TECHNICAL UNIVERSITY OF CRETE

SCHOOL OF ENVIRONMENTAL ENGINEERING

MASTER THESIS:

«A recharge suitability assessment for the Geropotamos aquifer in the Messara area of the island of Crete»

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Chania, 2020

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my supervisor Prof.Georgio Karatza and Dr.Varouchaki Emmanouil, for their valuable contribution and helpful advice throughout my Diploma Thesis, as well as my family and friends for their support. Finally, I would like to thank Prof.Nikolaidi Nikolao and Dr.Varouchaki Emmanouil for their participation in the examination Committee.

ABSTRACT

Throughout the Mediterranean region, semi-arid climate in conjunction with intensive agriculture are stressing scarce groundwater supplies which are over-exploited to cover irrigation water demands. Such a case is the Messara Basin in the island of Crete. This has led to increased costs associated with groundwater extraction, seawater intrusion along the coastal zone, and negative environmental impacts (disappearance of wetlands). As a result, and in order to stabilize groundwater levels, managerial measures on groundwater withdrawals were imposed by the government in 2017. These regulations prohibit, among others, the drilling of new wells, the groundwater withdrawals above certain limits and the modification of current infrastructure related to groundwater production. According to the recent Water Resources Management Plan (WRMP) for the Water District of Crete targets for the improvement of the quality and quantity of the degraded groundwater bodies in the Geropotamos Basin have been set based on the EU Water Framework Directive. According to the regional authorities, groundwater pumping is not expected to stop and it was suggested within the WRMP the consideration of appropriate managed aquifer recharge, suitability studies and assessments.

The present study was developed in the framework of the postgraduate studies of the Department of Environmental Engineering at the Technical University of Crete and deals with the identification of the areas that are most suitable for the aquifer recharge, in the area of the Geropotamos basin, using GIS multi-criteria decision analysis (GIS-MCDA) method to identify suitable sites for implementing MAR (Managed Aquifer Recharge) type spreading method.

The criteria combining a high relevance and high data availability, and providing unique information , selected to assess the suitability of MAR spreading methods in Geropotamos basin are slope, land use, hydrogeology, rainfall, groundwater level, soil texture and distance to source water. This study uses the 'Pairwise comparison' to assign criteria weights, developed by Saaty (1980) as part of the AHP.

In this study were examined 4 scenarios. In the first scenario was not taken into account the criterion of distance to the water source. In the second scenario was added to the criteria the distance to the dam of Faneromeni. In the third scenario was added the criterion of distance to the river of Geropotamos. Finally, in the fourth scenario, was added to the criteria both, distance to the dam of Faneromeni and the river of Geropotamos.

In all 4 scenarios the areas that are west of the study area and close to the river Geropotamos, coincide as the most suitable for aquifer recharge.

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1. INTRODUCTION

Water is a unique natural resource as it is essential for the survival of humans and other organisms.

In particular, groundwater is the largest freshwater reservoir in the world. To date, it is mainly used for water supply needs (approximately 75% of the inhabitants of the European Union depend on underground reserves for the supply of water for human consumption). It is also a very important resource for meeting the needs of water in industry and agriculture (irrigation).

However, it is wrong to treat groundwater only as a good quality water tank where water will be pumped for various uses, as it has great environmental value and it is important for the water resources to be protected. Groundwater plays a catalytic role in the hydrological cycle and is important for conserving wetlands and rivers, especially during periods of drought, as they ensure their permanent flow.

Recently,in most of the European rivers 50% of their annual flow comes from groundwater. During summer that percentage reaches up to 90% in some rivers. That is why the deterioration of groundwater quality can directly affect aquatic and terrestrial ecosystems. There has also been a reduction in water resources as well as pollution due to various human activities and climate change.

A typical field case is Messara valley, which is located in Geropotamos basin in the south-central part of Crete (figure 1). The economy and development of the region is mainly based on the primary sector with the cultivation of intensive aquaculture and less on tourism. The climatic conditions in the area are characterized as dry, especially in the summer, which creates an increased demand of water. During the summer, the irrigation needs are covered exclusively by the groundwater of the basin aquifer, the exploitation of which began in the 1980s. (Kritsotakis, 2009).

As a result, the groundwater of the Geropotamos basin has undergone a huge reduction due to over-exploitation, in combination with the climatic conditions of the area as well as the deterioration of the water quality (pollution), with devastating effects on the environment and economy.

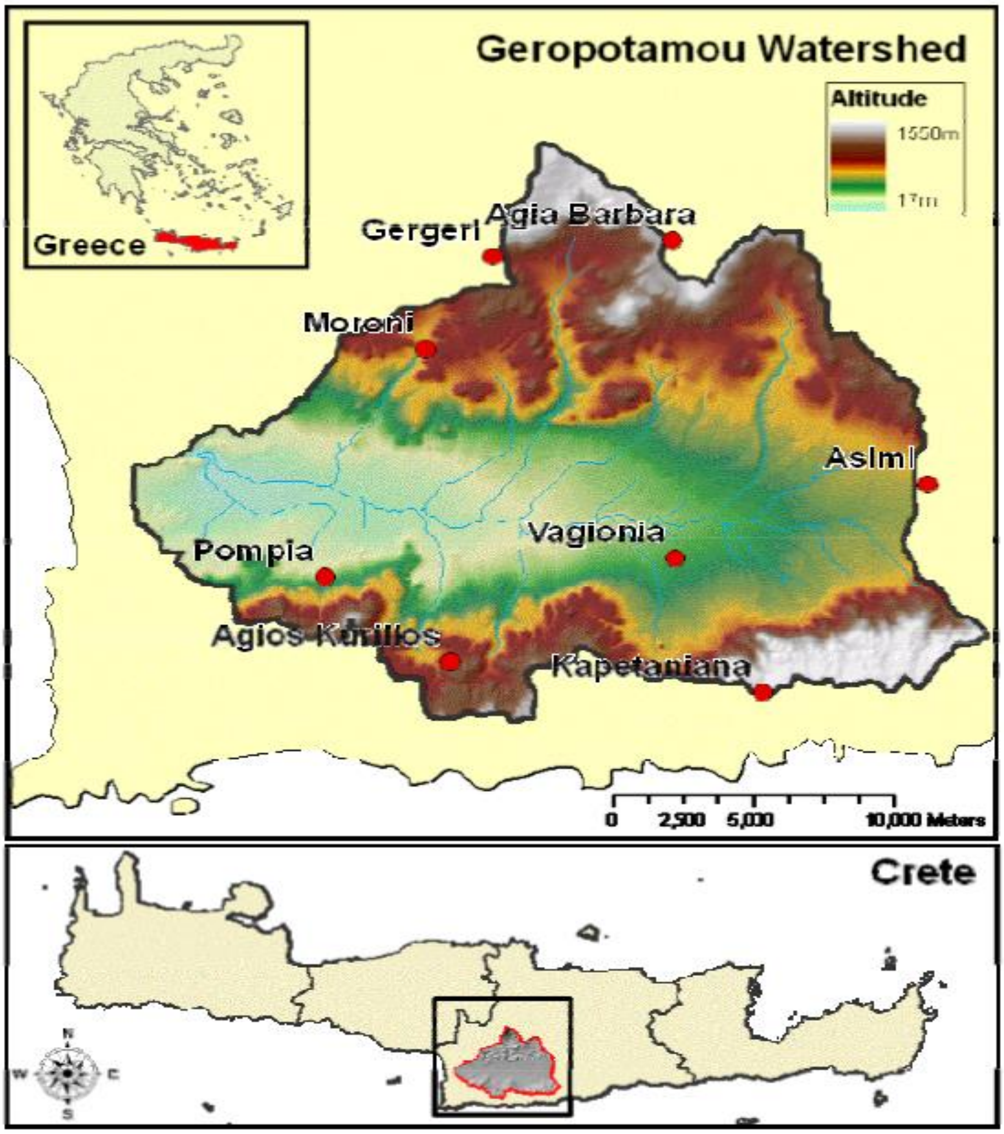

Figure 1. Location of Geropotamou basin (Tsanis et all, 2006)

In most of the Geropotamos basin, groundwater is being over-exploited and polluted. This is because most areas are arable. So it is necessary to enforce measures in order to improve groundwater quality and quantity..

To deal with the above phenomenon, in the year 1995 a small diversion dam was built in the riverbed of the river Geropotamos (of about 2.5 m high) in the area of the Municipality of Mires in order to create recharge conditions for the aquifer of Messara (Figure 2,3).

Figure 2. Diversion dam on the river Geropotamos (Bouloukakis, 2007)

Figure 3. Transmission channel of water for the recharge of the Messara aquifer. (Bouloukakis , 2007)

To apply aquifer recharge to an area, it is appropriate to perform a study of suitability analysis in the study area. Generally, the suitability analysis consists of:

Socio-economic analysis: Socio-economic data give insights on the spatial distribution of current sectoral water demand and supply. Water withdrawals, procurements and use are mapped and provide the basis for assessing the sustainability of the current management strategies. This analysis identifies areas of agricultural, domestic, and industrial water demand, the proportions of surface water/groundwater covering the demand and the identification of (seasonal) deficits in supply.

Surface feasibility: Surface characteristics are analyzed to assess the potential applying suitable MAR applications. The combination of parameters related to surficial geology (outcrops), soil characteristics, land use and cover, elevation, slope, flow accumulation, etc. define the surface feasibility.

Subsurface feasibility: Characteristics of the subsurface are analyzed to assess whether the physiographic conditions are suitable at a given location to host a MAR application. The required information is obtained from hydrogeological and lithological maps, data from geophysical surveys, borehole information on subsurface lithology, mineralogy, groundwater levels and groundwater quality. Areas composed of alluvial deposits are ideal, from a hydrogeological point of view, for the application of free infiltration techniques such as pond recharge, infiltration basins, and retention dams/river bank filtration (if streams are present). Impermeable layers are not to be excluded as well-infiltration methods can be implemented if MAR interventions are required.

Source water availability: The availability of excess surface water which can be used for aquifer recharge is obviously a prerequisite for the implementation of any MAR application. Analysis of source water availability consists of assessing the type, quantity, quality, and temporal availability of surface water. The source water can be obtained from reservoirs (e.g. Faneromeni dam), excess surface runoff (streams), harvested rainwater and treated wastewater. The seasonal availability of stream runoff is analyzed and water balances are computed for the calculation of water volumes which are lost directly and indirectly to the sea. Direct losses consist of excess streamflow which is lost to the sea. The term “excess” indicates that the streamflow is above the minimum environmental requirements so that it is available for artificial recharge. Indirect losses consist of the fraction of streamflow which naturally recharges karstic systems further downstream and are consequently lost to the sea via springs along the coastline. The exploitable freshwater volume at a given location along a stream equals the total measured streamflow discharge minus environmental flow requirements minus possible human water needs downstream of the location being assessed. Besides quantity, possible water transfers from the source to the recharge site need to be considered too in combination with available or required infrastructure (i.e. channels, pipelines).

Financial/Economic assessment: Upon identification of suitable locations, a financial assessment is performed to compare (1) costs associated with different MAR techniques for each location and (2) the investment in MAR and its associated benefits with alternative options (desalination, water transfer, other infrastructure).

Numerical modeling: The development of hydrological and groundwater flow models assists in obtaining further insight on MAR feasibility and assessing the possible impacts of environmental flow requirements, native groundwater flow, native groundwater quality (i.e. salinity), and aquifer geochemistry (reactions triggered by the recharged water).

The purpose of this work is to determine the areas of the field case that are suitable for the aquifer recharge (suitability analysis) by analyzing **surface and subsurface feasibility** . This enhanced storage can be achieved with various methods called Managed Aquifer Recharge (MAR), defined as the "purposeful recharge of groundwater to aquifers for subsequent recovery or environmental benefits" (Dillon *et al.*, 2009).

A MAR application haw many interests including enhancing the security of water supplies, improving groundwater quality, preventing saltwater intrusion, mitigating floods, maintaining groundwater-dependent ecosystems.

The present study uses GIS multi-criteria decision analysis (GIS-MCDA) method to identify suitable sites for implementing MAR type spreading method.

GIS-MCDA is defined as a set of tools to design, evaluate, and prioritize the choice among alternatives. In the particular case of MAR site selection, GIS-MCDA ranks the entities that compose the study area based on the decision-makers' goals and preferences. Those entities are generally referred to as criteria and they are the basic element of GIS-MCDA .

The suitability assessment is performed through Analytic Hierarchy Process (AHP) model, which is a technique that allows an estimation of the weights.

Saaty (1980) presented the Multi-criteria decision analysis (MCDA) technique which has been widely accepted and it is very much suitable for complex decision problems and Analytic Hierarchy Process (AHP), and helps to find out the weight of each criterion through pair-wise comparison.

The aquifer recharge is a key tool for tackling problems of quantitative reduction or quality degradation of groundwater systems caused by pressures in groundwater, such as over-pumping, pollution, etc.

It is an environmental action that utilizes the natural underground reservoirs that are formed in the subsoil to store good quality water during the winter so that they are available for use during the summer period of increased demands.

Also aquifer recharge aims at quantitative reinforcement and quality upgrading of groundwater systems. It is also important to contribute to the restriction and gradual repulsion of the marine penetration front in coastal aquifers.

The effectiveness of managed aquifer recharge depends on a number of factors such as determining the storage capacity of aquifers, the availability of sufficient recharge water for the needs of the application and the quality compatible and desirable better than the water quality of the recharged groundwater system.

2. STUDY AREA

2.1. Messara Valley

The Messara Valley is located in Geropotamou basin, belongs to the Prefecture of Heraklion and is located in the southern central part of Crete. Messara is the largest valley in southern Crete about 50 km from the Prefecture of Heraklion and covers an area of 398 km^2. This valley extends from east to west on the southern coast of Crete. It is bordered on the north by the Psiloritis mountain range, while on the south by the Asterousia mountain range. It is a coastal plain as it is wet to the southwest by the homonymous bay, which is part of the Libyan Sea. Geropotamos is a river that crosses this plain and empties into the gulf of Messara, in the municipality of Tympaki. There are also two tributaries that end in Geropotamos, Koutsoulidis and the river Mageras, in the municipality of Tympaki. In recent years, an artificial lake has been constructed in the area, the Faneromeni dam, with the aim of irrigating almost the entire plain. Another nearby river is Platis, which comes from the prefecture of Rethymno and flows into Agia Galini.

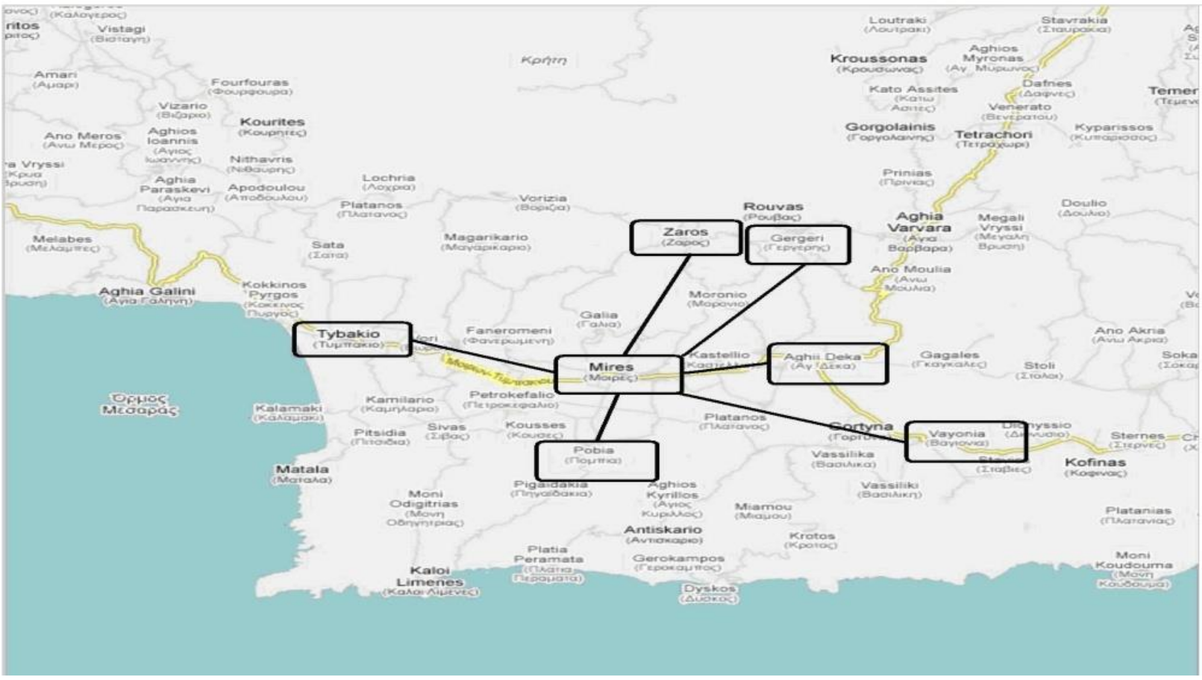

Figure 4. Messara Valley (Varouchakis, 2012)

The valley is the most important agricultural area of Crete, as 250km^2 of its total area is cultivated. The valley of Messara has a population of about 40,000 inhabitants and is mainly a rural area.

In the area, the main source of irrigation is groundwater as in summer the surface water source is limited. That is why the problem of over-pumping in the region has increased especially in the last 20 years where demand has increased significantly. So there is the problem of falling groundwater levels. (Varouchakis, 2012)

2.2. Land cover

As mentioned above, Messara is the most important area of Crete since most of its area is cultivated (from 398 km^2 250km^2 are cultivated). The arable lands are mainly covered by olive groves and vineyards, while the rest of the area is used for growing vegetables, citrus fruits and cereals. To be precise, 75% of the crops are olives, 10% are vines, 2% are citrus fruits and 13% are vegetables (mainly outdoor crops and some greenhouses). As far as the forest areas are concerned, protected areas have been declared in the south and east of Psiloritis. On the slopes of Psiloritis a rocky landscape with minimal vegetation is formed. (Varouchakis, 2012)

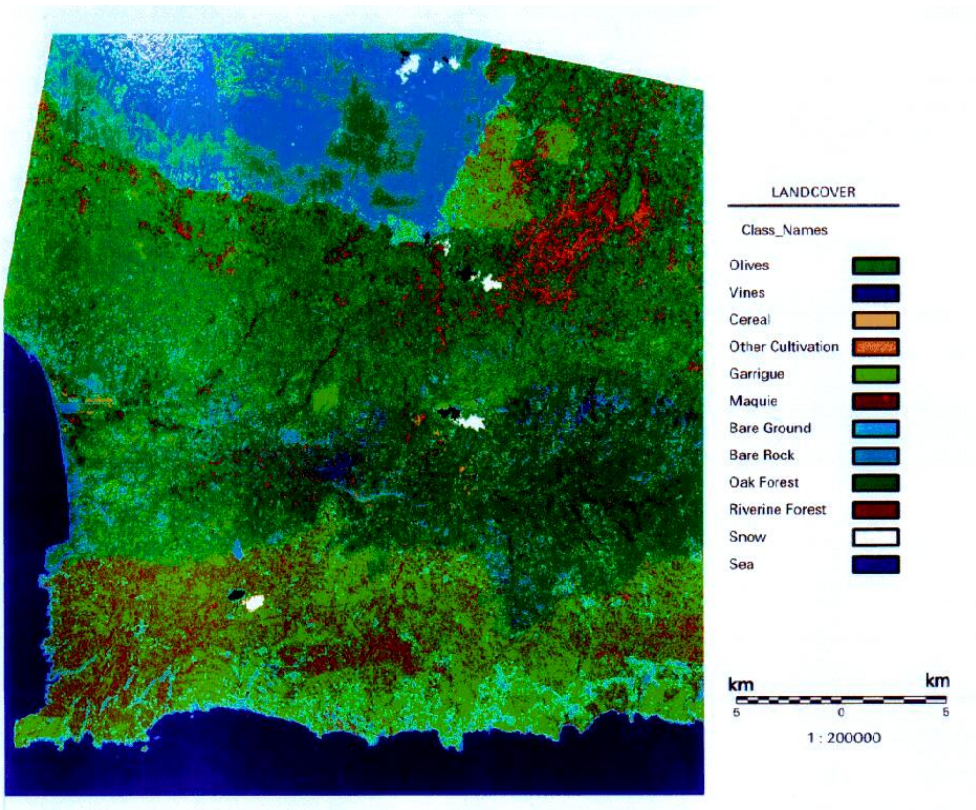

Figure 5 . Land use of Messara Valley, (Varouchakis, 2012)

2.3. Geology – Topography

The western Messara includes a plain of 112km^2, about 25km long and 3km wide, where in the northern and southern part there are steep mountain slopes whose altitude ranges from 1700m to 600m in the north and west to east. The highest peak is located in the Idi mountain range at 2540 m, which consists mainly of limestone. In the southern part is the mountain range of Asterousia, the altitude of which reaches 600 in the west and 1200 in the east.

In the area of Phaistos, west of the plain the catchment area of the river Geropotamos is located at 30m asl. The catchment area of the northern mountainous areas has an area of 160 km^2 while the southern part 126 km^2.

As for the geological deposits in the area, there is inhomogeneity, so there are several alternations of hydrogeological features even at short distances. Geological formations are mainly quaternary alluvial clays, silt, sand and gravel with a thickness of up to 100 meters or more.

The northern slopes consist mainly of silt and pearl neogene formations while the southern slopes are mainly slate and limestone formations of Mesozoic formations. The flow is limited to **a canal** which is located in an impenetrable tertiary layer near the area of Phaistos to the West of the catchment area. The geology of the area is shown in Figure 6.

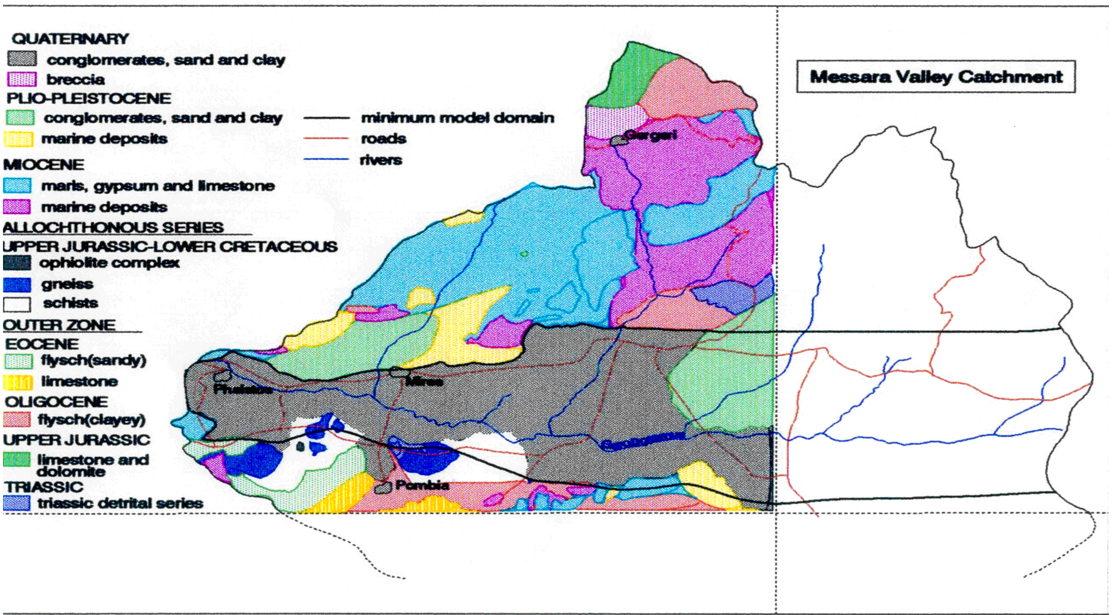

Figure 6 . Geological map of the Messara Valley. (Varouchakis, 2012)

2.4. Hydrogeology

The geological formations encountered on the island of Crete were classified based on their hydro-lithological behavior and separated into the following categories. (Perleros et all,2004)

Karst formations

- High to medium hydraulic conductivity (K1)

Limestones, dolomites, crystalline limestones and marbles high to moderate hydraulic conductivity.

