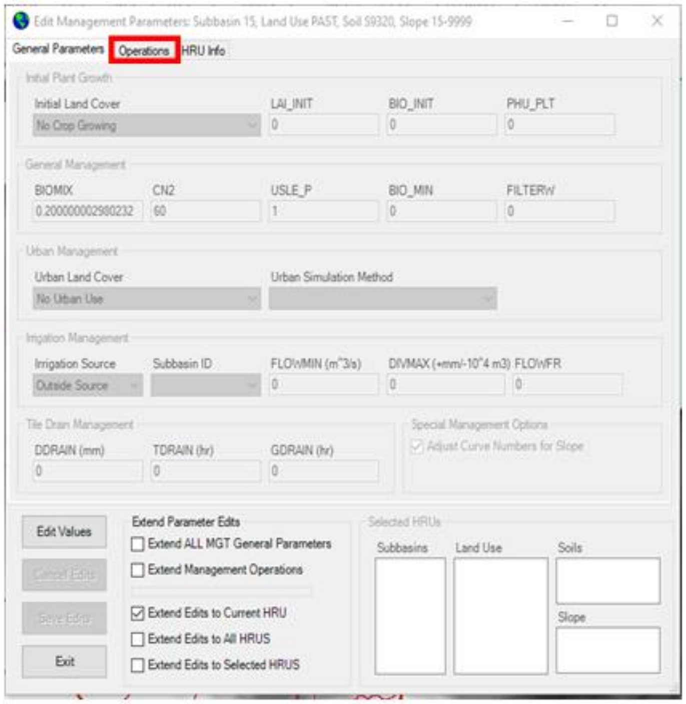
09 SELECT SUBBASIN/HRU WINDOW

In the Select Subbasin/HRU section, the user needs to select the HRU in which want to remove the presence of sheep/goats. The HRU will be determined by choosing the Subbasin, Land Use, Soils and Slope.