- Medium to small hydraulic conductivity (K2)

In the formations that are characterized with medium to high hydraulic conductivity the movement of water is controlled by the interference of flint, chert and clay shale. In these formations, they are developed underground aquifers with a medium to low-capacity. Because of their intense tectonics in those cases that exhibit significant surface growth, they are involved in the supply of important karst springs.

- Medium to high hydraulic conductivity (K3)

They have both primary and secondary porosity and host important aquifers that are discharged through valuable sources.

Granular formations

- Granular alluvial deposits mainly with ranging hydraulic conductivity (P1).

In this category are alluvial deposits, river and marine terraces, the conglomerates river origin and the side scree cones when they have significant spread. They are developed, in places, remarkable well aquifers. Near the sea these aquifers have suffered in specific positions, deterioration due to seawater intrusion.

- Miocene and Pliocene deposits of moderate to low hydraulic conductivity (P2).

In this category they are included the conglomerates and marly limestones of the Neogene formations.

- Granular non-alluvial deposits of small to very small hydraulic conductivity (P3).

This category includes Pliocene and Miocene marls and indivisible formations of Neogene as well.

Impermeable formations

- Practically impermeable formations of low to very low hydraulic conductivity values(A1)

This category includes formations of flysch and slightly transformed clay sediments of different areas. At certain positions within the flysch layers, they are developed local aquifers with small to medium capacity.

- Practically impermeable or selective movement formations of small to very small hydraulic conductivity (A2)

Part of this class are the transformed and igneous rocks of different zones and covering.

Gypsum

In the formation of the gypsum aquifers with high potential are developed because of the dissolution with high sulphate content.

Across Crete karstic formations occupy 37.6% of the total area of the island, granular formations 39.6% and impermeable formations 22.58%. Last, a very small percentage end up as gypsum accounting for 0.21%.

2.5. Climate

The climate of the plain is sub-humid with mild wet winters and dry, hot summers. The highest percentage of rainfall (about 40%) occurs in December and January, while the lowest is from June to August where rainfall is negligible. It is also estimated that about 65% of water is lost due to evaporation, 10% due to surface runoff and only 25% is used to renew groundwater reserves.

The exhaust according to the measuring stations is estimated at 1500 ± 300mm per year while the winds are mainly westerly. The average winter temperature is 12 ^{0}C while in summer 28 ^{0}C. The relative humidity during the winter is about 70% while in the summer about 60%.

2.6. Hydrological characteristics

The rainfall in the area varies with the altitude from about 500 mm in the plain to about 800 mm on its slopes and 1100mm in the Asterousia mountains. Figure 7 shows the average annual rainfall in the Messara basin for the years 1970 to 2020. As can be seen from the diagram, the driest hydrological year was in 2016 and the wettest in 2003. The wet season lasts from November to March or April, while the dry season from June to October.

The main mean of surface runoff of the plain is the river Geropotamos in the Strait of Phaistos to the west. At this point the altitude is 30m above sea level. The river Geropotamos was constantly flowing, and at the western end of the catchment area in Phaistos there was a wetland. However, the drop in groundwater levels resulted in the drying up of the wetland, the lack of flow in the river during the dry period of 1990 as well as during the hydrological year 1992-1993.

This was the first time the riverbed had dried up, according to historical records. The average annual runoff was calculated based on historical data from 1967 to 16.88 Mm3, while the highest average monthly runoff was observed in January and February and the lowest in July and August.

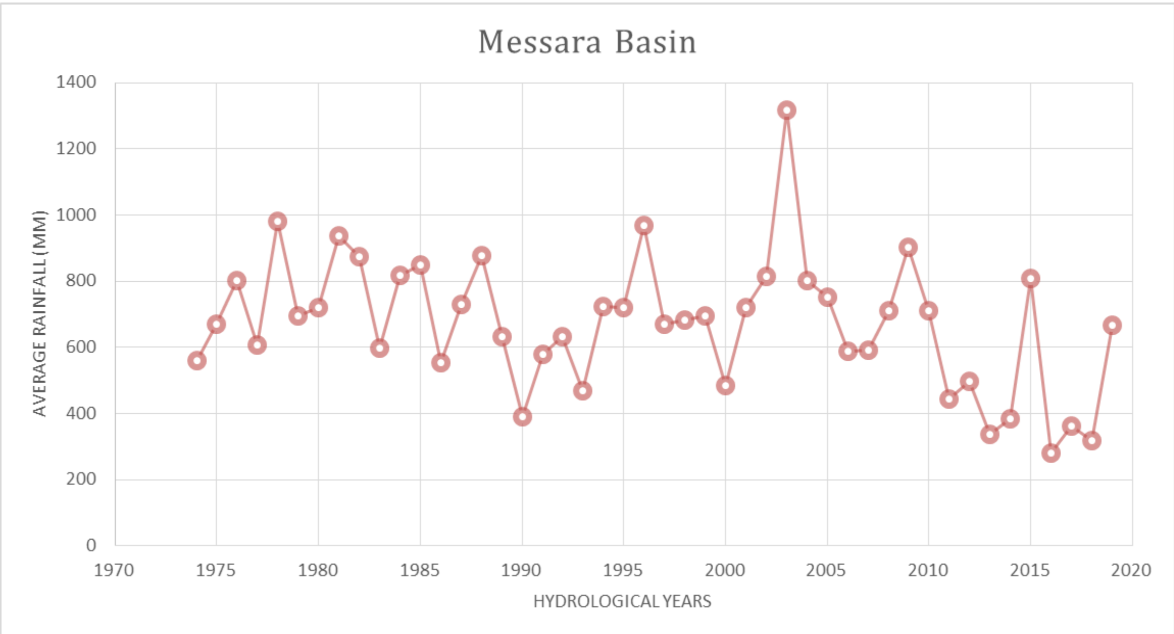

Figure 7. Average monthly rainfall in the Messara basin

The Valley of Western Messara includes both bigger and smaller aquifers of complex hydrogeological properties. Their level reaches its maximum in March or April and then there is a steady decline until the reserves are renewed in the winter. The aquifers were highly efficient with high pumping capacity of about 300 m^3/hr in the early 1970s. Nowadays, it has been reduced to about a tenth of that.

The lateral groundwater outflows from the plain are small in relation to the size of the pumps carried out in the area. An extensive drilling network has been installed since 1984 and it is estimated that about 10 Mm^3/yr of groundwater was pumped from the aquifers before the network was installed, followed by an estimated 40 Mm^3/yr after the installation.

However, such a large pumping resulted in a huge drop of 35 m of the aqifer level. In recent years there has been very little surface runoff and groundwater reserves have been steadily declining. Prior to the installation of the irrigation system, the annual surface runoff of the plain was about 20 Mm^3/yr which corresponds to 50mm of annual rainfall. It is estimated that the annual renewal of groundwater reserves was about 60 Mm^3/yr (150 mm.). The losses due to evaporation were about 160 Mm^3/yr (400 mm.) (Kritsotakis, 2009).

The highest hydraulic conductivity values are recorded in the Squadron hydrological basin, where the permeability ranges between 10 and 120 m day indicating the presence of a large number of gravel formations in the alluvial formation. The least permeable areas are in the area of the Vagiona hydrological basin, where the sparse presence of sandstone results to an average value of only 1m/d. Smaller values also appear on the north side of the Squadron's hydrological basin, where the lower rocky rocks, similar to those found in the Vagionia area, decay.

In general, the behavior of the aquifer shows that although inhomogeneous and locally limited, at the plain level it behaves and is characterized as an unconfined aquifer.

The alluvial aquifer of the Basin of Fates is the most important in Messara. Its thickness is variable and the highest values to be in the quaternary deposit ditch located approximately in the current flow of Geropotamos and Lithaios. Its water capacity is estimated at 86 Mm^3 of water volume, based on the drilling data of the FAO of 1972. (Varouchakis, 2012)

However, the current real storage volume of the Alluvian aquifer of the Squadrons is smaller and is estimated of 55 Mm^3, due to the groundwater level drop due to over-exploitation, (Kritsotakis, 2009).

2.7. The dam of Faneromeni

The dam of Faneromeni is located 7 km west of the village of Zaros and about 7 km north of Tympaki, on the outskirts of the village of Faneromeni in the province of Pyrgiotissa. It is

located in a green valley at the southern part of Psiloritis and covers an area of about 1000 acres and a capacity of 20 million square meters. The main feeder is the Koutsoulidis River, which carries water from the Rouvas forest.
It was built in 2005 to cover the increased water demands for irrigation of the "thirsty" valley of Messara. In the few years of its operation, dam of Faneromeni has become an extremely important wetland, where rare bird spices and animals nest and stop. The access to the dam is mainly through the village of Voroi, from where there are signs for directions. Other ways of access it are through the village of Galia, but also from Zaros.

The Faneromeni Dam was built by the former Ministry of Agriculture and was completed in 2005. The dam was built in the Koutsoulidis torrent, a tributary of the Geropotamos, upstream of the pre-existing small dam, at a distance of about 200m from it and upstream of the Koutsoulidis junction with Geropas 5 km from it. It is located in the area of Skourvoula and is about 5 km from the settlement of Moires in the Municipality of Phaistos. The purpose of its construction is the irrigation of the area of Messara. It is located at an absolute altitude of + 157m.

The reservoir was filled in 2010, but the irrigation water distribution networks were completed in 2013. The average annual runoff is 13×10^6 m^3 (minimum 4.7×10^6 m^3 and maximum 29.5×10^6 m^3) and the recoverable quantity per year is 8 , 7×10^6 m^3 (for a recovery period of 10 years). The water supply in the valley of Messara for the period August - December 2013 reached 6,000,000 m^3. The reservoir irrigates 40,000 acres of greenhouses in the valley of Messara (settlements Skourvoula, Galia, Faneromeni, Voroi, Tympaki, A-B-C zone of Messara), consisting of 60% olive trees, 30% vegetables and 10% of various others. The area of Messara covers the largest percentage of olive oil production in Crete and a large part of Greece.

Figure 8. The dam of Faneromeni (Pappa, 2018)

The following table presents the technical characteristics of the dam.

Table 1. Technical characteristics of Faneromeni dam

Faneromeni dam	
Type	earthy
Surface area	1.017 km^2 (1017 acres)
Height	69 m
Length of coronation	484 m
Reservoir volume	19670 m^3

3. Pressures on the aquifer of the Geropotamos basin – Solutions

3.1. Problems faced by the area – Quantity of groundwater

The Geropotamos basin is an area with very important agricultural production such as vegetables, olives, citrus fruits and vineyards. In the area are cultivated mainly olive groves and less vineyards and vegetables. Some of the products produced are sold in the internal market while olive oil, fresh grapes and other products are exported to European markets. It is essentially an area where its economy is based on agriculture and less on livestock and tourism.

In recent years, the area has been facing significant problems with its groundwater supplies as the aquifer level is showing a significant drop and part of the groundwater is facing problems with quality.

The report on "capture from the soil of pollutants escaping from surface water" includes a large number of complex processes that take place underground and lead to the final distribution of pollutants escaping from the surface, to different underground recipients, including in the underground aquifer. This complex process ultimately induces effects on groundwater systems from the pressures exerted on surface waters.

The vast majority of these are indirect effects, except in cases of direct discharge of pollutants into groundwater through e.g. drilling, which are immediate effects. Impacts on groundwater systems are not easily accessible nor can they be quantified immediately. The route of movement and the end of a pollutant introduced into the ground is not given or clear. It depends on a large number of factors including: the chemical nature of the pollutant (element mobility), soil conditions (presence of coarse or fine components, presence of clay components), soil permeability, hydrometeorological conditions (amount of water for filtration) and others. Therefore the end of the pollution as an addition (impact) to the groundwater is not always possible. Some of it can be adsorbed by the solid phase, another portion of it can be transformed due to ion exchange phenomena, a third part of it can be diluted without chemical transformation and end up in the aquifer with concentrations of pollutants that are not measurable. In this highly complex process, a safe indicator of the effects of pressure is only the measured effect on groundwater chemistry and this only in terms of quality. For example, disposal of municipal and livestock waste in a coarse-grained, or karstic soil is expected to show an increased groundwater content of pollutants, mainly nitrates and chlorides. However, in a clay soil, this may not be immediately apparent or it may be much less obvious, due to the processes that take place during the movement in the solid phase (unsaturated zone). It is obvious that in such a complex environment of physico-chemical processes it is not possible to quantify the impact, in the sense of a clear correspondence of the amounts of pollutants that are trapped from the soil or escape from surface water, with nitrates or chlorides, or other elements identified in groundwater.

One of the pressures that the region receives is the over-pumping of groundwater from the intense agricultural activity due to the lack of planning but also information - education of the farmers. The areas that have the main problem of falling level of the underground aquifer are first the area of Mires and then Tympaki.

Figure 9. Quantitative status of groundwater in Crete (Managment Plan of Crete,2017)

3.2. Problems faced by the area – Quality of groundwater

Apart from the quantity of groundwater, its quality is also a problem, mainly in the area of Mires and in Tympaki. In Mires the main pressures are the sewage treatment plant that is in the area and the olive mills. In the groundwater of Mires there are nitrates which are due to the olive mills and the intense agricultural activity. Locally there is an excess of SO_4 possibly due to geological background. Also, the fall of the groundwater level is one reason that the pesticides pollute the groundwater as the aquifer becomes more vulnerable. In the area of Tympaki the groundwater shows salinization and the main pressures that the area receives are the sewage treatment plant and the marine infiltration.

Figure 10. Chemical status of the groundwater of Crete (Managment Plan of Crete,2017)

Also in the area of Messara, there is a local overexploitation of groundwater, excess of nitrate ions, chlorides, and sulfates, due to agricultural activity and background.

The problems of the Geropotamos river basin can be summarized as follows:

- Over-exploitation of an aquifer resulting in a drop in water level of about 30 meters and pollution of the aquifer.
- Increased nitrates, chlorides and sulfates by areas (in the underground aquifer) due to agricultural activity and background.
- Surface and groundwater burden from pollutants produced by animals, in natural pastures and meadows (pastoral livestock) and from livestock units.
- In the area there is only one Sewage Treatment Plant resulting in a problem in the management of municipal wastewater (Disposal through cesspools to underground or surface recipients).
- Surface and groundwater burden from oil mill waste.
- The agricultural sector also faces the problem of lack of properly trained human resources (unorthodox and deep plowing, reckless use of plant protection and fertilizers, etc.).

3.3. Problems faced by the area – Climate change

Finally, an important problem that must be mentioned is the climate change that has been observed in recent years on our planet.

Climate change at the Intergovernmental Panel on Climate Change (IPCC) is a climate condition that can be identified by changes in the average and / or variability of its properties and that persists for an extended period of time, usually decades or more. The term "climate change" refers to the change in the average weather conditions of an area. In recent years, this term has been commonly used to denote the recently observed change in weather conditions on a planetary level, which, as everything shows, is due to the human influence.

Climate change and the destruction of the environment are considered to be among the most important problems of modern civilization worldwide. Extreme weather conditions, heavy rainfall, heat waves, droughts, hurricanes have been on the rise in recent years. All of this is happening because people are constantly striving, in a reckless way, for growth and prosperity. Growth and progress are only compatible when the natural foundations of life are secured and renewed, when the present does not mortgage the future. The causes of environmental problems must be sought in the relations of man with nature and man with man. The solution to these problems will come through the collective actions of political leaders, governments, industries and citizens around the world. Therefore, we need a campaign to inform and raise public awareness about the problem of climate change and its consequences as well as to show the ways to deal with them, changing some habits in everyday life. Controlling climate change remains, without a doubt, one of the greatest challenges facing humanity today.

Studying the geological history of the planet, it will be found that the climate has changed many times. Periods of particularly high temperatures where even at the poles there was no ice, were followed by periods of low temperatures (glacier seasons). These changes took place even before human activities became so widespread and intense that they could affect the climate. So in addition to man-made, there are natural causes that change the planet's climate. Research on this subject has identified the following causes of natural climate variability:

- Changes in the Earth's orbit around the Sun.
- Changes in the intensity of solar radiation
- Volcanic eruptions
- The change of greenhouse gas concentrations
- The change of sea currents

Climate change greatly affects the hydrological cycle. Consequently, temporal and spatial changes of the hydrological cycle take place and this has many implications for water resources. One of them is the possible flows and droughts where they change the surface runoff. Climate change also has a serious impact on groundwater through changing groundwater recharge and this is an important aspect of their future management. Many areas around the world depend on groundwater as drinking water.

Recent Climate Warming) has been confirmed by the Intergovernmental Panel on Climate Change (IPCC, 1996, IPCC, 2001) and shows changes in global average air temperature since 1850. It is now known that temperature rises have a direct effect on natural systems. Glacier shrinkage is particularly sensitive to global warming.

Climate scenarios show a rise in temperature of up to 3 ° C by the end of this century and a reduction in precipitation in many parts of the world. Climate change has affected ecosystems in particular in terms of biodiversity reduction. Melting ice and rising sea levels have a significant impact on coastal and coastal areas, but groundwater is significantly affected by sea intrusion and consequently their quality is affected.

The effects of climate change on groundwater have been addressed in many studies around the world as groundwater is vital for humans and our planet in general. Most studies on the impact of climate change on groundwater resources focus on North America and Europe, with few analyzes in Asia, Australia and Africa. A part of this study investigates the effect of climate change on the study area.

Groundwater is one of the most important natural resources that is very important for humans and the environment. Groundwater is a source of drinking water as well as water for industrial and agricultural use. It is also very important for the conservation of rivers, lakes and wetlands and contributes to the conservation of biodiversity.

3.3.1. Studies for the impact of climate change on groundwater in Europe

1. Climate change effect on groundwater resources in South-East Europe during 21st century (Nistor,2018))

Mărgărit-Mircea Nistor's research concerns climate change impacts on groundwater resources in South East Europe during the 21st century. In this study, climate models and land cover data were used for two displacement periods, present (2011-2040) and future (2041-2070), to assess the impact of climate on groundwater. The method NISTOR-CEGW was proposed for this study because it involves a spatial-scale analysis based on land cover, actual crop evapotranspiration (AETc), effective precipitation and the Aridity De Martonne index. This method uses a matrix of conclusions to combine effective rainfall and the Aridity De Martonne index to assess the impact of climate on groundwater, yielding six impact categories, from very low to extremely high. As shown in fig.11 at the present time, the research findings show extremely high climatic impacts on the Pannonian basin, eastern and southern Romania, northern and southern Bulgaria, eastern and central parts of Macedonia, northern and eastern parts of Greece and the Northern European part of Turkey. In the future, areas with extremely high groundwater impacts are mainly on the north, east and southeast sides of the South East European region. Dionysus and the Alps mountains have very low groundwater impacts. In these areas prevails very humid and extremely humid climate. The findings show that about half of South-Eastern Europe's land is facing drought and the environment, groundwater and related ecosystems are facing severe climate change problems.

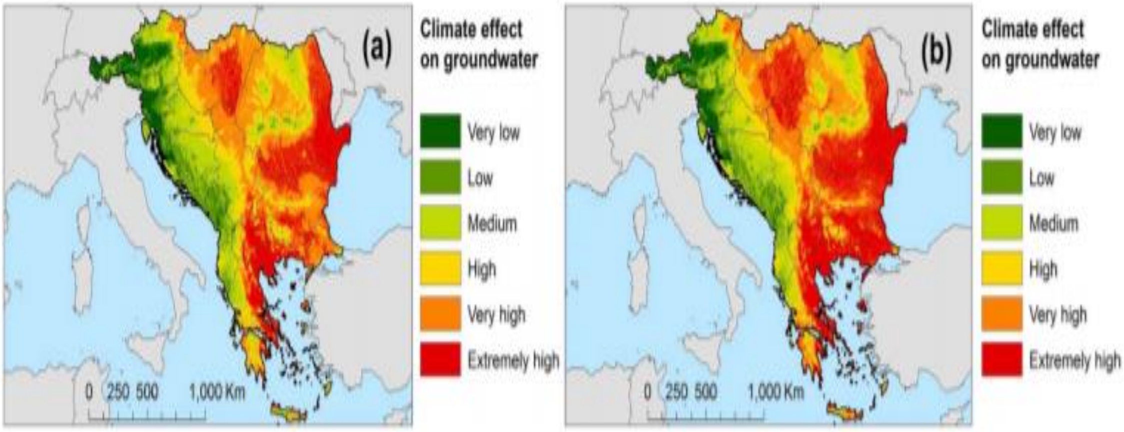

Figure 11. Climate effect assessment on groundwater resources in the South East Europe region. (a) Spatial distribution of climate effect during the present period (2011–2040). (b) Spatial distribution of climate effect during the future period (2041–2070). (Mărgărit-Mirce Nistor,2018)

2. Groundwater recharge assessment in dry years (Kubicz et all, 2019)

Justyna Kubicz et.all's research is an attempt to assess groundwater recharge in the years of drought resulting from climate change in Western Pomeranian region in Poland. Groundwater recharge is an informative indicator of the amount of water beneath the surface of the soil and largely determines how vulnerable groundwater is to contamination. The main factor affecting the recharge of groundwater is the filtration of atmospheric precipitation. This process depends on geomorphological, geological, climatic conditions and biosphere-related factors, as well as on anthropogenic factors such as human economic activity. These factors are characterized by high spatial variability. From a temporal point of view, some of them may be considered relatively stable, while others (mainly climatic and meteorological) are subject to constant changes, both in long and short periods. The initial phase of the research consisted of selecting the years during meteorological and hydrological droughts, using the Standard Precipitation Index (SPI) and the Standard Water Level Index (SWI). In their research they used the WetSpass model for specific and long periods and they estimated the volume of groundwater recharge. According to the standard drought indices, meteorological droughts occurred in 1982 and hydrological droughts occurred in 1992. Drought is a phenomenon that is directly related to the amount of rainfall that falls in an area for a given period of time compared to the expected (normal) for

Western Pomeranian region in Poland. A significant reduction in rainfall compared to normal is a key indicator of drought. In addition, drought is highly dependent on evaporation (temperature, wind, humidity, radiation / sunshine), as well as the natural environment, geology, etc. Meteorological drought is the reduction in atmospheric precipitation of a region over a given period of time significantly below its average or below a critical value that determines the start of the drought. Meteorological drought usually results in Hydrological drought (abnormally low water availability in terms of surface flows, dam levels and groundwater aquifers). Human activities can also lead to hydrological drought. The Standardized Precipitation Index (SPI) is the most common index in the world for the detection and characterization of meteorological droughts. The SPI index, developed by McKee et al. (1993), and described in detail by Edwards and McKee (1997), measures rainfall changes at a given location by comparing observed total precipitation rates over a given time period (e.g., 1, 3, 12, 48 months) , with a long-term rainfall record for this period. The historical record is classified into a probability distribution (the gamma distribution), which is then converted to a normal distribution such that the mean SPI value for this position and period is zero. As the SPI drops below -1.0 the area lacks rainfall (drought) while it has increased rainfall when the SPI rises above 1.0. Since SPI can be calculated over different precipitation accumulation periods (typically ranging from 1 to 48 months), the resulting different SPI indicators allow estimating different potential impacts of a meteorological drought:

- SPI-1 to SPI-3: When SPI is computed for shorter accumulation periods (e.g., 1 to 3 months), it can be used as an indicator for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks.
- SPI-3 to SPI-12 When SPI is computed for medium accumulation periods (e.g., 3 to 12 months), it can be used as an indicator for reduced stream flow and reservoir storage.
- SPI-12 to SPI-48: When SPI is computed for longer accumulation periods (e.g., 12 to 48 months), it can be used as an indicator for reduced reservoir and groundwater recharge.

This study calculated SPI-24 for 2 years in 1982 and 1992. The analysis of the SPI was performed for two selected measurement points in Resko and Szczecin. In 1982, at Resko, there were 2 meteorological drought periods (February-April and June-December). In both cases, months with severe drought (SPI> -2) occurred (table 2). At Szczecin station, meteorological drought occurred from February to September 1982. Analysis of the SWI at two selected points, the Rega River in Resko and the Ina River in Stargard Szczeciński, showed that all months should be considered. In addition, there was extreme drought at Resko station in June and July. At Stargard Szczeciński the lowest SWI was calculated for July and coincided with the severe drought (Table 3). The year 1982, which characterized as dry, was the only one characterized by a negative average annual groundwater recharge rate in summer. The highest rate of evaporation in water (88%) occurred in 1982. During that year, groundwater recharge accounted for only 9% of the water balance. According to the standard drought indices, meteorological droughts (as shown by the SPI index) occurred in 1982, while in 1992 there was a hydrological drought (as indicated by the SWI). The research conducted allowed the authors to conclude that the drought in 1982 has greatly influenced the water balance structure. It caused an increase in evapotranspiration in the aquatic balance of the analyzed (88%), which in turn led to degraded groundwater as the recharge was only 9%. On the other hand, the consequences of the 1992 drought were less significant (evapotranspiration 77%, groundwater recharge 21%).

Table 2. Values of SPI in study sites in 1982(Kubicz et all, 2019)

Site	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Resko	0.37	− 2.04	− 1.01	− 0.11	0.34	− 0.39	− 1.02	− 2.02	− 3.06	− 0.40	− 0.77	− 0.08
Szczecin	0.59	− 1.63	− 0.23	− 1.22	− 0.02	− 0.07	− 1.34	− 1.89	− 2.32	0.11	− 0.67	− 0.60

Table 3. Values of SWI in study sites in 1982(Kubicz et all, 2019))

Site	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Resko	− 1.34	− 1.26	− 0.70	− 0.81	− 1.09	− 2.22	− 2.28	− 1.61	− 1.28	− 1.51	− 1.00	− 1.31
Stargard Szcz.	− 0.41	− 0.49	− 0.35	− 0.28	− 0.10	− 1.49	− 1.74	− 1.46	− 1.06	− 1.62	− 1.03	− 1.38

3. Climate and Drainage (Lóczy, 2015)

This excerpt is from Dénes Lóczy's book Landscapes and Landforms of Hungary. Hungary has a moderately humid continental climate and in most parts of the country drought is a recurring phenomenon. Typical temperatures range between 10 and 11 ° C for most of the territory. However, there are various extreme temperature effects within the country such as the absolute minimum temperature in Miskolc-Görömbölytapolca which was -35.0 ° C (16 February 1940) and -31.9 ° C in Zabar in 2015. Forecasts of extreme events will increase in the future as shown in Table 4.

Table 4. Expected extreme temperatures in Hungary in the 21st century based on PRECIS model simulation, A1B scenario (after Department of Meteorology, Eötvös Loránd University in: NAK 2013), (Lóczy, 2015)

Extreme temperature indices	Average value (days per year)	Expected value (days per year)	
	1961–1990	2021–2050	2071–2100
Number of frost days (T_{min} < 0 °C)	93	58	39
Number of summer days (T_{max} > 25 °C)	67	105	135
Number of hot days (T_{max} > 30 °C)	14	48	79
Number of very hot days (T_{max} > 35 °C)	0.3	12	34
Number of heat alarm days (T_{mean} > 25 °C)	4	34	63

In terms of groundwater, Hungary has many reserves, especially in thermal waters. In most lowland and hilly areas, the groundwater aquifer is 3-6 meters below the surface, but its depth is highly seasonal and has a tendency to decline in some sand deposits areas (for example, on the Danube–Tisza Interfluve). However, the infiltration of nutrient-rich water caused serious contamination of groundwater. There are more than 50,000 artesian wells in Hungary and this indicates the importance of the limited groundwater resource in the supply of potable water. In the thermal wells there is a well - developed network of thermal springs where their water has medicinal properties. In the elevated mountains, which are built of limestone and dolomites, there is a recurring karstic water system. To allow bauxite mining, an enormous artificial depression was created, but with the termination of mining activities the karstic water station is steadily increasing and some karstic springs are reactivated. One of Hungary's geomorphological sites, the Egerszalók travertine hill owes its existence directly to the deposition of carbonates from groundwater. The changing weather and the increasing emergence of new temperatures and rainfall are evidence of global climate change. A comparison of three different scenarios described in the Intergovernmental Panel on Climate Change (IPCC) evaluation reports shows a significant trend of temperature rise (1-2.5 ° C at average temperatures) for the 21st, strongest in summer and winter. and less intense in spring and autumn (Fig. 13). The models predict that in the 21st century, winter will be greatly reduced and droughts will increase, especially in summer (-20% rainfall compared to the 1961-1990 reference period). The number of consecutive days without precipitation will decrease in winter (by about 10-15%) and increase in summer (by 15-25%) - especially in the eastern half of the country. This means that groundwater reserves will be significantly reduced and the risk of deterioration will increase. Climate change simulations suggest that Hungary's highest drought regions will be the Interfluve Körös-Maros and the Gödöllő hills in the last decades of the 21st century. Climate change will also affect hydrological and geomorphological processes.

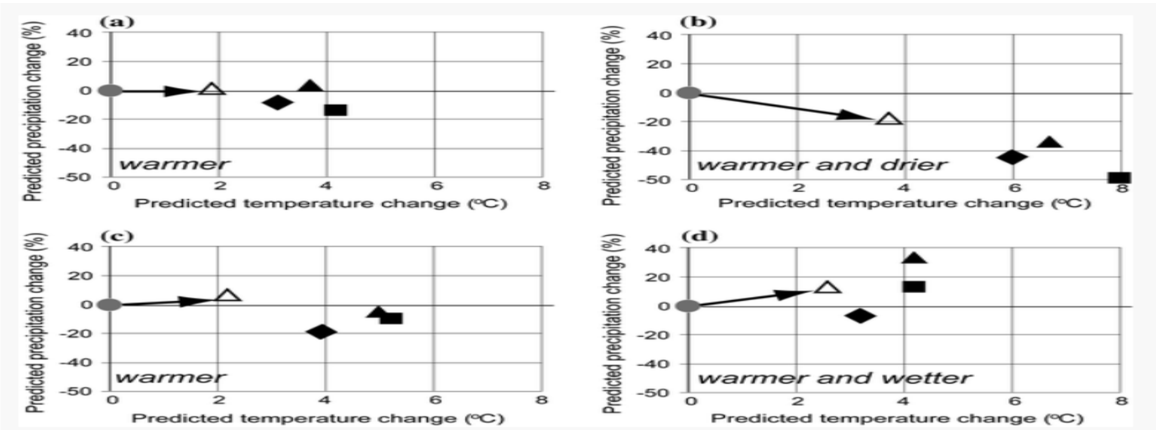

Figure 12. Predictable climate change for Hungary based on simulations using the PRECIS regional climate model (after Bartholy et al. 2013). Reference period: 1961–1990 (grey circle at point 0). a spring; b summer; c autumn; d winter. White symbols change between 2021 and 2050; black symbols change between 2071 and 2100. Squares change according to IPCC scenario A2; triangles A1B; rhombus B2. (Lóczy, 2015)

4. Groundwater vulnerability in Europe under climate change (Nistor,2019)

The study of Mărgărit-Mircea Nistor is an attempt to determine the sensitivity of groundwater to climate change in the wider region of Europe. To create Europe's groundwater vulnerability map, aquifer geology, soil morphology and monitoring of nitrate (NO_3) and arsenic status (As) were combined environmental climate data and its cover land. High-resolution and land-cover climate models were used to create the groundwater models for different time periods. Geographical Information Systems (GIS) technology was used to analyze the various maps and calculate the groundwater sensitivity. In many parts of Europe there is intense agricultural activity resulting in increased chemicals in groundwater. Thus, the study used data on both the quantity and quality of groundwater. Determining the vulnerability of groundwater to climate change depends on parameters that determine water status and environmental changes at a spatial scale. Thus these parameters are the types of aquifers (fig. 14), direct measurements, soil configuration, amount of rain, and land cover.

Study area

The terminology and biodiversity of the European continent are very diverse. The coasts have uncontrolled shapes with many peninsulas, islands and bays. Its altitude is 4810 meters at the top of Mont Blanc, in the Alps. Most of them are occupied by plains (eg, North European Plain, East European Plain, Po plain, Pannonian basin, Romanian Plain). The most important mountain chains are the Alps, the Pyrenees, the Carpathian Mountains, the Scottish mountains, the Dinaric mountains, the Scottish mountain, the Scandinavian mountains and the Apennines mountains. Europe's geology is complex as we find sand, pebbles, limestones, sandstones and dolomites with limestones composing the main types of aquifers. In this study, they studied the continental part of Europe and some islands. The eastern part of Europe, the territory of Iceland and some islands of the Atlantic Ocean were not included in the analysis due to the lack of data.

Methodology

In this study, the spatial approach was made through GIS application to determine the vulnerability of groundwater. Groundwater models from 1961-2070 and soil morphology were used to estimate the amount of groundwater. Groundwater quality factors were the aquifers layer including geological composition, land cover data over the period 2000-2040 and measurements of the last decade NO_3 and As from groundwater monitoring. Finally, the combination of the layers of quantity and quality of groundwater and the calculation of groundwater vulnerability was performed using the NISTOR-GWV index. The methodology is presented with details in Figure 14.

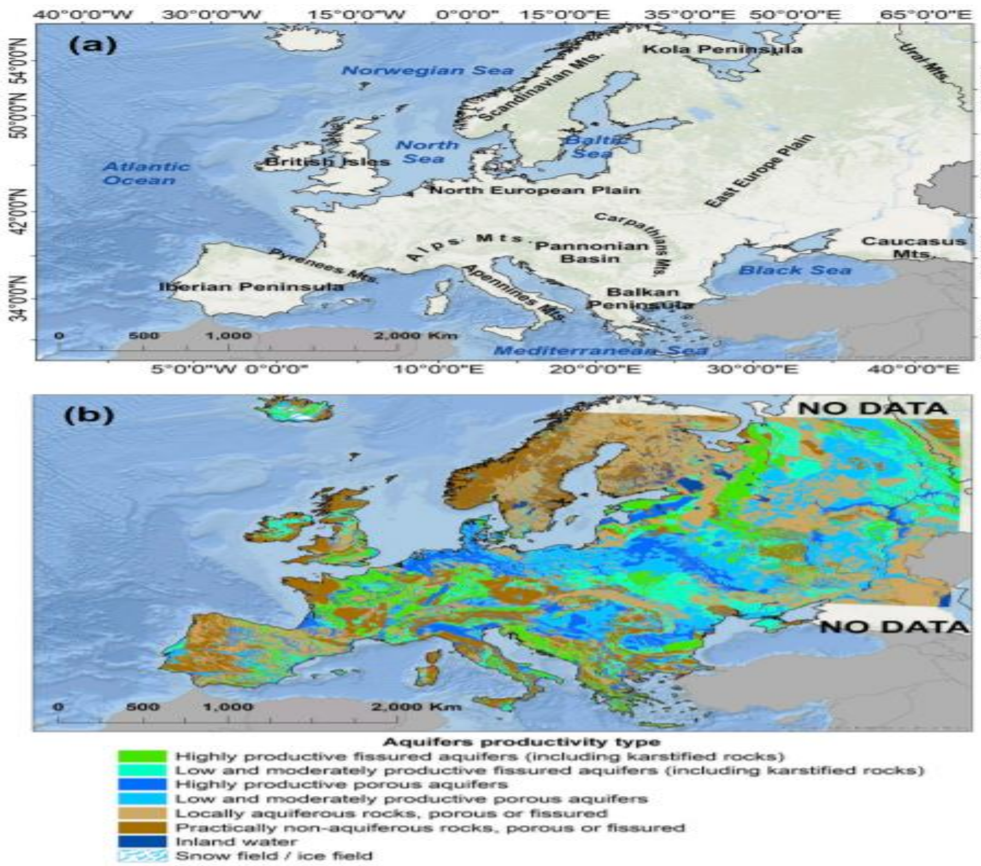

Figure 13. a. Physical map of Europe within the main geomorphological units. b. Type of aquifers in Europe.(Nistor,2019)

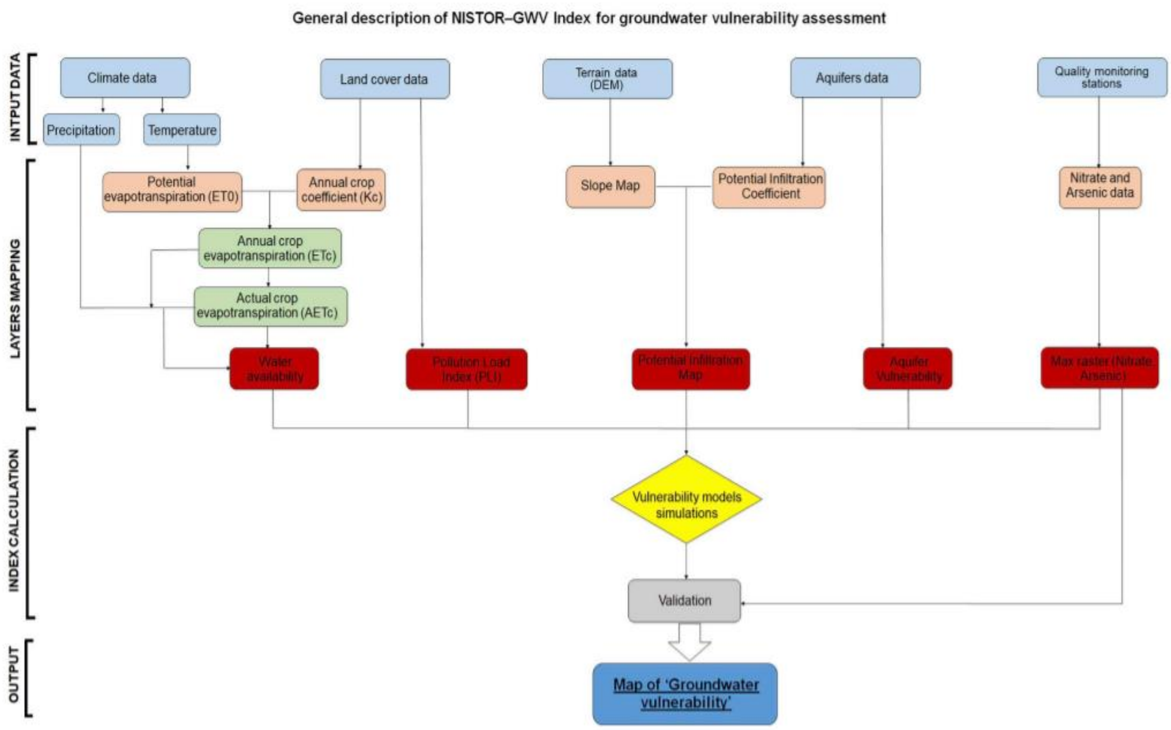

Figure 14. Schematic diagram showing the NISTOR-GWV Index methodology (Nistor,2019)

The NISTOR-GWV index for the determination of groundwater vulnerability is a methodology that considers spatial analysis as the sum of weighted layers. Regarding the performance of weights the climate plays a very important role in determining the vulnerability of groundwater, so 60% of the weight was attributed to the availability of water. The pollution load index and the aquifer sensitivity factor have the same weight (50%), while the map of potential infiltration was rated at 40%. The NISTOR-GWV index is defined by the ratio between the quality and quantity layers (Equation 1). The raster file of maximum NO_3 and As is included as a ratio pointer. Using this indicator, spatial analysis, groundwater sensitivity maps have been created for Europe for the past (90s), present (2020s) and future (2050). All levels were normalized (values between 0 and 1), and the final maps were divided into five maps of vulnerability as follows: 0-0.2 for very low vulnerability, 0.21-0.4 for low vulnerability, 0.41-0,6 for moderate vulnerability, 0.61-0.8 for high vulnerability, and greater than 0.8 for very high vulnerability.

$$\text{NISTOR-GWV Index} = \left[\frac{(PLI\times0.5+AV\times0.5)\times0.4}{((1-WA)\times0.6+PIM\times0.4)\times0.6}\right]^{\frac{1}{\max(NO_3,As)}} \quad (1)$$

Where:

GWV = Groundwater Vulnerability

WA = Water availability

AV = Vulnerability factor of aquifer

PIM = Potential infiltration map

PLI = Pollution load index

NO_3 = Nitrate (normalized)

As = Arsenic (normalized)

Results of the study

The results of this study showed that for the previous period (1990s), climate models for Europe show average annual temperature values are between -14.5 ° C and 19.2 ° C (fig. 15a). In the present period (2020), the temperature will range from -12.7 ° C to 20.75 ° C (fig. 15b), while in the future (2050), the average annual temperature will range from -11 ° C to 21 ° C. ,(fig. 15c). This increase in temperature has a direct impact on evapotranspiration in the European region and therefore on the availability of groundwater. The maximum annual precipitation in Europe decreased from 3698 mm per year (1990s) (fig. 15d) to 3552 mm per year (2020s) (fig. 15e). In the future (2050) precipitation will be 3487 mm per year in Europe. (fig. 15f). There was also an increase in the maximum annual evapotranspiration in Europe between 1990 (595 mm) and 2020 (1030 mm) (fig. 15g and h). For the year 2050, annual values of evapotranspiration are projected up to 1129 mm (fig. 15i). Water availability during the 1990s ranged from 7 mm to 3549 mm and from 1 mm to 3423 mm, in 2020 the highest values of water availability (over 2000 mm) occur in the Alps, the Scandinavian mountains and the north of the British Islands. The lowest water availability values (below 200 mm) are found in the central and southern parts of the Iberian Peninsula, in the Mediterranean islands, in the central and southern peninsula of Italy, in eastern and south-eastern Europe. These areas are projected to have the biggest problem with groundwater availability. Also, by 2050 the maximum value of water availability is expected to be reduced to 2696 mm and 2654 mm. Finally, the scenarios indicate that by 2050 there will be more areas with low water availability such as the Northern European section.

Regarding the quality of groundwater in Europe in terms of penetration, the highest penetration was found in the Pannonian Basin and Eastern Europe. Most parts of Europe have a low penetration rate due to impermeable lithology and soil morphology. Vulnerability is greater, mainly in central, southern and eastern parts of Europe. These areas have aquifers which consist limestones and karstic rocks. These types of aquifers are found in the territories of France, Italy, Greece, Slovenia, Germany, Spain, Russia, Ukraine, Romania, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia. England, Austria and Lithuania.

Regarding groundwater quality in Europe in relation to land cover, high rates of contamination are found in rural areas. Thus, for past and present, land cover contamination shows high values (above 0.75) in the main plains where the permanently irrigated and non-irrigated arable land is located. Maximum PLI values of 0.9 and 0.93 were respectively shown in paddy fields and landfills. Ecosystems such as forests with low-PLI (below 0.23) have high drinking water quality and large quantities of water to supply a large part of Europe.

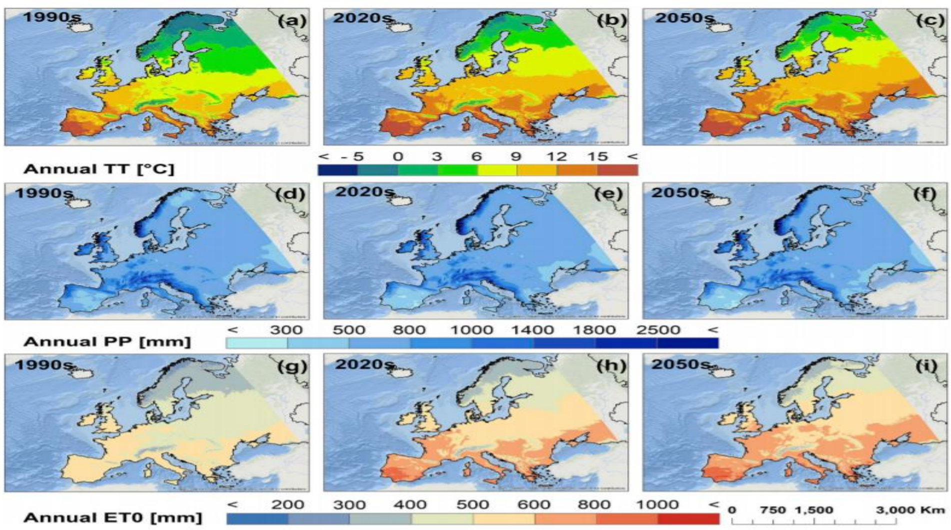

Figure 15. Spatial distribution of mean annual air temperature (TT), annual precipitation (PP), and potential evapotranspiration (ET0) in Europe. (a) TT in 1990s. (b) TT in 2020s. (c) TT in 2050s. (d) PP in 1990s. (e) PP in 2020s. (f) PP in 2050s. (g) ET0 in 1990s. (h) ET0 in 2020s. (i) ET0 in 2050s. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors. (Nistor,2019)

Areas with low PLI overlap with the Carpathian Mountains, the Alps, the Southern Scandinavian mountains, south of the Iberian Peninsula and north of the British Islands.

Areas with a high NO_3 concentration are located in central Europe (e.g. East of Austria, South of Germany, and West of Hungary) and Northern Europe (e.g. France, North of Germany, Netherlands). Values above the acceptable level of 0.5 mg / l of As have been found in a few areas in Europe (e.g. Southwest England and North East Italy).

Finally, in 1990 and 2020 (Figs. 16 and 17), the most vulnerable areas are in Northern Europe, the central and North-Western part of Europe, south of the British Islands, in the north and south-east of the Italian Peninsula, in the Pannonian and in Romanian plains, on the coast of the Eastern Adriatic and the Balkan Peninsula (e.g. Greece, Bosnia and Herzegovina, Croatia, Montenegro). Also, some lands of great vulnerability were found on the west and East coasts of the Iberian Peninsula, on the territory of Spain and Portugal. Moderate groundwater vulnerability was found over central Europe, the Iberian Peninsula, Southern and South-Eastern Europe and east of the British Isles. Low and very low groundwater vulnerability was found in the northern part of Europe to a large extent, north and west of the British Isles, in southern, western, eastern and central Europe mainly in the highlands of the Scandinavian mountains, in the Alps, in the Carpathians, in the Central France, north of the Apennines from Italy and the Pyrenees. Areas of very low vulnerability are those to the west of the Iberian Peninsula (e.g. Northwest of Spain, Northeast of Portugal), west of the British Isles (e.g. West of England, North and Southwest of Ireland) and some locations in the South Dinaric.

Areas facing significant changes of 20-30% are Northern Europe, Poland and German territories. In these areas, the vulnerability of groundwater is increased due to soil changes and not due to climate change. Between 1990 and 2050, the relative changes range from 6% to 10% in the central, southern, northern and western sides of the continent, and are 10% to 20% in northern Europe. Between the 1990s and 2050, northern Europe is experiencing the most significant changes (20-30%) in groundwater vulnerability. Groundwater vulnerability changes in the Scandinavian Peninsula, north of Germany and Poland are due to the fact that forests and pastures have become agricultural, semi-natural or residential areas. In the western and southern parts of Europe, change is mainly due to climate change. Figure 18 illustrates the changes in groundwater vulnerability in Europe between the years 2020 and 1990 and 2050s.