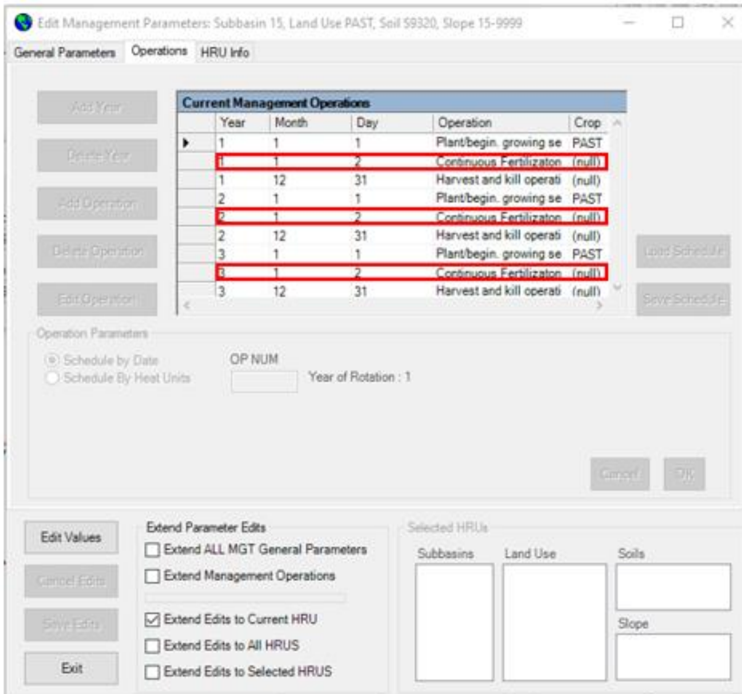
10 EDIT MANAGEMENT PARAMETERS

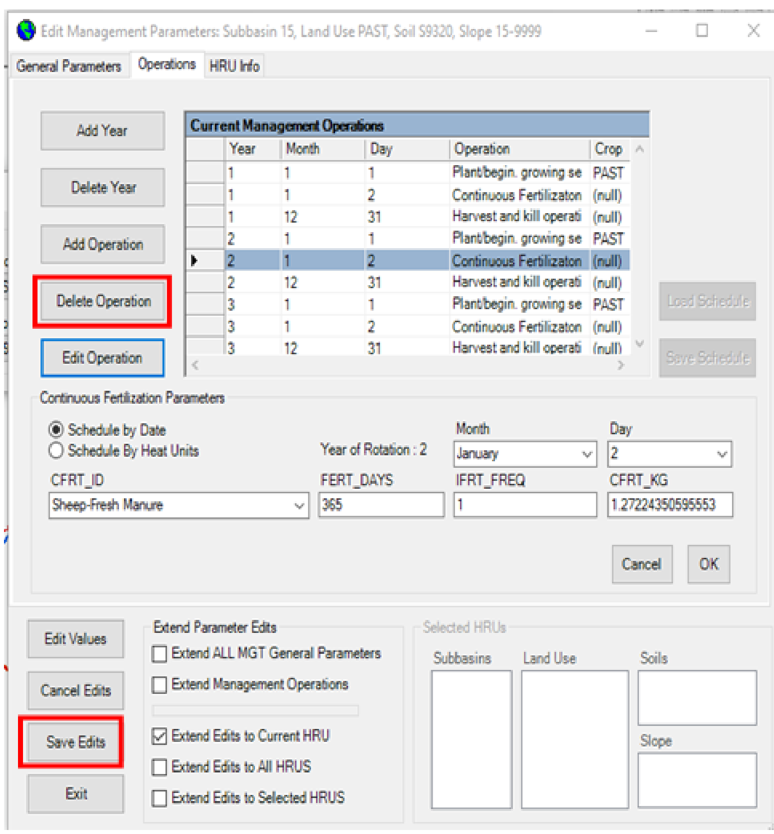
In pop up window which concerns the parameters of management, we select the tab "operations."



11 SELECT SUBBASIN/HRU WINDOW

At this step, we delete the existing processes that indicate the presence of sheep/goats. After make sure that the "continuous fertilization" refers to manure, we deleted the operation. In the second figure of this step presents information about sheep/goats' fertilization.


Edit Management Parameters: Subbasin 15, Land Use PAST, Soil S9320, Slope 15-9999
General Parameters
Operations
HRU Info
Current Management Operations
Year
Month
Day
Operation
Crop
Plant/begin. growing se
Continuous Fertilizaton
Harvest and kill operati
PAST
(null)
Load Schedule
Save Schedule
Operation Parameters
Schedule by Date
Schedule By Heat Units
OP NUM
Year of Rotation : 1
Cancel
OK
Edit Values
Cancel Edits
Save Edits
Exit
Extend Parameter Edits
Extend ALL MGT General Parameters
Extend Management Operations
Extend Edits to Current HRU
Extend Edits to All HRUS
Extend Edits to Selected HRUS
Selected HRUs
Subbasins
Land Use
Soils
Slope


Edit Management Parameters: Subbasin 15, Land Use PAST, Soil S9320, Slope 15-9999
General Parameters
Operations
HRU Info
Add Year
Delete Year
Add Operation
Delete Operation
Edit Operation
Current Management Operations
Year
Month
Day
Operation
Crop
Plant/begin. growing se
Continuous Fertilizaton
Harvest and kill operati
PAST
(null)
Load Schedule
Save Schedule
Continuous Fertilization Parameters
Schedule by Date
Schedule By Heat Units
Year of Rotation : 2
Month
January
Day
2
CFRT_ID
Sheep-Fresh Manure
FERT_DAYS
365
IFRT_FREQ
1
CFRT_KG
1.27224350595553
Cancel
OK
Edit Values
Cancel Edits
Save Edits
Exit
Extend Parameter Edits
Extend ALL MGT General Parameters
Extend Management Operations
Extend Edits to Current HRU
Extend Edits to All HRUS
Extend Edits to Selected HRUS
Selected HRUs
Subbasins
Land Use
Soils
Slope