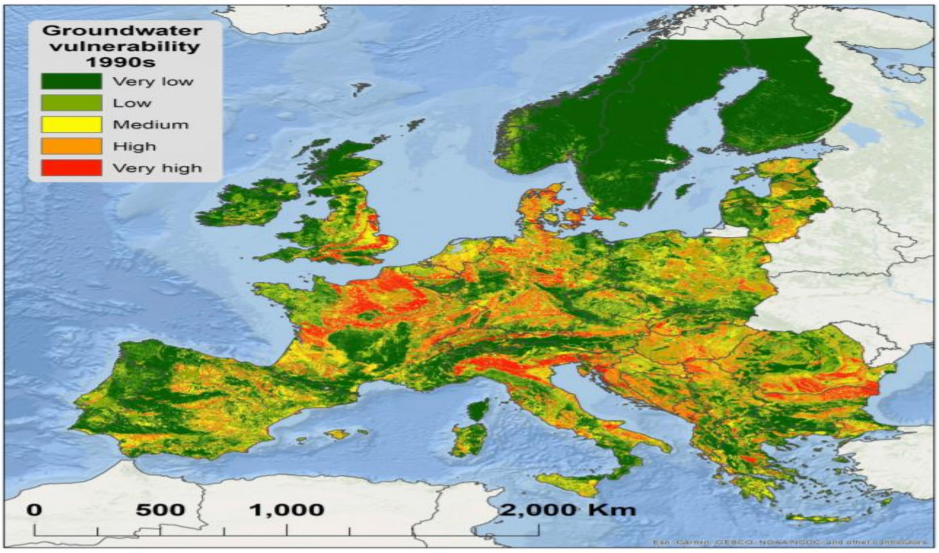

Figure 16.Groundwater vulnerability map of Europe related to the past period. (Nistor,2019)

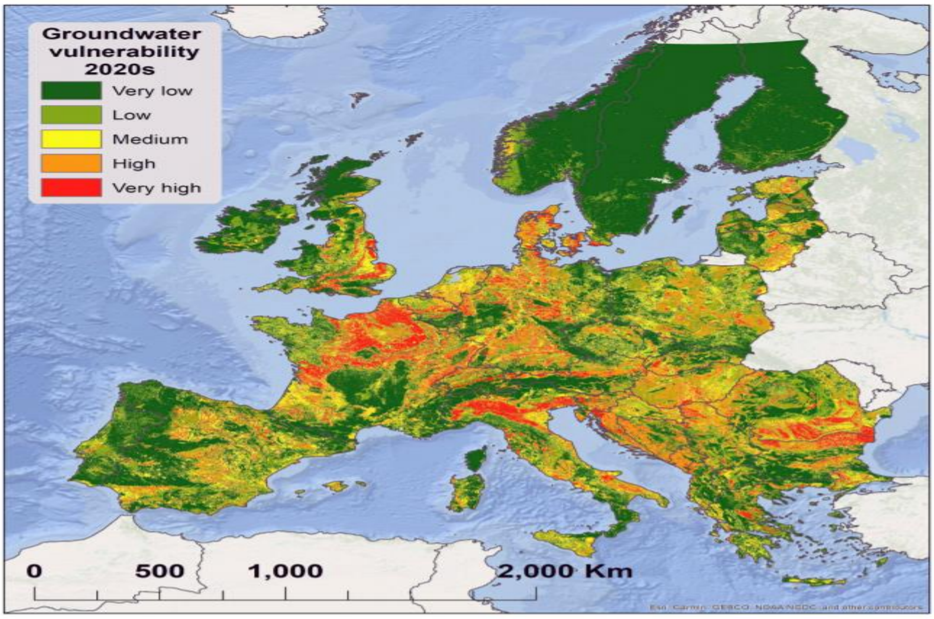

Figure 17. Groundwater vulnerability map of Europe related to the present period (2020s), (Nistor, 2019)

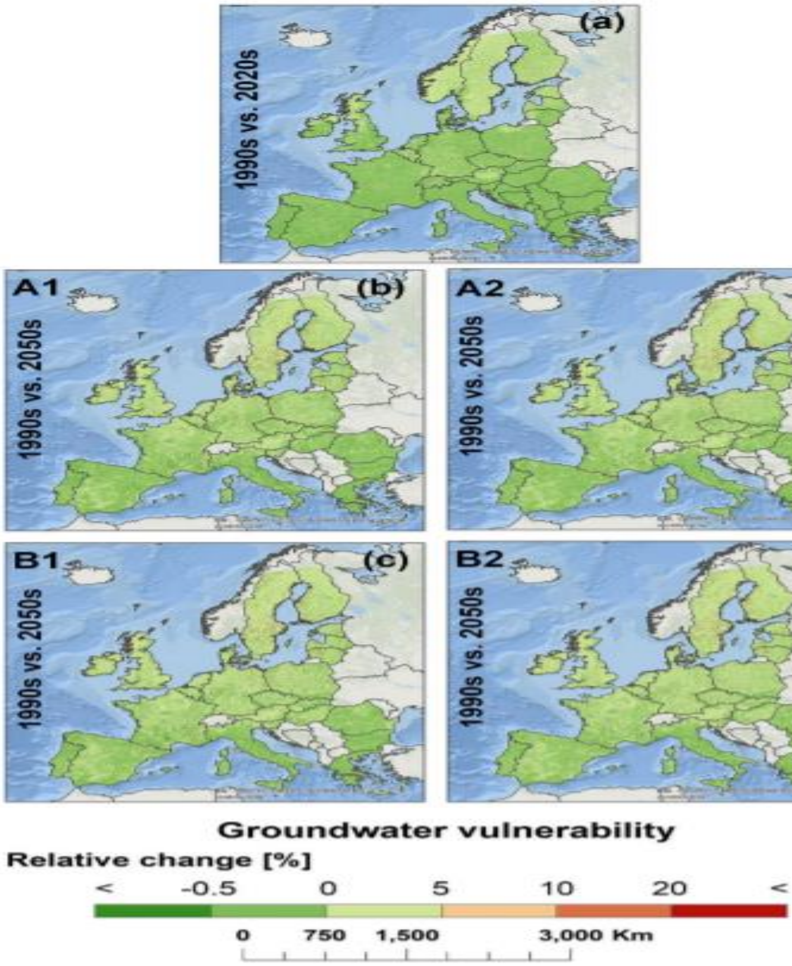

Figure 18.Relative changes of growndwater vulnerability. (a) Relative change between 1990s and 2020s. (b) Relative change between 1990s and 2050s (c) Relative change between 1990s and 2050s (d). Relative change between 1990s and 2050s(e) Relative change between 1990s and 2050s.(Nistor, 2019)

5. Groundwater vulnerability GIS models in the Carpathian Mountains under climate and land cover changes (Nistor et al, 2018)

In this study, a complex methodology based on the Geographic Information System (GIS) was used to detect the vulnerability of groundwater to climate change and soil changes. Spatial analysis includes aquifers, water availability, load pollution index and data from the Carpathian Mountains area, from Central Europe. The analysis presented in this study analyzes three periods, which include 30 years climate data models for 1961-1990 (1990), 2011-2040 (2020) and 2041-2070 (2050).

The results of groundwater vulnerability in the 1990s (fig. 19a) show that much of the territory is marginally vulnerable to climate change and land cover. Very low vulnerability is found in the Western and Southern Carpathians only in elevated areas (over 2000 meters).

High vulnerability areas were identified in the Curvatures Carpathians and South of the Apuseni Mountains. During the year 2020, groundwater vulnerability (Fig. 19b) shows high groundwater vulnerability in a large area, especially in the Curvatures Carpathians, while very low vulnerability decreases spatially. Future forecasts (Fig. 19c-e) show a decrease in the very low vulnerability area and an increase in the category of high vulnerability.

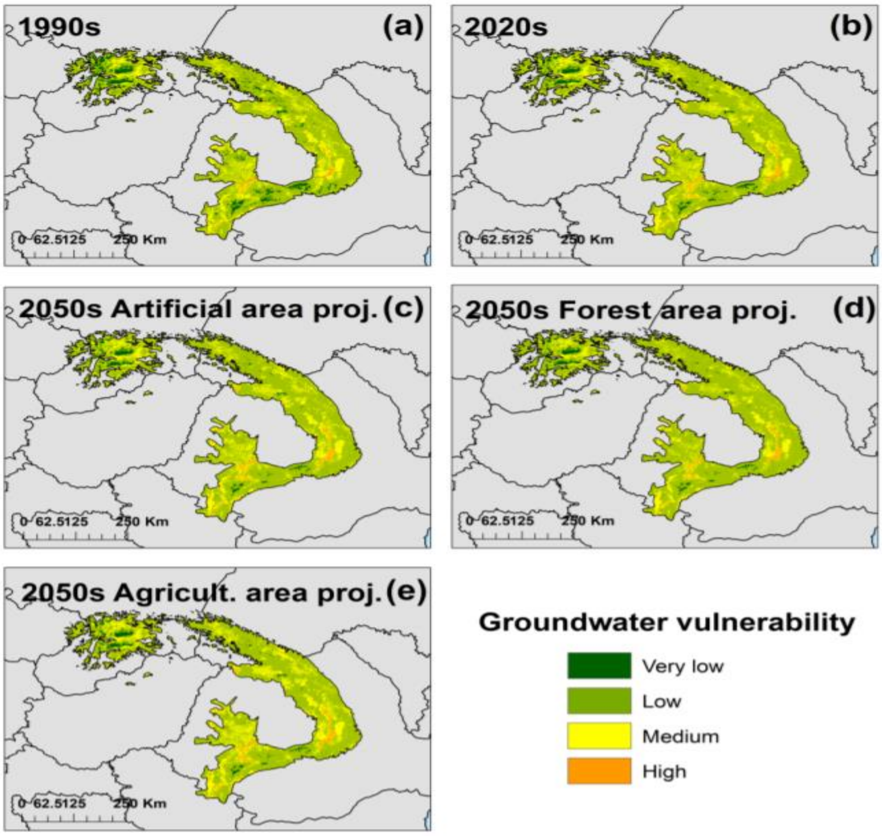

Figure 19. Vulnerability map of the Carpathian Mountains region. (a)Groundwater vulnerability Groundwater map related to the past period (1990s). (b) Groundwater vulnerability map related to the present period (2020s). (c) Groundwater vulnerability map related to the future period (2050s) artificial area projection. (d) Groundwater vulnerability map related to the future period (2050s) forest area projection. (e) Groundwater vulnerability map related to the future period (2050s) agricultural area projection. (Nistor et all, 2018)

The table below shows the percentage of areas depending on how vulnerable they are to groundwater. The southern regions of the Carpathians are affected by climate change with regard to groundwater and they have increased vulnerability. These changes are due to the increase in the territory that has low water availability (below 200 mm) for the years 2020 and 2050. So, as the recharge of aquifers decreases quantitatively, the sensitivity of groundwater is increased.

Regarding groundwater quality, artificial areas and agricultural areas are affected by increased vulnerability of groundwater, while areas such as forests and grass have low vulnerability. For this reason, low vulnerability extends to a larger area (approx. 77.73%)

Table 5. Percentage area of groundwater vulnerability calculated in Carpathian Mountains area (Nistor et all, 2018)

Vulnerability classes	GW vulnerability 1990s (area %)	GW vulnerability 2020s (area %)	GW vulnerability 2050s, artificial projection (area %)	GW vulnerability 2050s, forest projection (area %)	GW vulnerability 2050s, agriculture projection (area %)
Very low	6.19	3.50	2.75	2.49	2.67
Low	70.45	71.73	72.29	77.73	68.66
Medium	22.16	22.64	22.83	17.87	26.25
High	1.19	2.13	2.13	1.91	2.41

From the findings of the above studies we understand that climate change has greatly affected the groundwater of Europe and it will affect them even more in the future. The main problem is the increase in temperature but also the decrease in precipitation in recent years, resulting in the increased evapotranspiration and the reduction in groundwater reserves. However, an important problem is human interventions, especially in agriculture that large quantities of water are pumped and the quality of groundwater from pesticides is degraded. But if we think about it well, climate change is directly linked to the catastrophes caused by humans in the environment.

The lowest water availability rates (below 200 mm) are in the central and southern parts of the Iberian Peninsula, the Mediterranean islands, the Central and Southern peninsula of Italy, Eastern and Southeastern Europe. These areas are projected to face the biggest problem in terms of groundwater availability in the future. Areas with a high NO_3 concentration are located in central Europe and northern Europe. Values above the acceptable level of 0.5 mg / l As have been identified in a few areas in Europe. The western and southern parts of Europe face the biggest problem in terms of the amount of groundwater that comes from climate change. Extremely high climatic impacts are in the Pannonian basin in eastern and southern Romania, northern and southern Bulgaria, eastern and central parts of Macedonia, northern and eastern Greece and northern European part of Turkey.

3.4. Proposed solution to the problem of the area

Based on the problems faced by the area, measures should be taken to maintain / improve the ecological and chemical status of the water system, to maintain / increase the available water resources, to transfer innovation from educational institutions to production and farmers and to evaluate impact of the forthcoming climate change on farms in the region. All this will help create new crops and new jobs in the area.

The specific study aims to provide a solution to the preservation and improvement of both quantity and quality of the groundwater of the Geropotamos basin through the method of managed aquifer recharge.

Surface runoff can be utilized in the following ways:

- By direct pumping from the bed of the hydrographic network, while flowing, before reaching the sea.
- By constructing dams in the artificial lake which are stored and from which it can be used.
- By using it for managed aquifer recharge of aquifers.

In the first case the solution is usually advantageous, but only a small percentage of surface water can be utilized. Moreover, the water demand is maximum when the supply of the hydrographic network is minimal or zero. So in countries like Greece it is not a solution today that requires utilization of all water resources, or at least a large part of it.

In the second case, Greece, Mediterranean countries and in the rest of the world have the construction of dams and the use of water from their artificial lakes. Depending on the characteristics of the construction site of the dam, the solution may be more or less advantageous or sometimes quite to completely unprofitable, but necessary for social reasons, when there is no other solution.

In the third case there is a solution that over the last decades has developed slowly because it has many advantages. Of course, this solution is appropriate when the geological and hydrogeological conditions are suitable and the economic parameters are finally advantageous in the context of overall management of the water resources of an area or basin. In some areas this is either the only possible or necessary solution and therefore must be implemented regardless of economic parameters and returns.

3.4.1. Definition of managed aquifer recharge

In a basin the area that is under natural conditions, without human intervention, the water of the sediments that reaches the aquifers and feeds them, is the natural recharge either directly by penetration or indirectly by infiltration from the beds of the hydrographic network. Its height is defined every hydrological year and depends on the geological composition, the rainfall height and the rainfall system (annual distribution of rainfall).

People have the ability to increase this amount of water, that is, to cause "managed aquifer recharge". Therefore, as a managed aquifer recharge of the aquifers we could characterize the increase of the quantities of meteoric water that enters the aquifers using processes, techniques, installations-devices by humans. In the broadest sense we would say that managed aquifer recharge is the introduction of additional amounts of water into the aquifers. This additional water can come from surface water or from water from adjacent aquifers.

3.4.2. Purpose of managed aquifer recharge

The purpose of managed aquifer recharge is one of the following or a combination of more than one of them:

- The increase of the exploitable quantity of groundwater or the creation of a temporary underground storage for exploitation.
- The restoration of the hydrological balance (because of the hydrological balance) of aquifers or systems that were disturbed due to their over-exploitation (over-pumping) or the prevention of the threatened disturbance of the hydrological balance and its consequences.
- The induction of level rise (locally or generally) in coastal aquifers to avoid or block sea penetration and salinization of aquifers.
- The rise or even the maintenance of the level of aquifers to avoid their agglomeration and retreat of the soil surface.
- The modification of groundwater quality by enriching it with another suitable quality.
- The treatment of surface water to be exploited by their filtration from suitable soil-geological layers.
- The maintenance of the supply that is threatened with reduction or even complete sterilization or reopening of an already sterilized source of pumped well (or drilling) or any water intake (water storage) project.

- The energy use of water by introducing cold and pumping hot in areas of geothermal fields.
- The operation of refrigeration plants and factory mechanisms with the introduction of hot water and cold pumping.
- The treatment of flood benefits by channeling part of them to areas with devices-installations of managed aquifer recharge.

3.4.3. Conditions for the application of managed aquifer recharge

The conditions for the application of managed aquifer recharge are the following:

• Sufficient amount of surface water.

• Quality of the surface water is and chemical compatibility with that of the groundwater.

• Suitable geological conditions (surfaces and subsoil with high permeability, aquifers in sequence and in hydraulic interconnection, etc.).

• Geomorphologically suitable areas.

• Construction and operating costs are not unprofitable.

3.4.4. Advantages and Disadvantages of Managed aquifer recharge

Among the advantages we could mention:

- It has generally positive effects on the environment: improving the quality of groundwater, protecting the existence and operation of springs and wetlands, avoiding coagulation and therefore quantitative degradation of aquifers, preventing or blocking the penetration of seawater into coastal aquifers.
- Underground reservoirs do not run the risk of natural disasters of surface reservoirs (landslides, floods, direct contamination, etc.).
- Any existing infrastructure from drillings, pipelines, etc. is not rendered useless due to over-pumping.
- Exhaust water losses are reduced.

The disadvantages could be:

- Continuous and diligent monitoring of managed aquifer recharge systems is required.
- There is a risk of groundwater contamination if contaminated water is used, even if it is used only occasionally.
- Suitable conditions for the application of managed aquifer recharge are not often found in nature under economically advantageous conditions.

3.4.5. Methods of managed aquifer recharge

For the application of aquifer recharge have been developed many methods such as:

1. Direct-surface recharge
    - Basin method
    - Ditch and furrow method
    - Flooding method
    - Stream – channel modification
    - Stream flow reactivation or augmentation
    - Irrigation method
2. Direct -subsurface recharge
    - Natural openings
    - Trench method
    - Reverse drainage method
    - Recharge well method
    - Aquifer storage and recover wells - ASR wells
    - Vadose – zone wells
3. Combinations of surface and subsurface recharge
    - Basins with subsurface drainage collectors and wells)
    - Basins with pits, shafts, or wells
4. Methods of indirect recharge
    - Induced surface water recharge
    - incidental recharge
    - Aquifer modification

4. Managed Aquifer Recharge - METHOD

Water resources are under pressure as a result of the combined effects of climate change and population growth. Managed Aquifer Recharge (MAR) is a promising measure to increase the availability of freshwater and become more resilient to climate change. The potential of suitability mapping using GIS-based Multi Criteria Decision Analysis (GIS-MCDA) to promote these methods in the future is investigated.

4.1. Definition

Managed Aquifer Recharge (MAR) is defined as the "purposeful recharge of water to aquifers for subsequent recovery or environmental benefits" (Dillon *et al.*, 2009). Its various applications are adaptable to many contexts, although they are still limited compared to traditional surface water storage methods. MAR presents many interests including enhancing the security of water supplies, improving groundwater quality, preventing saltwater intrusion, mitigating floods, maintaining groundwater-dependent ecosystems (Dillon et al., 2009).

4.2. Interest of subsurface storage

Increased water demand and climate change requires an increase in water storage capacity, which is now provided mostly by surface reservoirs contained behind small to large dams. However, large evaporation losses, water quality issues as well as growing concerns about dam safety, subsidence, environmental and social impacts demonstrate the limitations of surface water storage (Tuinhof et al., 2002).

The available water supply can be increased by enhancing water storage below the surface in aquifers, although the potential global storage capacity is still difficult to estimate (Tuinhof et al., 2002). Subsurface storage presents the great advantages of storing water for years with little or no evaporation losses, low environmental impact and allowing the removal of certain contaminants during slow water filtration through the soil (Gale, 2005).

4.3. Potential sources and uses of MAR

A prerequisite for the use of MAR is to have an adequate source of water available for recharging, which includes various types such as surface water, rainwater, storm water, recovered water or groundwater (Gale, 2005; Dillon et al., 2009). Depending on the initial quality of the spring water and the desired end use, a pre-treatment phase before recharge and finally post-treatment after recovery might be necessary to bring the water to a required quality standard that ensures the protection of public health. and environment (Dillon et al., 2010).

After recovery, the recharged water can serve for various uses such as drinking water, irrigation, industry, domestic use or ecosystem sustaining. This additional water supply from MAR can be highly beneficial for securing the water supply in periods of droughts by storing water for several years with little evaporation losses, preventing saltwater intrusion in coastal areas, protecting groundwater-dependent ecosystems by increasing groundwater levels, improving groundwater quality and mitigating flood damages (Dillon *et al.*, 2009).

4.4. Hydrogeological control on MAR

The success of a MAR scheme depends largely on the aquifer's storage capacity and the ability of the unsaturated zone to infiltrate water for applications recharging water to the aquifer from the surface (Tuinhof, 2002; Gale, 2005). A good knowledge of the hydrogeological conditions is decisive, including key factors such as the degree of confinement, aquifer properties (hydraulic conductivity, thickness), piezometric surface, water quality, nature and thickness of the unsaturated zone…

The nature of the geological formations composing the aquifer has an important control on the potential storage space available and the ability to recharge and recover water from it. Gale (2005) identified four categories of potential hydrogeological environments from the perspective of MAR: alluvium, fractured hard rock, sandstones and carbonate aquifers.

4.5. MAR types and techniques

4.5.1. Spreading methods

Spreading methods refer to MAR applications which aim at infiltrating water from the land surface to underlying aquifers. Possible schemes include diverting water to infiltration basins or trenches that will enhance infiltration through the unsaturated zone (localized land infiltration). Other possible techniques include irrigating crops in excess or diverting flood water to specific areas to allow infiltration (diffuse land infiltration). The recharged water is stored in the underlying aquifer and recovered in periods of high demand through wells. Spreading methods can be beneficial for increasing water storage as well as water quality due to the filtration process occurring when the water travels through the unsaturated zone.

4.5.2. Induced bank filtration.

In cases of low quality of surface water (river or lake), a series of wells can be installed parallel to a water body to enhance the infiltration of water through the ground induced by pumping. The water recovered at the wells will be of better quality as it benefited from the filtration process taking place when travelling through the river or lake bed, removing dissolved and suspended pollutants. This MAR type can also be applied to sand dunes, where water infiltrating through the sediments is recovered down-gradient with an increased quality.

4.5.3. Well, shaft and borehole recharge

In this class of MAR application, water is infiltrated through wells directly into the target aquifer. These techniques can typically be applied when the unsaturated zone does not allow water to infiltrate, when the aquifer is covered by a confining layer or to reuse existing shallow wells. The water is stored in the aquifer and can be recovered either at the injection well (ASR) or at a different well to benefit from an additional treatment process by extending the water residence time in the aquifer.

4.5.4. In-channel modification

Several MAR techniques consist in modifying the stream flow to enhance infiltration of water. Some of them aim at intercepting the flow in intermittent streams with dams built across the streambed. These structures can be used to control the release of water downstream to match the capacity of infiltration to the underlying aquifer or to enhance the infiltration of water behind the recharge dam. In impermeable streambeds, sands and gravels can be accumulated upstream of the dam to form an artificial aquifer storing storm water runoff. In intermittent streams with shallow bedrock, underground dams of low permeability material can be built across the streambed to retain storm water runoff in the alluvium. In permanent streams, the river flow can be modified by installing L shaped levees that allow enhancing recharge by increasing the infiltration area and decreasing the flow velocity.

4.5.5. Runoff harvesting

Rainwater can be harvested at the scale of a household to a village and directed to storage tanks that can contribute to groundwater recharge. Several structures allow collecting rainwater such as trenches or reverse drainage. Rooftop rainwater harvesting is being increasingly used in urban areas, helping to sustain groundwater levels and mitigate storm water runoff.

4.6. Suitability mapping with GIS-MCDA

4.6.1. General definition

In the field of environmental sciences, spatial decision problems typically involve a large set of feasible alternatives defined by multiple, conflicting and incommensurate evaluation criteria. Decision-makers require information and tools to incorporate their value judgments and understand the inherent trade-offs of a spatial problem. Multi Criteria Decision Analysis (MCDA), also known as Multi Criteria Evaluation (MCE), encompasses several techniques and procedures for structuring spatial decision problems as well as designing, evaluating and prioritizing alternative decisions. MCDA is commonly used in combination with a computer-based geographic information system (GIS) integrating spatially referenced data (GIS-MCDA). GIS-MCDA can be defined as a process that transforms and combines geographical data according to the decision-maker's judgement to obtain information for decision making.

4.6.2. Applications to MAR suitability

The selection of suitable areas for the implementation of a MAR site can be a complicated process as several factors need to be considered, including in priority information on the hydrogeological context and surface characteristics such as the geology, land cover slope. In addition, considerations of the social and financial context, policy and regulations, environmental impacts and others can appear decisive in the definition of suitable area, therefore adding much complexity to the decision process.

In Rahman et al. (2012), GIS-MCDA is presented as a method providing adequate solution procedures to deal with the complexity of MAR suitability at low costs, in comparison with traditional decision support systems and GIS-based analysis methods. This method allows identifying priorities in the considerations of a given MAR project, using and manipulating geographical data according to the decision-maker's preferences.

4.6.3. Steps

The process of a GIS-MCDA involves several steps to solve a spatial problem, such as finding suitable areas to implement MAR, described in the following section.

1. Set the goal/define the problem

The first necessary step to conduct a successful GIS-MCDA is to clearly define the goal of the study. The spatial problem should be characterized by one or several specific and measurable objective(s), attainable in the time frame available. The problem definition is a decisive step as it will greatly affect the rest of the study by influencing the selection of criteria and their respective weights.

2. Determine the criteria

The criteria form a set of spatial information that contributes to represent the multi-criteria nature of the decision situation (Keeney, 1992). Malczewski & Rinner (2015) state that each criterion should be comprehensive, measurable, decomposable, complete, operational, non-redundant and that the set of criteria should be kept minimal. The information represented by each criterion can be spatially measurable (e.g. slope), an attribute of the study area (e.g. land use) or a value derived from spatial information (e.g. drainage density). The set of chosen criteria should reflect the characteristics of the study area with a sufficient level of precision to answer the problem formulated.

3. Define the criteria values

There are two approaches to deal with each criterion, defining them either as a constraint or as a factor (Eastman, 2005). Constraint criteria will typically be represented by a Boolean statement of suitability for the decision considered, where the criterion is described by a binary system (true/false, 1/0…). This type of criterion serves to limit the alternatives under consideration by defining restrictive features for which an area will necessary be considered unsuitable. Constraint criteria are typically represented on a map with a separate mask layer, commonly called 'Constraint mapping'.In this work we define each criterion only as a factor.

For factor criteria, the approach is to give more quantitative information by describing the criterion as a continuous or step function, expressing varying degrees of suitability for the decision considered. All factor criteria have to be expressed with a common scale of suitability allowing to combine them on the same level, commonly called 'Standardization'.

4. Determine the weight of each factor

Several techniques exist to determine the weight of each factor criterion, with the most used in literature being the 'Pairwise comparison method', the 'Rating method' and the 'Ranking method' (INOWAS, 2018b). The 'Pairwise comparison method' is part of the Analytical Hierarchy Process (AHP), developed by Saaty (1980), being a framework to evaluate a problem by decomposing it into a hierarchy of sub-problems. In this method, the decision maker builds a matrix to compare each criterion to the other criteria, by evaluating its importance with a value from 1 to 9 (1: the criterion is considered equally important than the one compared; 9: the criterion is considered extremely more important than the one compared). Each method result in a numerical value assigned to each weight, with all weights summing up to 1.

5. Aggregate the criteria

The last step to produce the decision map is to calculate the final suitability score using a 'Decision rule' combining the criteria together using their relative weights. The most common method is the Weighted Linear Combination (WLC), in which the composite suitability score S is calculated for each cell using the following formula:

$$S = \Sigma wixi$$

Where:

S is the composite suitability score

wi is the weight assigned to the factor criterion i

xi is the index of the factor criterion at the cell considered i

Σ is the sum of weighted factor criteria

6. Validate/verify the result

The process of a GIS-MCDA highly reflects the value judgments of the decision-maker in the selection of criteria, the choice of constraints, the standardization of factor criteria and the weights assigned for aggregation. This subjectivity results in a potentially high uncertainty of the decision and is complicated to evaluate for problems which cannot easily be verified by field measurements. For instance, the suitability for MAR is not a straight forward variable that can directly be measured.

One method to assess the reliability of the results is to perform a 'Sensitivity analysis', in which the effect of altering one or several component of the GIS-MCDA is investigated. This can include altering the set of criteria by adding or removing a criterion or by modifying the respective weights of factor criteria. The decision-maker can reflect from the effects of these alterations whether the result appears reasonably close to reality or not. It is however important to note that this step does not decrease in any way the uncertainty of the results but rather contributes to acknowledge and communicate the subjectivity of the decision resulting from a GIS-MCDA to other users.

The reliability of a suitability map can however partially be assessed if some points are available for validation. In the case of MAR, existing sites can be used to assess the ability of a map to predict high suitability. In addition, the results can be verified by selecting sample areas to conduct an in-depth field survey.

5. Managed aquifer recharge in Geropotamos basin

Below are presented for the area of the Geropotamos basin all the steps analyzed in paragraph 4.6.3.

5.1. Problem definition

The problem faced by the study area is reported in detail in Chapter 3. The area has been facing significant problems with its groundwater as the level is showing a significant drop and part of the groundwater is facing problems with their quality.

A suitable site for MAR spreading methods should typically have a source of excess water available nearby, be located in a flat area with permeable soils and be underlined by an unconfined aquifer.

Being based only on a hypothetical need of MAR suitability, financial and legislative matters are not included in the process.

5.2. Choice of criteria

One important source of variability in MAR suitability maps comes from the initial choice of criteria. The criteria combining a high relevance and high data availability, and providing unique information were selected to assess the suitability of MAR spreading methods in Geropotamos basin:

- Slope (Influences the infiltration of water from the surface. Spreading methods require a flat terrain to optimize infiltration and minimize runoff)
- Land use (Defines the availability of the land and possible environmental disturbances associated with the implementation of a MAR project)
- Hydrogeology (Determines the ability to store water in the ground as a function of the hydraulic conductivity, the continuity (fractures, karst) of the medium and the confinement or not of the aquifer)
- Rainfall (Variation of rainfall influences stream discharge, therefore the potential availability of water for MAR. However, the water will preferentially be withdrawn during high discharge periods and stored as groundwater for the dry season)
- Groundwater level (Plays an important role for spreading methods sites aiming at improving water quality as it influences how good the filtration of water through the unsaturated can take place.)
- Soil texture (Determines the ability to infiltrate water through the unsaturated zone)

- Distance to source water (Implementing a MAR site is only possible if there is a source of water available at a reasonable distance).

5.3. Standardization of factor criteria

The standardization of the factor criteria follows an index ranging from 1 (minimum suitability) to 5 (maximum suitability), as presented in Table 6. It is important to note that assigning values to criteria mostly reflects the developer's preferences based on personal judgment and knowledge of the study area.

Table 6. Correspondence between scale of standardization index and suitability level

Suitability class	Index
Highly suitable	5
Suitable	4
Moderately suitable	3
Low suitability	2
Unsuitable	1

Slope

Terrain slope is a crucial criterion to characterize a site suitability to spreading methods. Indeed, an optimal infiltration will be achieved in areas where runoff is minimal, which is only the case in flat terrains. Table 7 shows the slope characterization for the study area.

Table 7. Standardization index for the factor of Slope

Slope	Index
0-2	5
2-8	4
8-15	3
15-30	2
30-34,8	1

Land use

The land use has an influence on surface runoff and gives information relative to the availability of land for implementation of MAR sites. For this study, 5 suitability classes group the main land cover listed in the Corine database according to their influence on infiltration and surface runoff, availability and potential environmental impact as presented in Table 8.

Table 8. Standardization index for the factor of land use

land use	Index
Rural areas	4
Vineyards	3
Bare rocks	1
Incinerated areas	1
Archaeological sites	1
Significant areas of agriculture	4
Wide Leaf Forest	2
Dotted Urban Building	1
Areas with sparse vegetation	5
Olive groves	3
Shrubs and fields	3
Non-irrigable arable area	4
Fruit trees and plants with fleshy fruits	4
Beaches, dunes	1
Hardwood vegetation	1
Complex systems Crops	3
Natural pastures	1
Mineral extraction sites	1

Hydrogeology

Table 9 shows the Hydrogeology characterization for the study area.

Table 9. Standardization index for the factor of Hydrogeology

Hydrogeology	Index
A1	**1**
A2	**2**
D	**4**
E	**1**
K1	**3**
K2	**2**
P1	**5**
P2	**4**
P3	**3**
Z	**2**
g	**2**

Rainfall

Table 10 shows the Rainfall characterization for the study area.

Table 10. Standardization index for the factor of Rainfall

Rainfall (mm)	Index
404,45-552	**5**
552-700	**4**
700-847,5	**3**
847,5-995	**2**
995-1142,24	**1**

Groundwater level

The lower the groundwater level the greater the need for managed aquifer recharge. Also the penetration of water into the underground aquifer is easier. Table 11 shows the groundwater level characterization for the study area.

Table 11. Standardization index for the factor of groundwater level

Groundwater level(m)	Index
0,0-18,8	**5**
18,8-32,9	**4**
32,9-62,7	**3**
62,7-159,8	**2**
159,8-399,5	**1**

Soil texture

Soil texture gives indications on the amount of water that can infiltrate through the unsaturated zone to reach the aquifer. Table 12 shows the Soil texture characterization for the study area.

Table 12. Standardization index for the factor of Soil texture

Soil	Index
Allotigenic orphans Alkaline Mediterranean	**4**
Aluvial REGOSOLS	**5**
Limestone retzines	**3**
Limestone retzines with impurities	**3**
Marl retzines	**1**
Podzolic acidic forest soils	**2**

Distance to source water

One requirement to implement a MAR site for spreading methods is to have an excess of water available at a distance that is small enough to withdraw it in an economically viable way. In this study two water sources were examined, the dam of Faneromeni and the river of Geropotamos. Table 13 & 14 shows the Distance to source water characterization for the study area.

Table 13. Standardization index for the factor of Distance to the dam of Faneromeni

Distance to the dam of Faneromeni (km)	Index
6	5
12	4
18	3
24	2
30	1

Table 14. Standardization index for the factor of Distance to the river of Geropotamos

Distance to the river of Geropotamos (km)	Index
1	5
2	4
4	3
8	2
11	1

5.4. Weight assignment

Weights need to be assigned to each criterion reflecting their relative importance within the set of criteria.

In this study were examined 4 scenarios. In the first scenario was not taken into account the criterion of distance to the water source. In the second scenario was added to the criteria the distance to the dam of Faneromeni. In the third scenario was added the criterion of distance to the river of Geropotamos. Finally, in the fourth scenario, was added to the criteria both, distance to the dam of Faneromeni and the river of Geropotamos.

Several methods exist to assign criteria weights, including the 'Pairwise comparison', developed by Saaty (1980) as part of the AHP.

Each criterion is compared one by one to every other criteria in a pair-wise comparison matrix in which a grade from 0 to 9 reflecting the importance of one criterion compared to the other (below 1, the criterion is judged less important than the other; 1 means that both are judged equally important; from 2 to 9, the criterion is judged more important than the other) is assigned (Table 15, Table 17 and Table 19). Each score is then normalized and converted into relative weights (Table 16, Table 18 and Table 20).

This method resulted in 'slope', 'hydrogeology' and 'distance to water source' as the most important criteria, according to the following reasoning: spreading methods cannot be applied on steep slopes even if all other criteria are highly suitable as most of the water available will be lost by runoff. Hydrogeology was considered as important as slope for spreading methods as there must be a suitable aquifer to store water. Therefore, the criterion 'hydrogeology' resulted second most important in scenario 3&4 and third most important in scenario 4. Finally, the criterion 'Land use' and 'Rainfall' resulted in the lowest weight.

Table 15. Pairwise comparison matrix for suitability of MAR spreading methods in Geropotamos basin (scenario 1)

	Hydrogeology	Rainfall	groundwater level	Slope	Soil	Land use	Total.1
Hydrogeology	1	5	2	1	3	5	17
Rainfall	0,2	1	0,5	0,2	0,5	1	3,4
groundwater level	0,5	3	1	0,5	2	3	10
Slope	1	5	2	1	1	5	15
Soil	0,33	5	0,5	1	1	3	10,83
Landuse	0,2	1	0,33	0,2	0,33	1	3,06
Total.2	3,23	20	6,33	3,9	7,83	18	59,29

The weights were calculated as follows:

Weights = Total.1 / 59,29

The final weights were calculated, normalizing the weights, dividing all the weights with the lightest weight and rounding them. This method of calculating the final weights was performed for all scenarios.

Table 16. Final weights- scenario 1

Criteria	Weights	Final Weights
Hydrogeology	0,29	6
Rainfall	0,06	1
groundwater level	0,17	3
Slope	0,25	5
Soil	0,18	4
Land use	0,05	1

Table 17. Pairwise comparison matrix for suitability of MAR spreading methods in Geropotamos basin (scenario 2&3)

	Hydrogeology	Rainfall	groundwater level	Slope	Soil	Landuse	Distance	Total. 1
Hydrogeology	1	5	2	1	3	5	1	18
Rainfall	0,2	1	0,5	0,2	0,5	1	0,14	3,54
groundwater level	0,5	3	1	0,5	2	3	0,5	10,5
Slope	1	5	2	1	1	5	5	20
Soil	0,33	5	0,5	1	1	3	0,2	11,03
Landuse	0,2	1	0,33	0,2	0,33	1	0,25	3,31
Distance	1	7	2	0,2	5	4	1	20,2
Total.2.	4,23	27	8,33	4,1	12,83	22	8,09	86,58

Table 18. Final weights- scenario 2&3

Criteria	Weights	Final Weights
Hydrogeology	0,21	5
Rainfall	0,04	1
groundwater level	0,12	3
Slope	0,23	6

Soil	0,13	3
Land use	0,04	1
Distance	0,23	6

Table 19. Pairwise comparison matrix for suitability of MAR spreading methods in Geropotamos basin (scenario 4)

	Hydrogeology	Rainfall	Groundwater level	Slope	Soil	Landuse	Distance F	Distance G	Total.1
Hydrogeology	1	5	2	1	3	5	1	1	19
Rainfall	0,2	1	0,5	0,2	0,5	1	0,14	0,14	3,68
groundwater level	0,5	3	1	0,5	2	3	0,5	0,5	11
Slope	1	5	2	1	1	5	5	5	25
Soil	0,33	5	0,5	1	1	3	0,2	0,2	11,23
Land use	0,2	1	0,33	0,2	0,33	1	0,25	0,25	3,56
Distance F	1	7	2	0,2	5	4	1	1	21,2
Distance G	1	7	2	0,2	5	4	1	1	21,2
Total.2	5,23	34	10,33	4,3	17,83	26	9,09	9,09	115,87

Table 20. Final weights- scenario 4

Criteria	Weights	Final Weights
Hydrogeology	0,16	5
Rainfall	0,03	1
groundwater level	0,09	3
Slope	0,22	7
Soil	0,10	3
Land use	0,03	1
Distance F	0,18	6
Distance G	0,18	6

5.5. Results- Suitability mapping

Slope

The EU-DEM file was used to calculate the slopes of the study area, which is a set of 3D raster data with altitudes recorded approximately every 30 meters. With the help of the Slope tool (3DAnalyst) of ArcMap in GIS, the inclinations in degree were first calculated and then in percentage. Below is the percentage slope map.

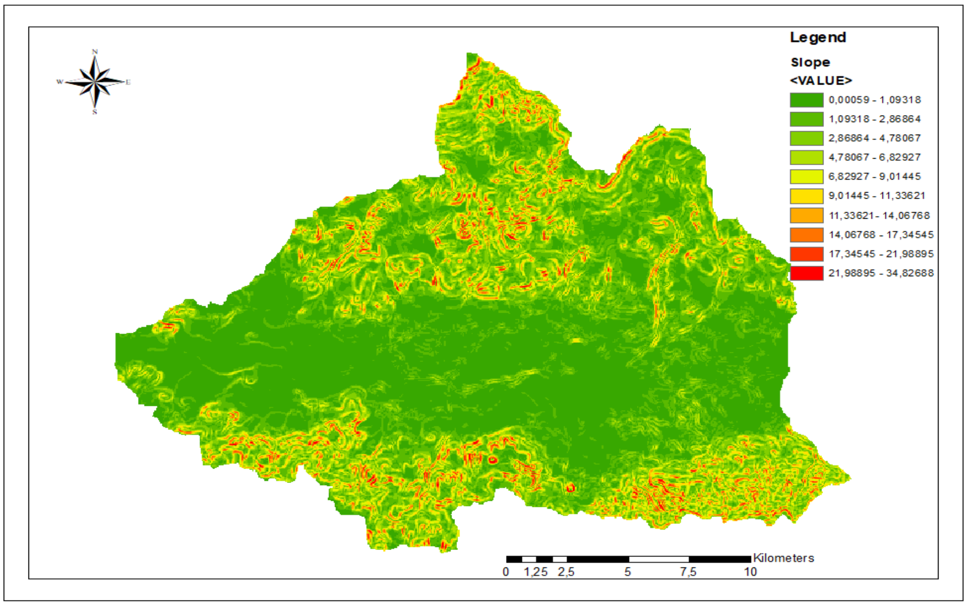

Figure 20. 'Slope' map in Geropotamos basin

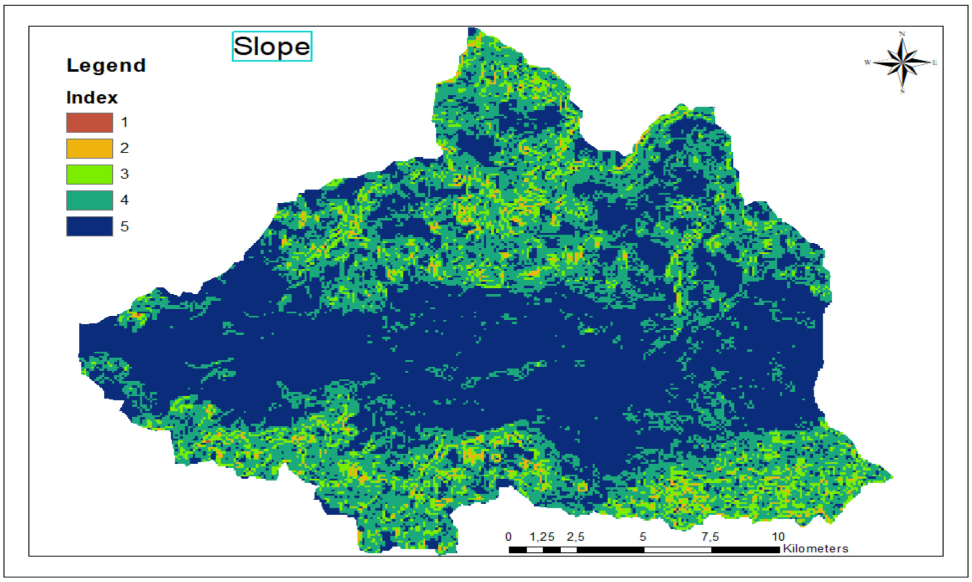

Figure 21. 'Slope' criterion map for MAR suitability in Geropotamos basin

Land use

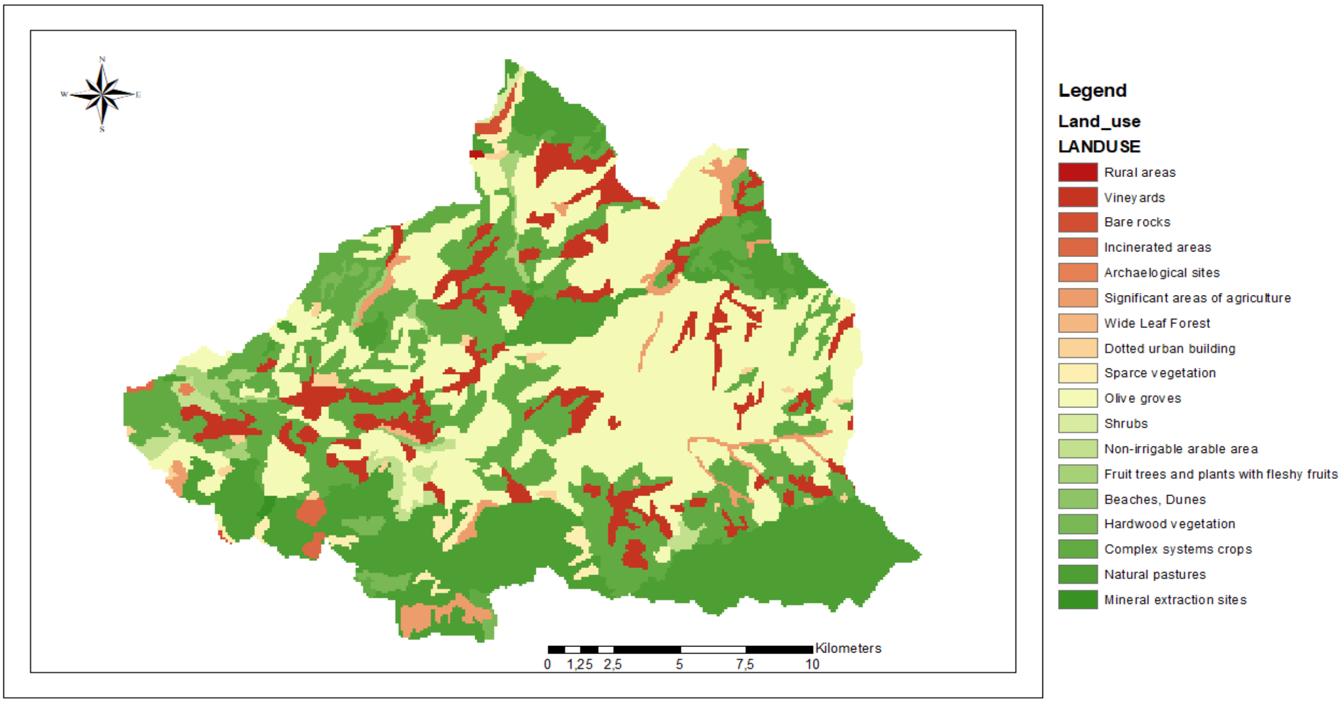

Figure 22. 'Land use' map in Geropotamos basin

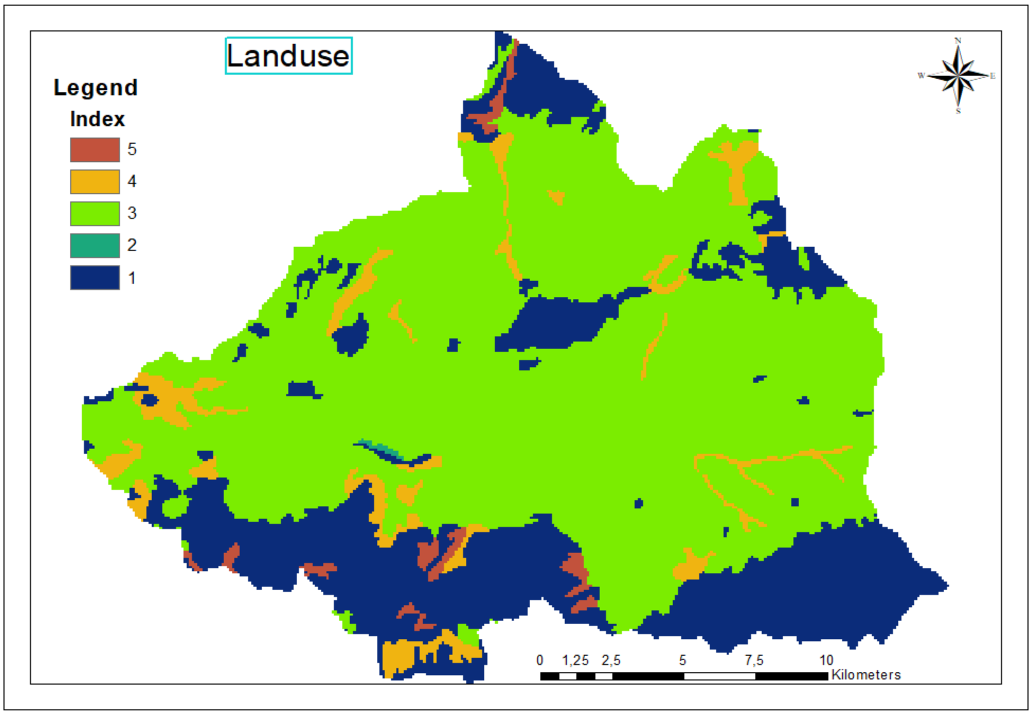

Figure 23.'Land use' criterion map for MAR suitability in Geropotamos basin

Hydrogeology

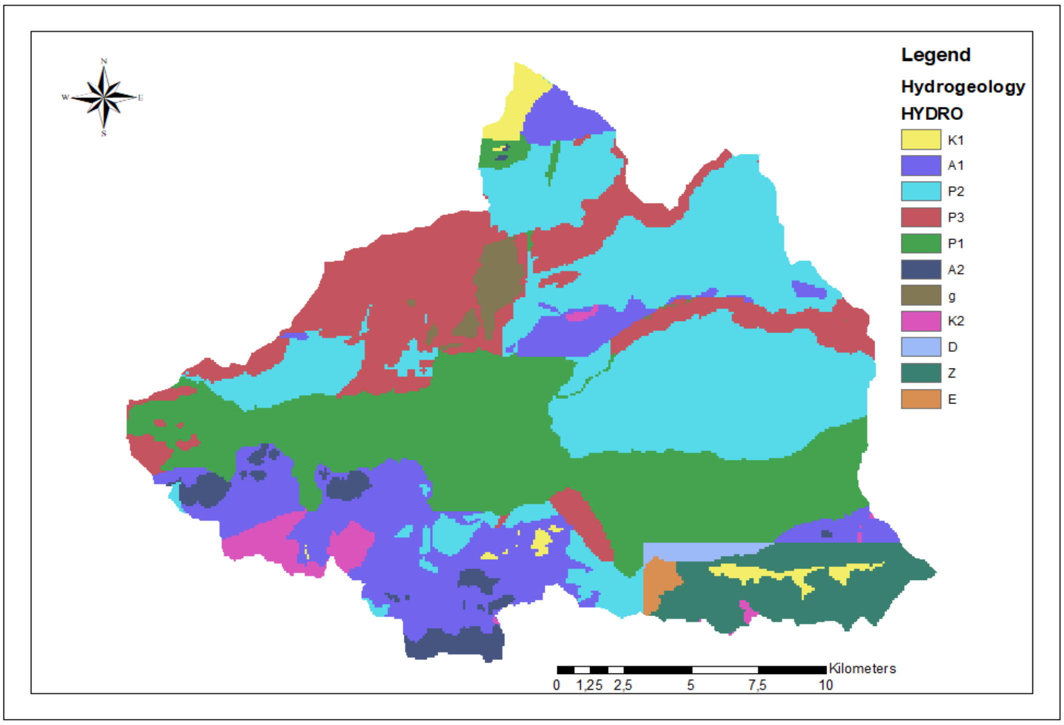

Figure 24. 'Hydrogeology' map in Geropotamos basin

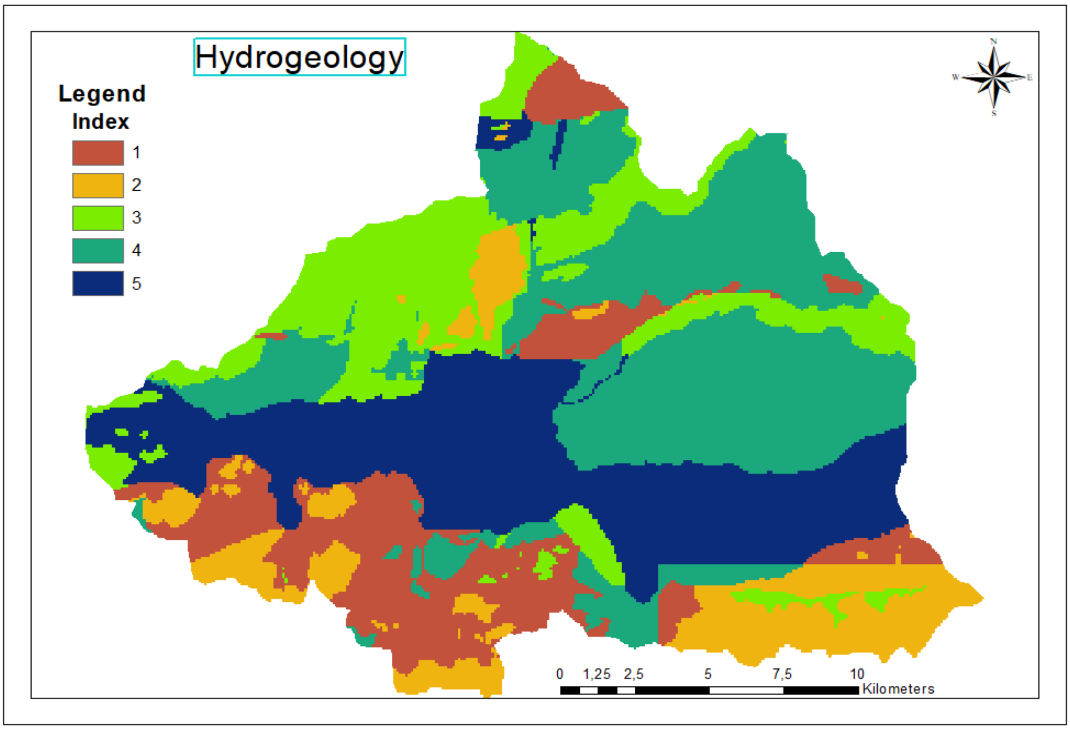

Figure 25. 'Hydrogeology' criterion map for MAR suitability in Geropotamos basin

Rainfall

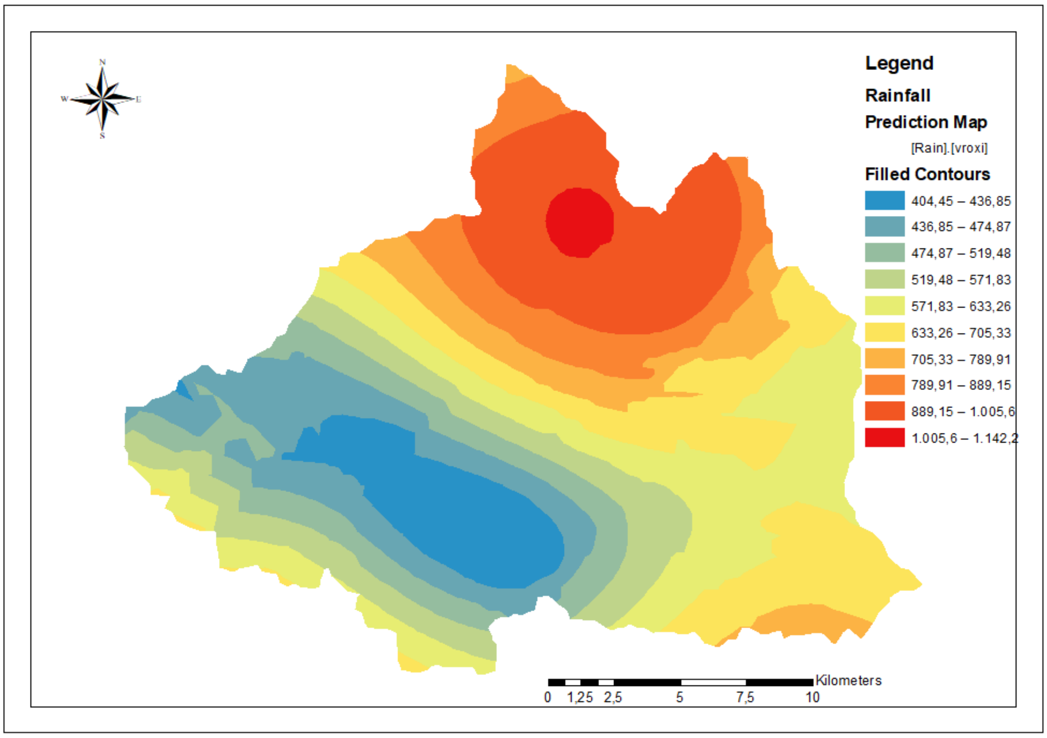

Figure 26. 'Rainfall' map in Geropotamos basin

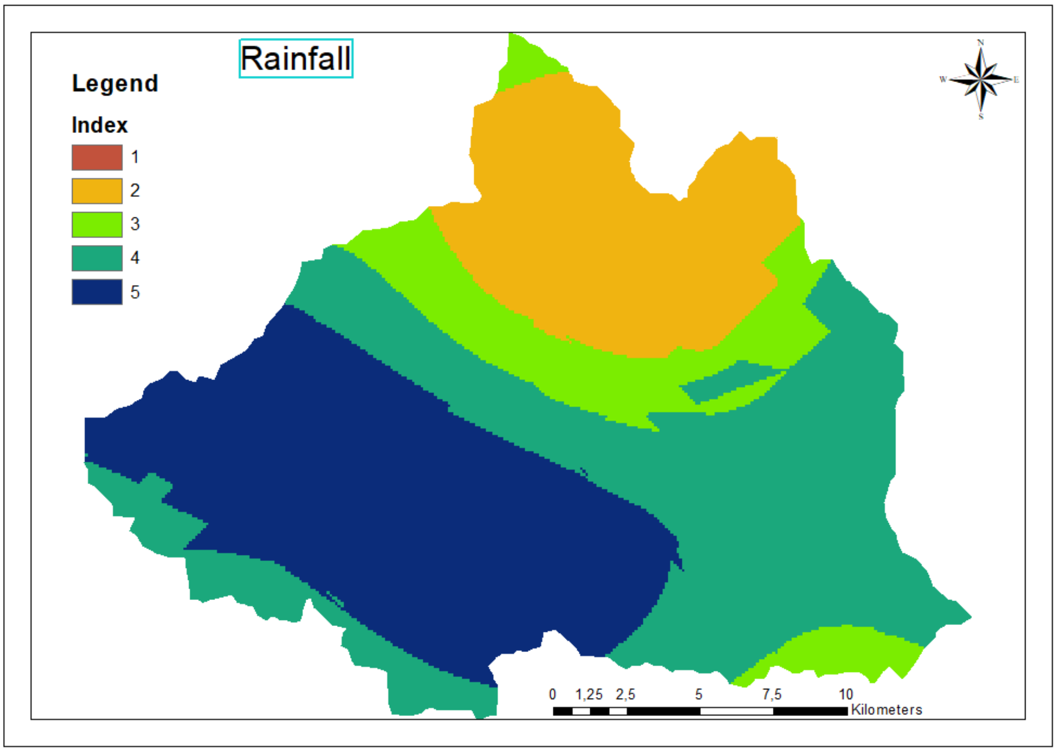

Figure 27. 'Rainfall' criterion map for MAR suitability in Geropotamos basin

Groundwater level

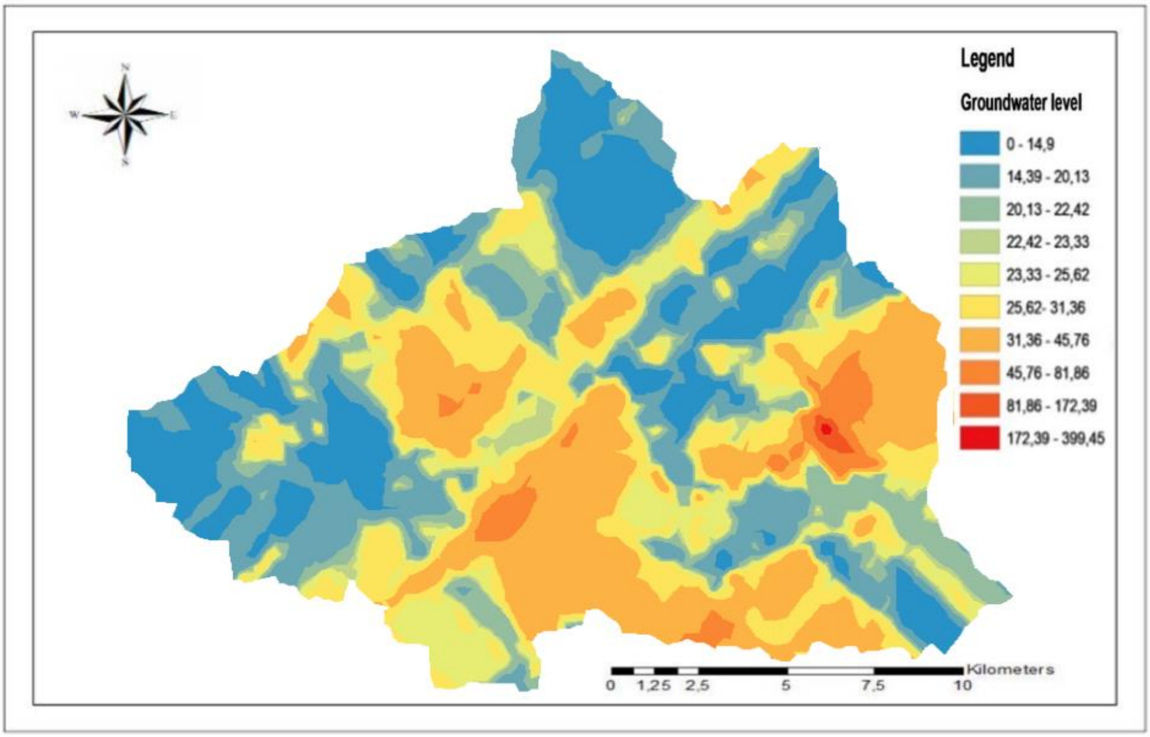

Figure 28. 'Groundwater level' map in Geropotamos basin

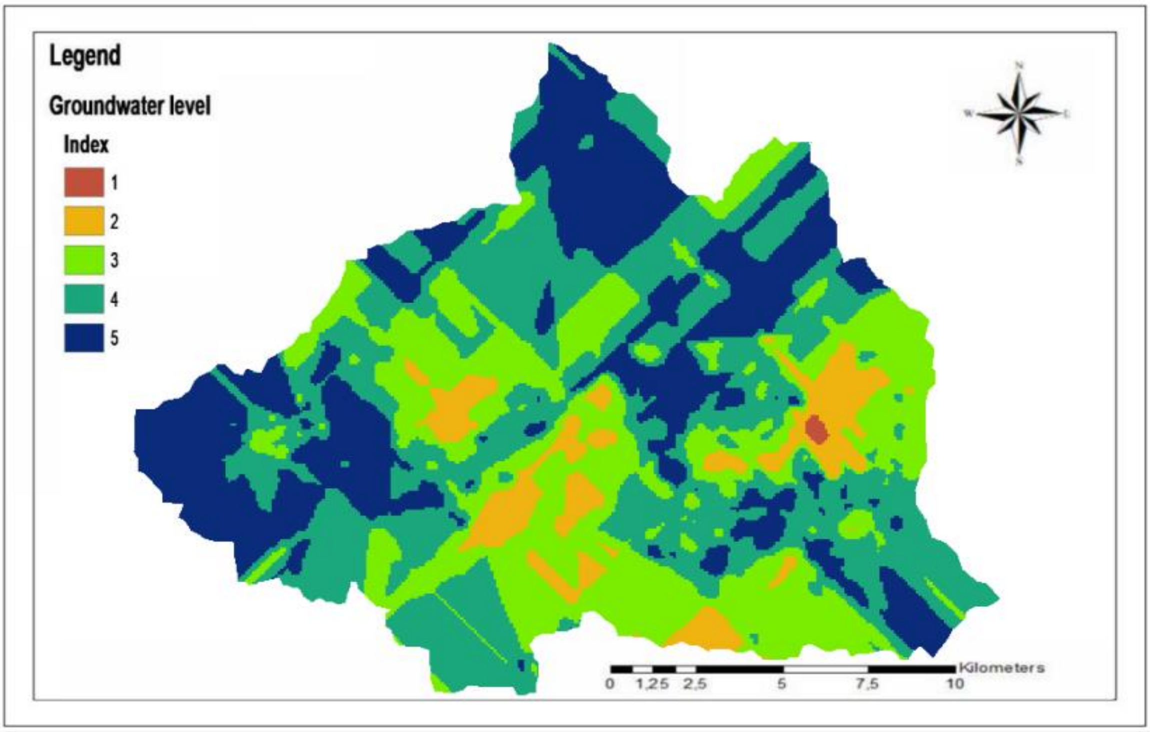

Figure 29. 'Groundwater level' criterion map for MAR suitability in Geropotamos basin

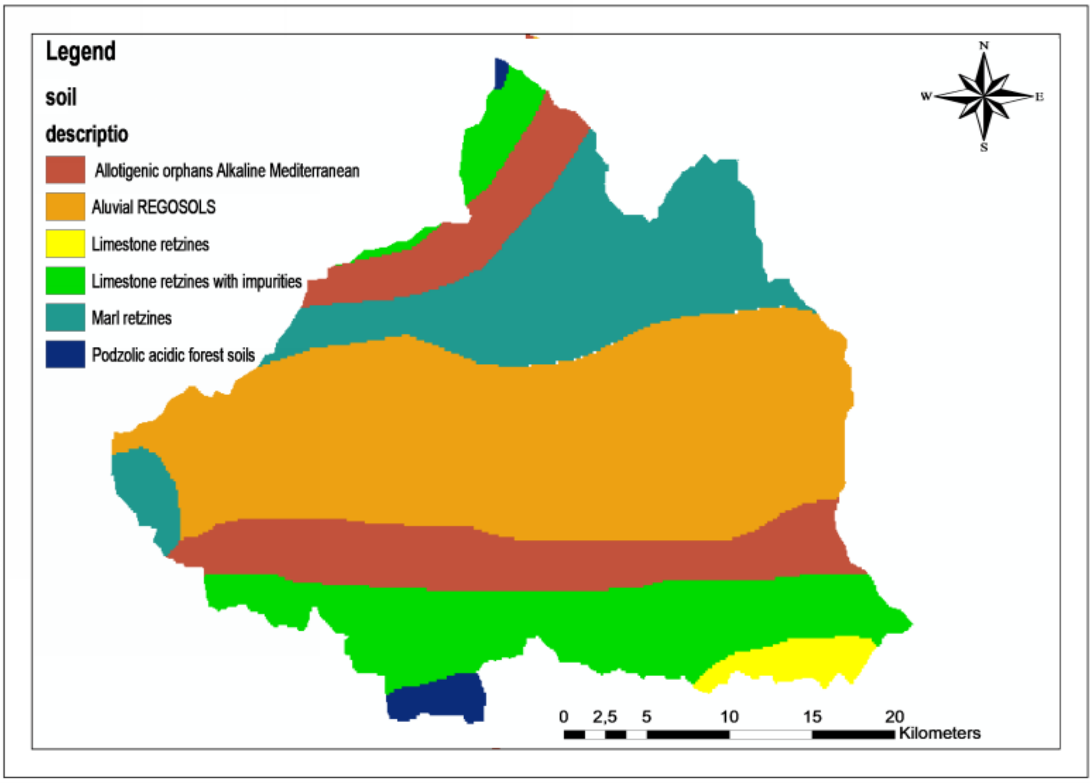

Figure 30. 'Soil texture' criterion map in Geropotamos basin

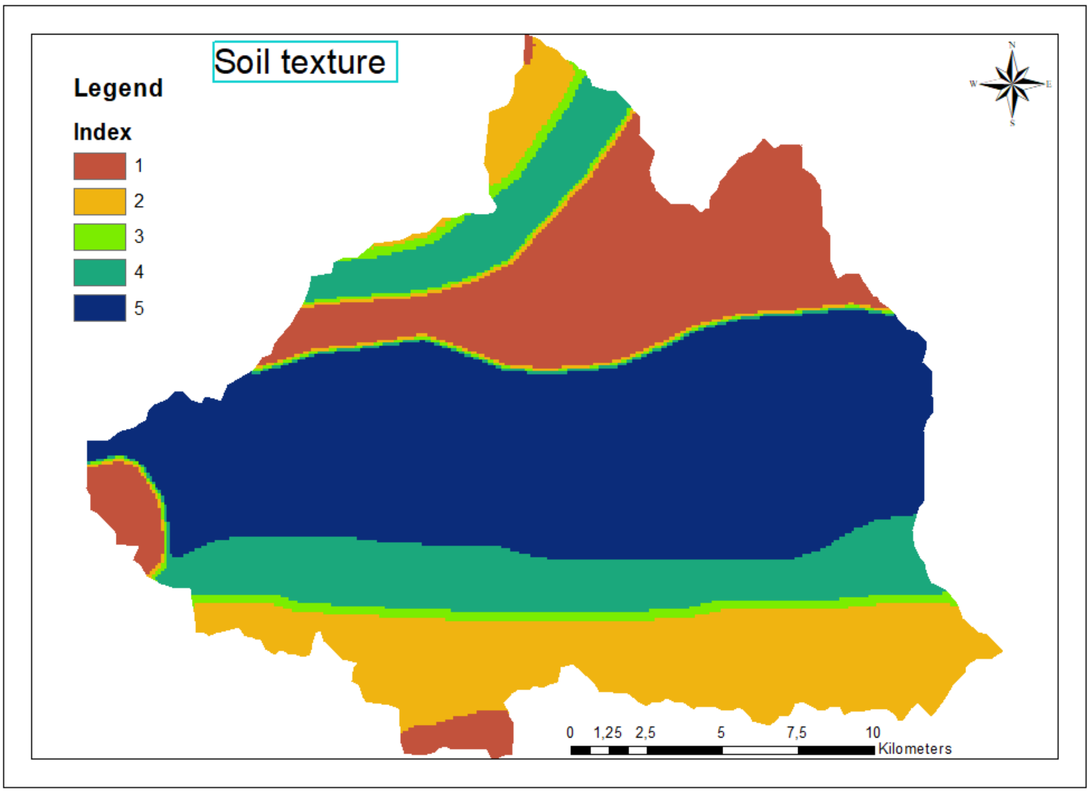

Figure 31. 'Soil texture' criterion map for MAR suitability in Geropotamos basin

Distance to Faneromeni dam

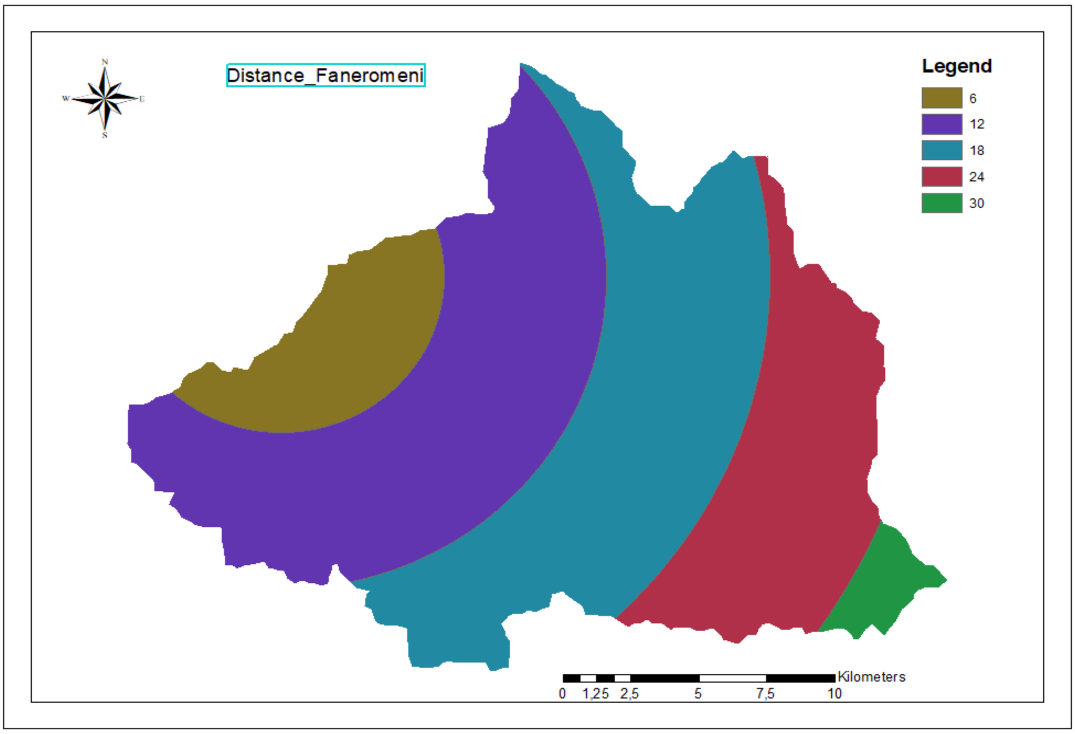

Figure 32. 'Distance to Faneromeni dam' map in Geropotamos basin

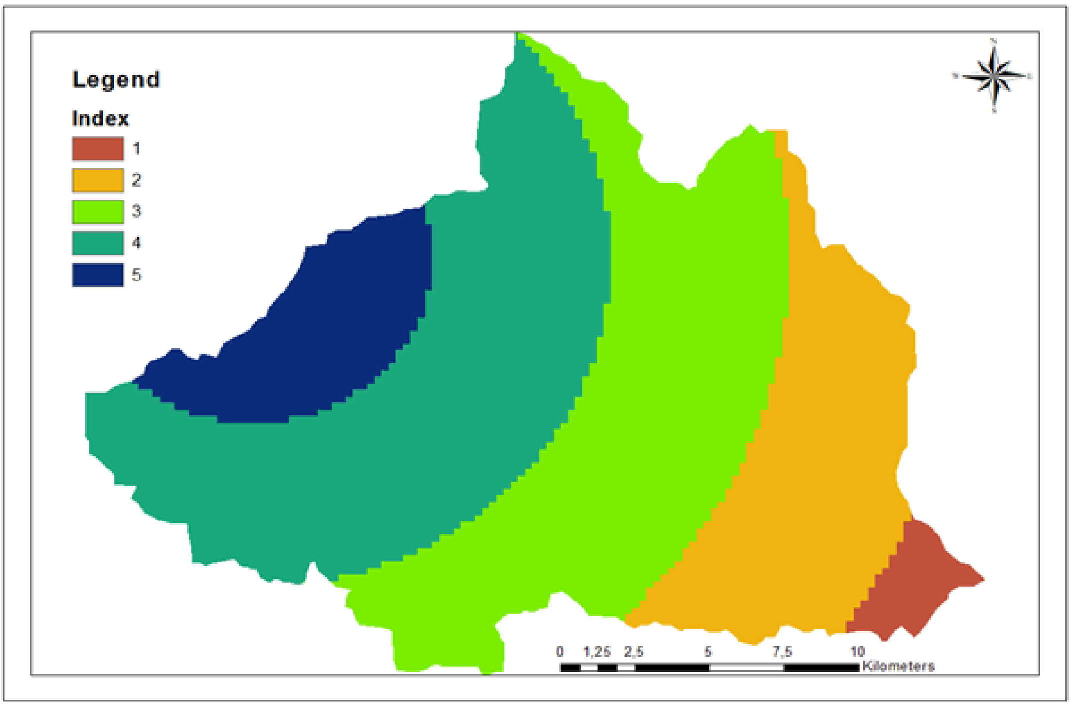

Figure 33. 'Distance to Faneromeni dam' criterion map for MAR suitability in Geropotamos basin

Distance to Geropotamos river

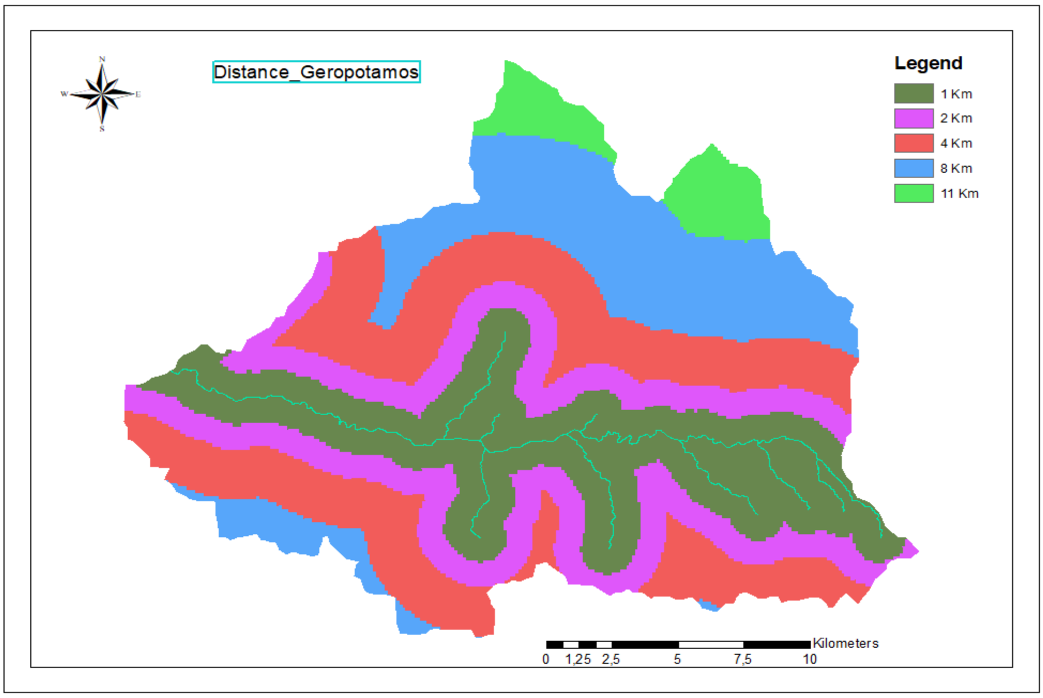

Figure 34. ' Distance to Geropotamos river ' map in Geropotamos basin

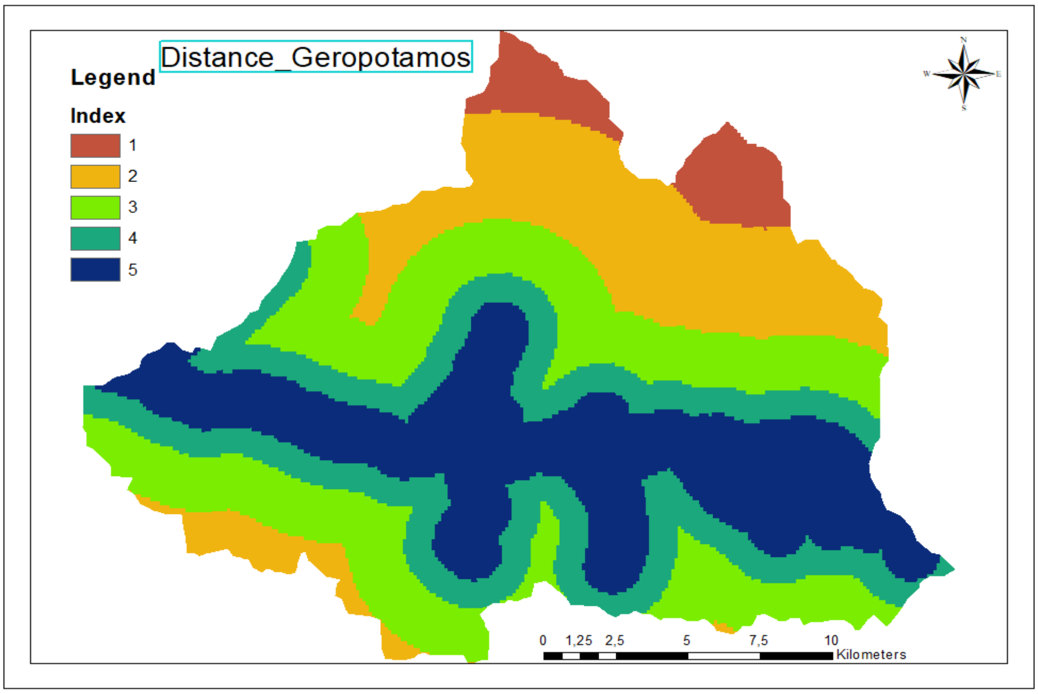

Figure 35. ' Distance to Geropotamos river ' criterion map for MAR suitability in Geropotamos basin

5.5.1. Suitability map after criteria combination

Scenario 1:

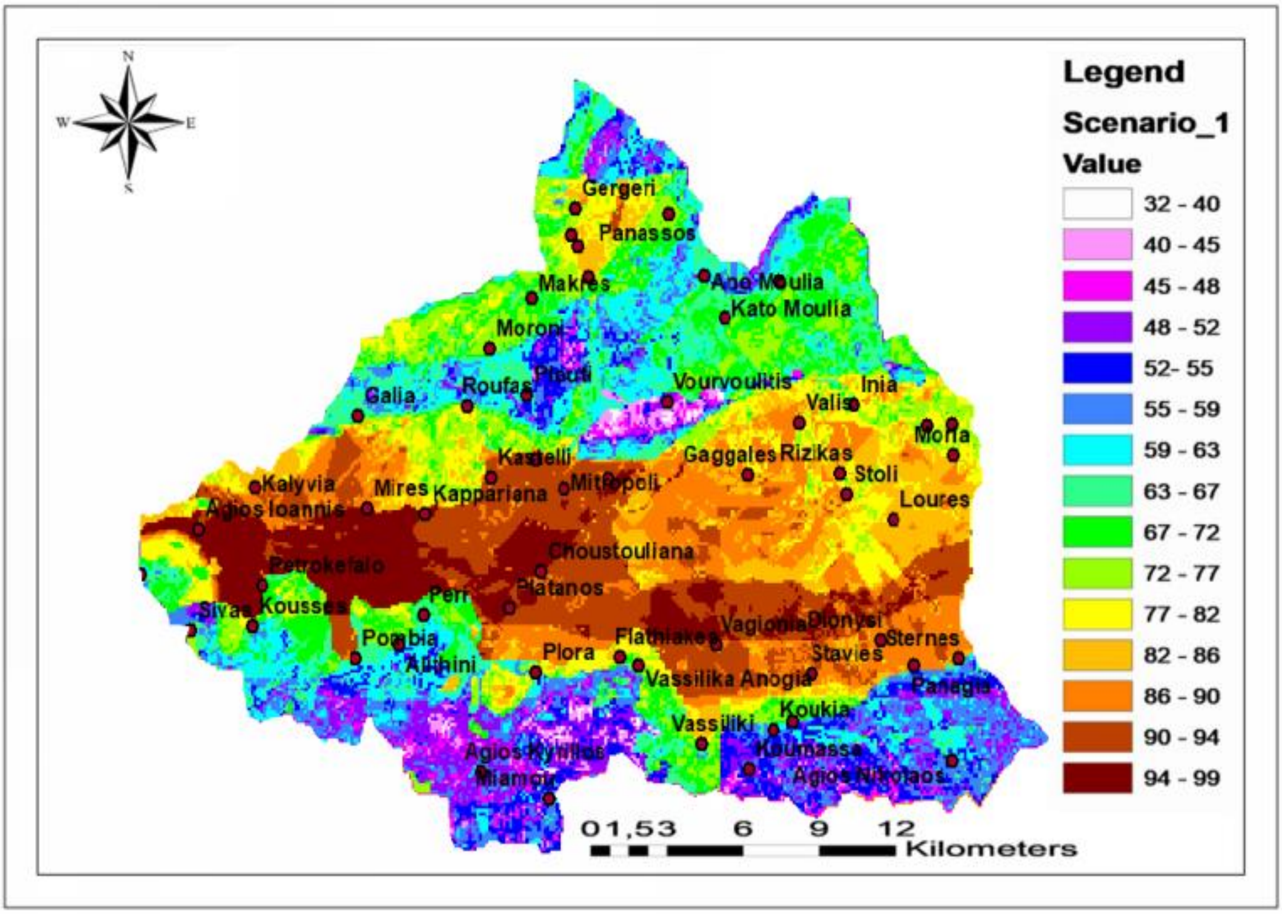

Figure 36. Suitability map for MAR spreading methods in Geropotamos basin (Scenario 1)

The suitability map for scenario 1 resulting from the GIS-MCDA (Figure 36) indicates that the highest suitability for MAR spreading methods in Geropotamos basin covers the western part and some areas in the central part of the region (Agios Ioannis,Petrokefalo, Kousses, Vagionia, Choustouliana, Platanos, Mitropoli, Kappariana), . This result is logical as the slope in this area is small, the hydraulic conductivity is high, the rainfall is limited and the groundwater level is very low.

Scenario 2:

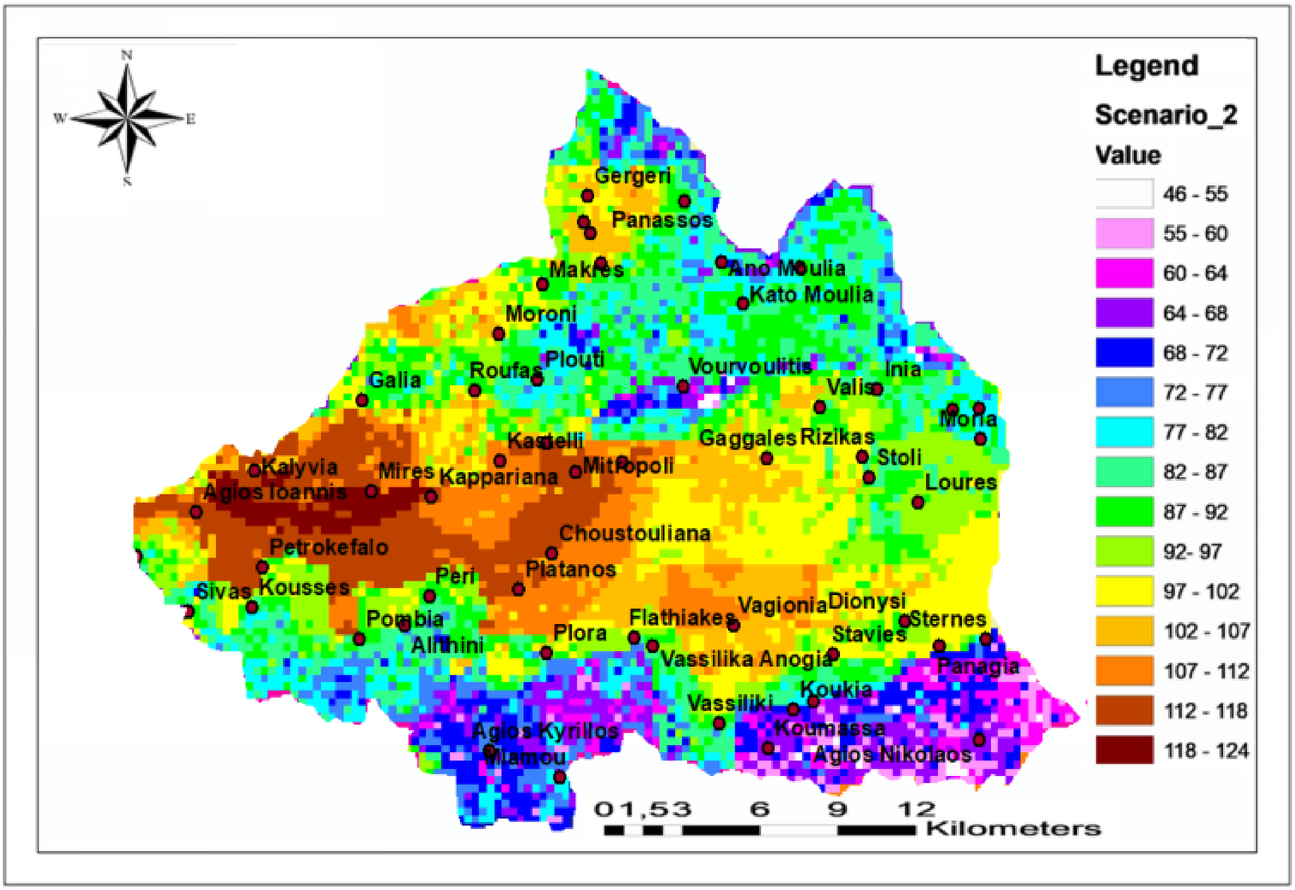

Figure 37. Suitability map for MAR spreading methods in Geropotamos basin (Scenario 2)

The suitability map for scenario 2 resulting from the GIS-MCDA (Figure 37) indicates that the highest suitability for MAR spreading methods in Geropotamos basin covers the western part of the region (Agios Ioannis, Mires, Kalivia, Kappariana). As in scenario 1, in scenario 2 the result is logical for the same reasons, with the difference that in scenario 2 the appropriate areas were reduced due to the criterion of distance from the dam of Faneromeni. The dam is located northwest of the study area , therefore the areas to the east are not suitable as they are in scenario 1.

Scenario 3:

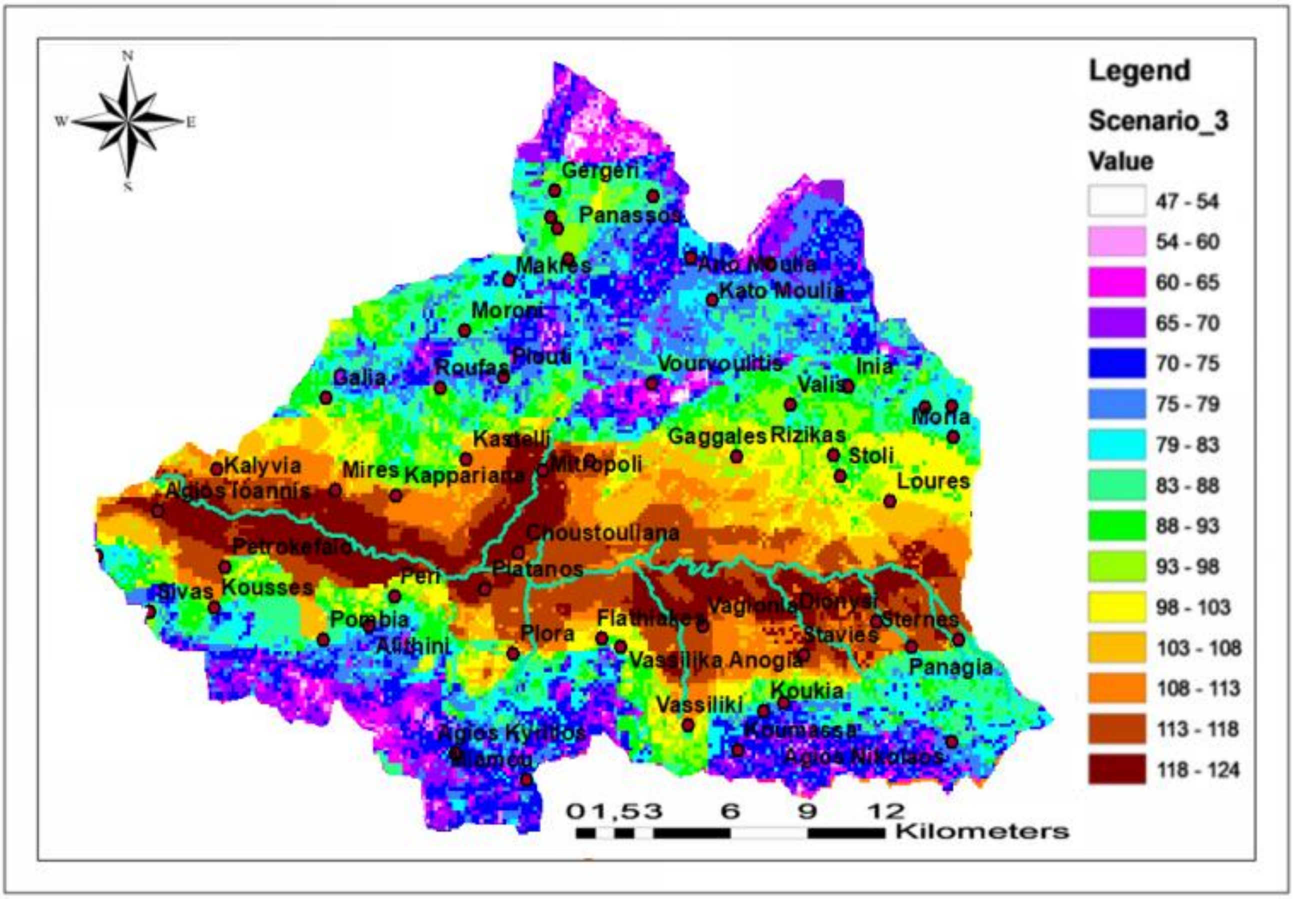

Figure 38. Suitability map for MAR spreading methods in Geropotamos basin (Scenario 3)

The suitability map for scenario 3 resulting from the GIS-MCDA (Figure 38) indicates that the highest suitability for MAR spreading methods in Geropotamos basin covers the western part and some areas in the central part of the region (Agios Ioannis, Mires, Petrokefalo, Platanos, Dionysi, Stavies, Kasteli, Mitropoli, Flathiakes, Vagionia), particularly around the Geropotamos River. The result of scenario 3 is very similar to that of scenario 1, in terms of the most suitable areas, with the difference that in scenario 3 the most suitable areas around the river Geropotamos have increased.

Scenario 4:

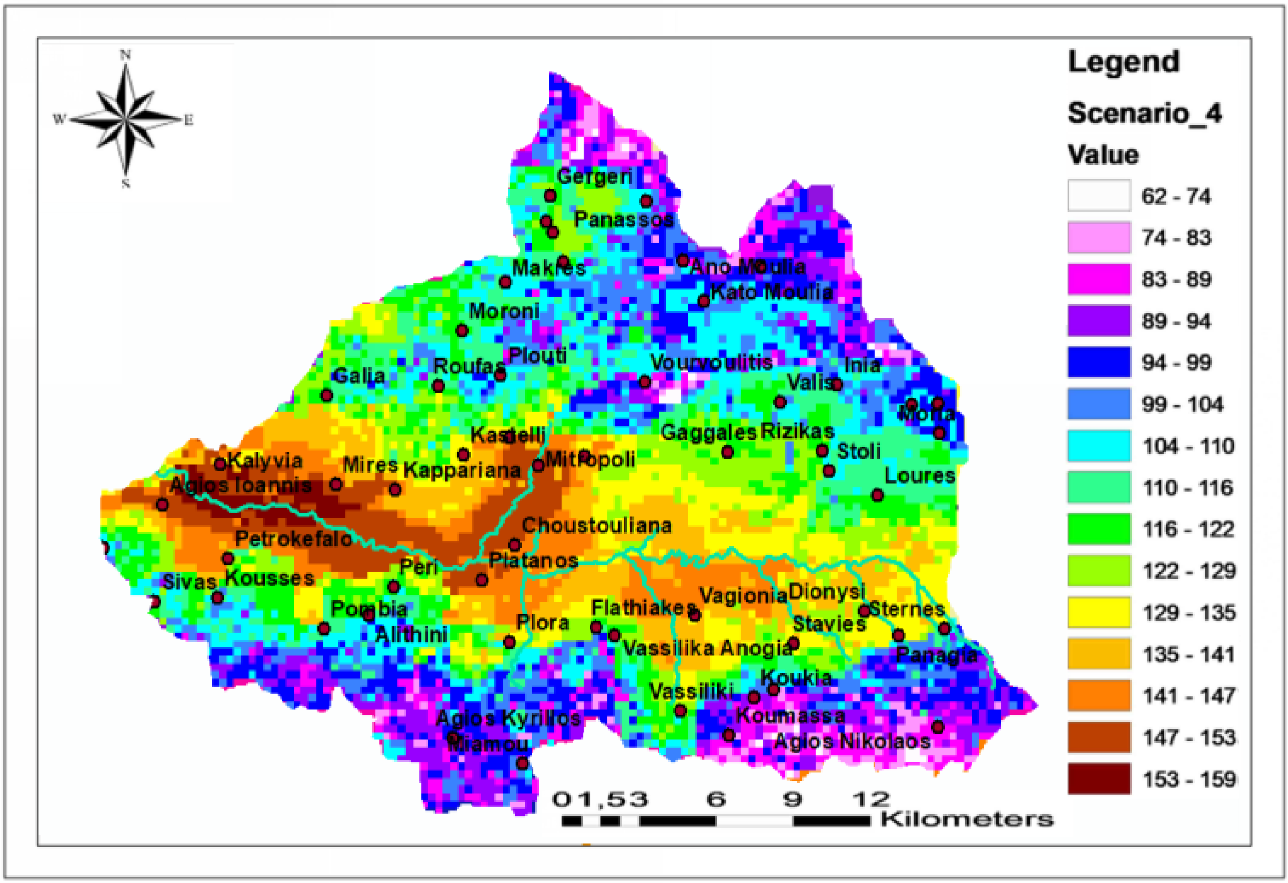

Figure 39. Suitability map for MAR spreading methods in Geropotamos basin (Scenario 4)

The suitability map for scenario 4 resulting from the GIS-MCDA (Figure 39) indicates that the highest suitability for MAR spreading methods in Geropotamos basin covers the western part of the region (Agios Ioannis, Kalyvia, Mires). The most suitable areas in scenario 4 are almost common with those of scenario 2. This is logical as looking at the maps of scenario 2 and scenario 3 we notice that they have some parts in common in which the suitability is greatest.

6. CONCLUSION- DISCUSSION

Throughout the Mediterranean region, semi-arid climate in conjunction with intensive agriculture is in many occasions stressing scarce groundwater supplies which are over-exploited to cover irrigation water demands. As a result, productivity has risen at the cost of an alarming drop of the groundwater table of over 35 meters. This has led to increased costs associated with extraction of groundwater, seawater intrusion along the coastal zone, and negative environmental impacts (disappearance of wetlands). As a result and in order to stabilize groundwater tables, managerial measures on groundwater withdrawals were imposed by the government in September 2015. These regulations prohibit, among others, the drilling of new wells, the groundwater withdrawals above certain limits and the modification of current infrastructure related to groundwater production. One such example is the Messara Basin in the island region of Crete.

The present study uses GIS multi-criteria decision analysis (GIS-MCDA) method to identify suitable sites for implementing MAR type spreading method in Geropotamos basin.

If we consider all the factors assessed in the study area at the areas where the suitability is greater for each scenario separately, we observe the following:

Scenario 1:

- The percentage slope is 0.00059-1.09318 (the smallest slope of the study area).
- These areas are mainly agricultural, which makes sense as the region's economy relies on the agricultural sector.
- In terms of hydrogeology there are Granular alluvial deposits mainly with ranging hydraulic conductivity (P1).
- Rainfall is the smallest we encounter in the Geropotamos basin.
- The groundwater level in the areas that came out more suitable is the smallest in the Geropotamos basin.
- The soil texture is alluvial with REGOSOLS

Scenario 2:

For scenario 2 the same applies as for scenario 1 for each factor separately in the areas with the highest suitability, with the difference that the areas that are more suitable have been greatly reduced as the distance factor from the Faneromeni dam has been added. Thus, the most suitable areas are those that are closer to the Faneromeni dam, but combining all the above characteristics.

Scenario 3:

For scenario 3 the same applies as for scenario 2, with the difference that the most suitable areas are those that are closer to the river of Geropotamos.

Scenario 4:

For scenario 4 the same applies as for scenario 2. This is logical as looking at the maps of scenario 2 and scenario 3 we notice that they have some parts in common in which the suitability is greatest.

In conclusion, we observe that the method worked very well as the areas that seem to be the most suitable for aquifer recharge, are the most suitable for each factor separately. So the fact that no limiting factors were used in the method did not affect the result.

Unfortunately in the area there are no managed aquifer recharge sites, except the small diversion dam which was built in 1995 in the area of Mires, so we can compare our results with these areas. Nevertheless, this dam is among the areas that are most suitable for aquifer recharge in this study.

An aquifer recharge study, in the study area, was conducted by Eleni Ioannidou entitled "Assessing Managed Aquifer Recharge (MAR) suitability in the Mesara Valley (Crete, Greece) following a GIS-based approach". This study collects all relevant information, spatially distributed or point data, required to assess the suitability of MAR in the basin of Mires and Vagionia in the Messara valley and evaluates the suitability of MAR by producing maps showing zones with low, medium and high potential (MAR). These maps provide a useful starting point for identifying areas where additional field tests need to be performed to accurately locate suitable locations for MAR application. The parameters used in the MAR suitability study are the following:

1. Land use

2. Slope

3. Geology

4. Distance to Geropotamos

These parameters are checked for two cases:

• Use of filtration basins

• Use of filtration wells

The final results are presented in the figure 40, 41.

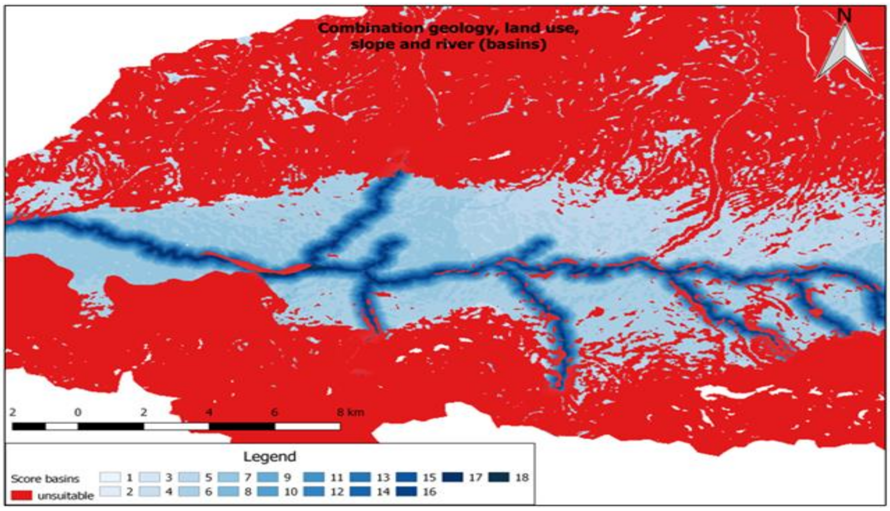

Figure 40. Map suitability with scores for filtration basins (Ioannidou, 2016)

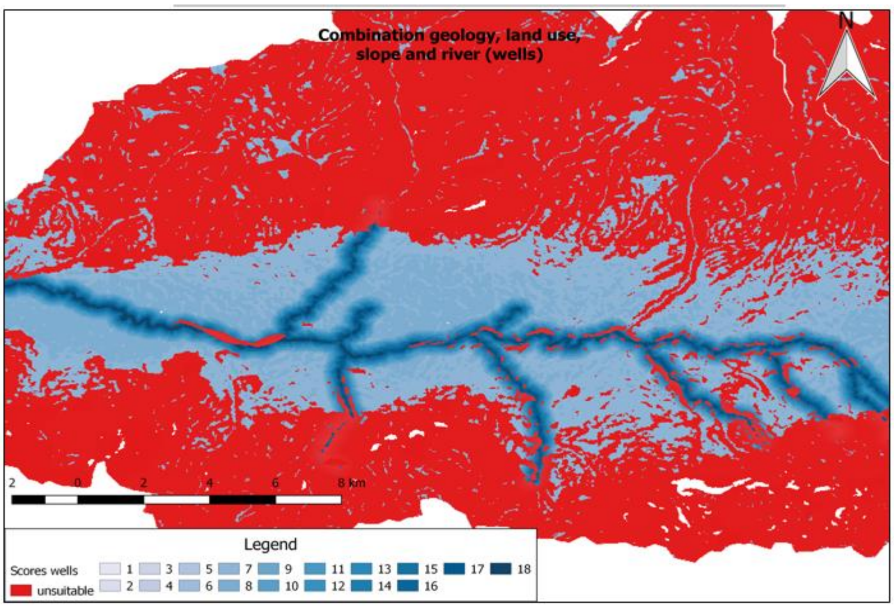

Figure 41. Map suitability with scores for filtration wells (Ioannidou, 2016)

We observe that the most suitable areas are those around the river as the distance factor has been added. In this study, several factors are not considered as in the present study, however, we observe that the result is close to that of scenario 3 of the present study.

It is also planned to build a dam on the river in Platy, which is located in the southeastern part of the Prefecture of Rethymno. This is a major project that will breathe new life into the primary sector in both South Rethymnon and Messara. Platis is one of the largest rivers in Crete that is fed by waters of the northeastern Kedros and the Amari Valley. Its estuary is located on the beach of Agia Galini in South Rethymnon. Platis belongs to the rivers of Crete that they have a lot of water and dense vegetation. In fact, along it there are beautiful stone bridges with arches built in the past by the locals to cross the river. The river is watered by the valley of Amari and joins the tributary of the Smilianos Gorge, the Lygiotis River, which begins near Gerakari. The hydrological basin of Platys has an area of 210 km^3 and the average annual surface runoff volume amounts to 50,000,000 m^3.The capacity of the river reservoir is estimated at 26,000,000 m^3 . (Pappa Dimitra, 2018)

Based on the final hydraulic study - Water transfer pipeline in Messara by Pavlos Pavlakis in 2013, the points where the pipeline passes, which are shown in the map below, are suitable for aquifer recharge.

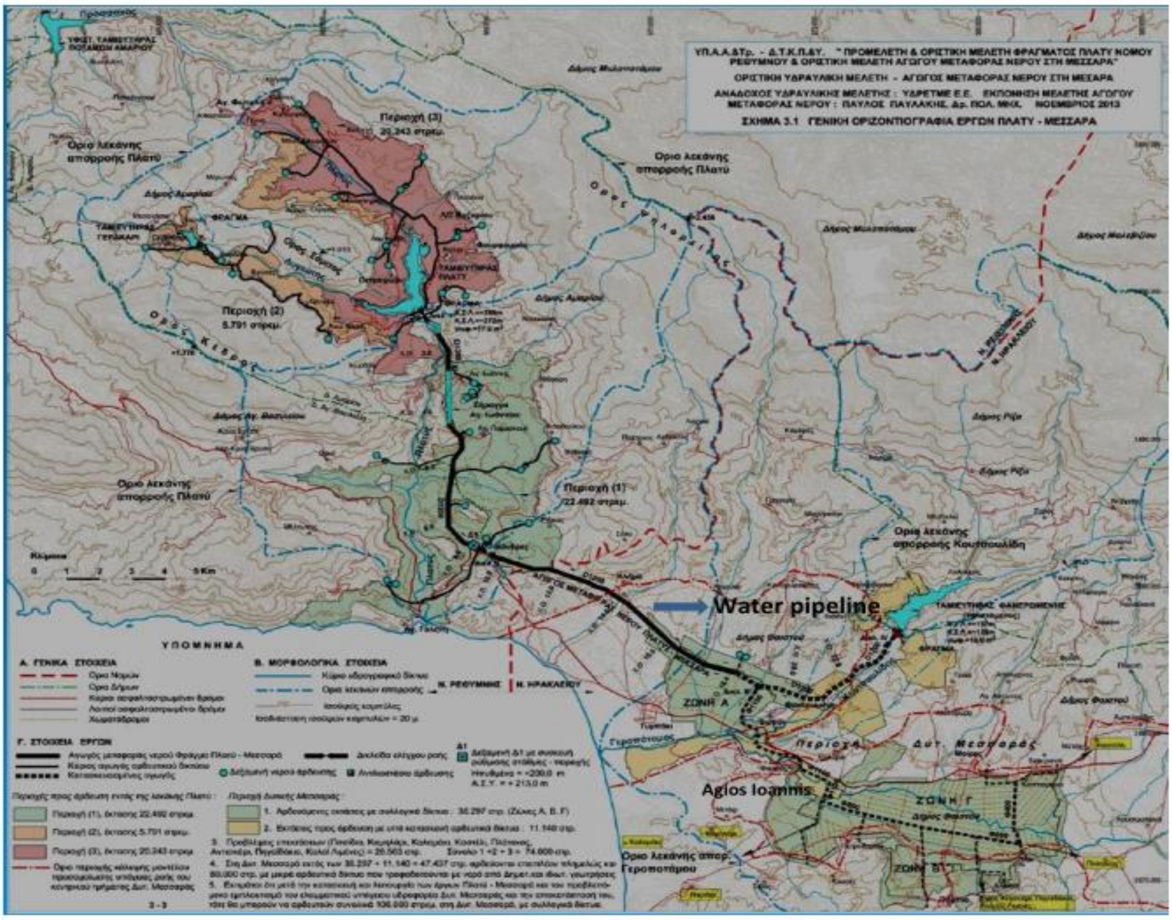

Figure 42. Water transfer pipeline in Messara (Pavlakis, 2013)

We observe that some of the points through which the pipeline passes are identified with those which are suitable for aquifer recharge of the present study.

Also, when conducting α MAR study, we must also consider which areas in the aquifer face a problem of water quality and not just quantity. There is not much groundwater quality data in the area. Nevertheless, we know that the area of Mires is the most vulnerable in the study area and nitrates are found in groundwater. As part of my undergraduate studies at the Department of Environmental Engineering of the Technical University of Crete, I carried out my diploma thesis on the vulnerability of the aquifer of the Mires basin (figure 43) , through the DRASTIC-LU method, using the ArcMap program of GIS. Vulnerability or pollution susceptibility of groundwater or aquifers is sensitivity to pollutants.

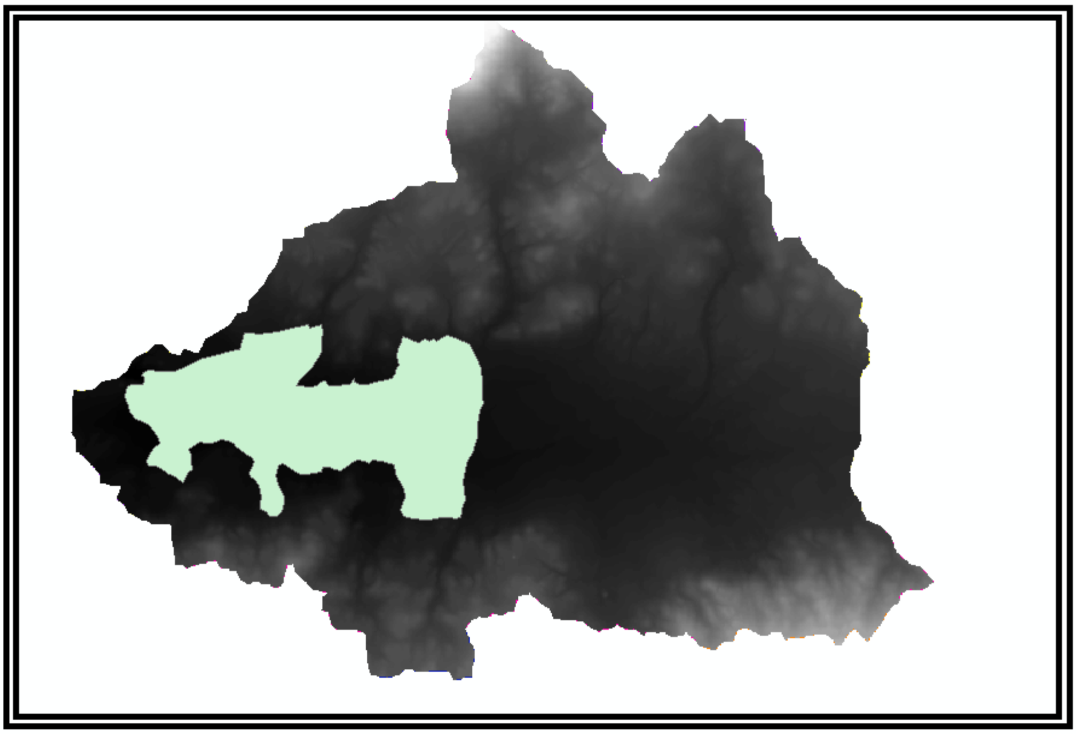

Figure 43. Mires basin location

The DRASTIC-LU method is flexible and the user has the ability to modify it by adding parameters or changing the values of gravity. The word DRASTIC-LU is derived from the acronyms: D (Depth) groundwater depth, R (Recharge), A (Aquifer), S (Soil), T (Topography), I (Impact of the vadose zone), C (Hydraulic Conductivity of the aquifer) and LU (Landuse). The above parameters form the DRASTIC-LU index, which is calculated from the following relation:

$$DL=D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w + LU_rLU_w$$

The index r expresses the value of the parameter and the index w the weight of each parameter.

The final vulnerability map is presented below.

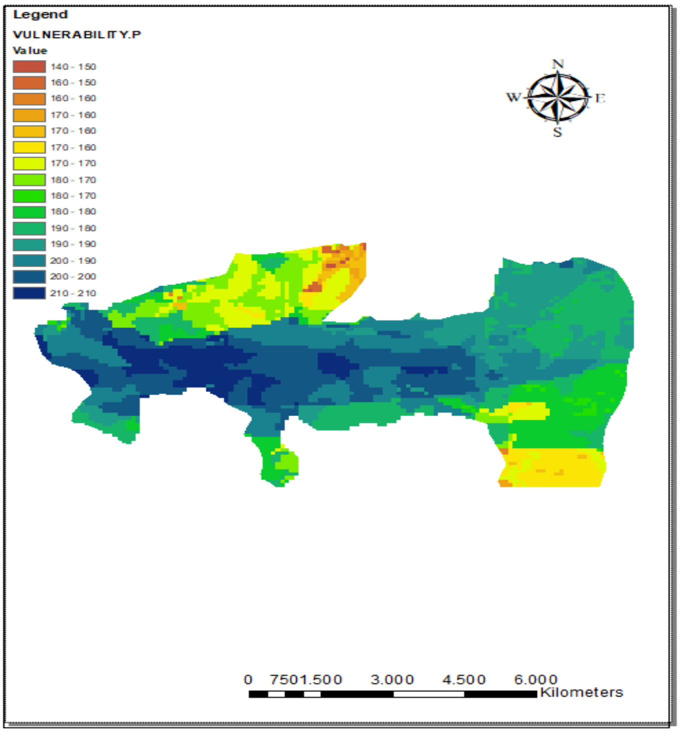

Figure 44. Vulnerability of the basin of the Mires

The points with the intense blue color are the ones that show the greatest vulnerability.

In all scenarios the most suitable areas for aquifer reharge are in the basin of the Mires.

If we focus on the Mires basin in terms of the MAR results of the present study we have as a result the following maps for each scenario separately.

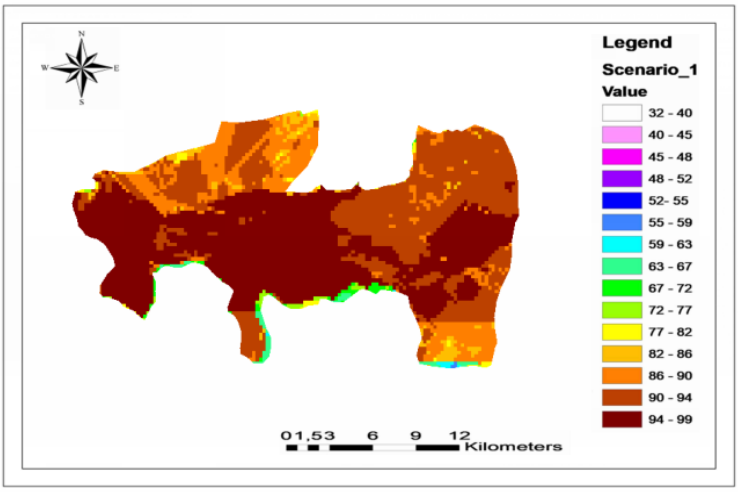

Figure 45. Suitability map for MAR spreading methods in Mires basin (Scenario 1)

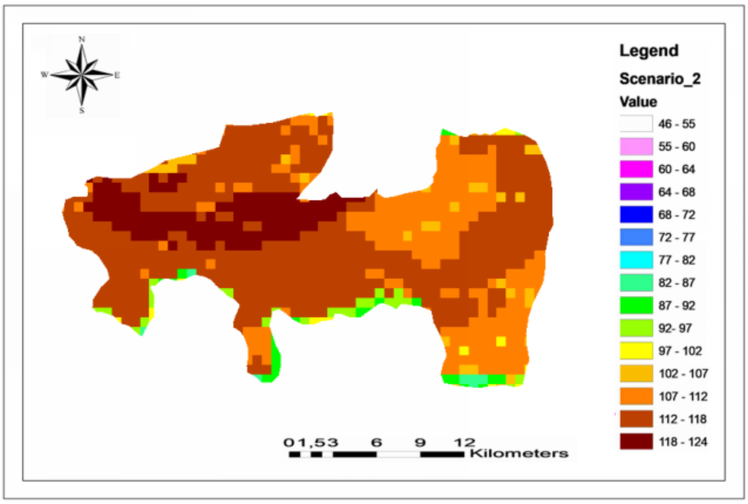

Figure 46. Suitability map for MAR spreading methods in Mires basin (Scenario 2)

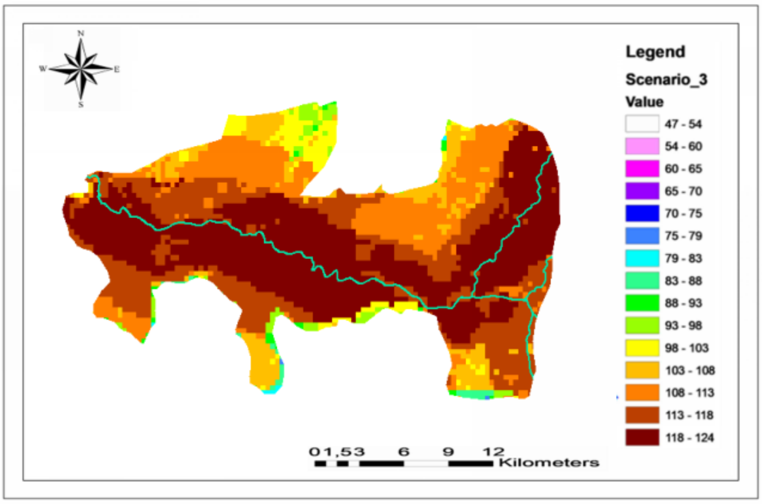

Figure 47. Suitability map for MAR spreading methods in Mires basin (Scenario 3)

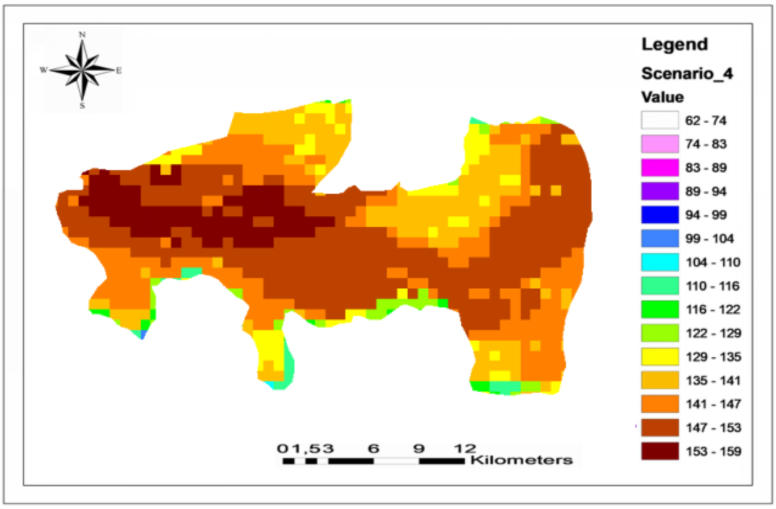

Figure 48. Suitability map for MAR spreading methods in Mires basin (Scenario 3)

Comparing the suitability maps with the vulnerability map we notice that they are almost the same. This is a logical result as the areas that are most vulnerable, are more passable than the rest and have a low aquifer level.

The method used in this study is very similar to the DRASTIC-LU method, as similar factors are examined and the important thing is that it can be used in an aquifer recharge in the Messara valley in combination with a MAR suitability model and measurements of existing pollution in the area.

In conclusion, we observe that in the MAR study of Eleni Ioannidou, the vulnerability study DRASTIC-LU , the hydraulic study of the Water transfer pipeline in Messara of Paulos Paulakis and in the present study the results have many similarities. Thus, the results of the present study seem to be reasonable.

These maps provide a useful starting point for identifying areas where additional field tests need to be performed to accurately locate suitable locations for MAR application.

This simple methodology could be used in the future as an efficient visual tool to raise awareness on the wide applicability of MAR and encourage water authorities to consider MAR more often for water resources management strategies.

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