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Suitability Analysis for Stone pine Reforestation using Geospatial Technologies

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Abstract The Stone pine "*Pinus pinea*" is native to the Mediterranean region. It has been used and cultivated for their edible pine nuts since prehistoric times. At present most of the decision makers in the world are enforcing new policies which will increase forest cover in their countries in order to mitigate the effect of the climate change specifically forest species that withstands harsh and climate change. In this research Geospatial technologies are used to help in the forest expansion as part of the forest management by implementing a new Stone pine suitability model. This model is applicable in any area in the world where the indicated natural and geographic conditions are met. The model was applied to an area rich in Stone pine and the results show that more than 60% of the total study area can be reforested. Hundreds of existing Stone pine forest locations is used to verify the accuracy of the suitability map. The verification showed that 96% of these locations are on the high and medium classes of the map.
Keywords *Stone pine; Geospatial Technologies; Agriculture; Environment; Economy; Management; Forests*

1. Introduction

The Stone pine "*Pinus pinea*" also called Parasol Pine (Figure 1), is a tree native to the Mediterranean region, occurring in Southern Europe, North Africa, and the Levant. It is a coniferous evergreen tree that can exceed 25 meters (82 feet) in height.

Figure 1: *Stone pine "Pinus pinea"*

Stone pine is a coniferous evergreen *tree* with a height that varies between 10–25 m, it has long horizontally spreading or ascending branches that give its adult crown a characteristic umbrella-like shape. Twigs are glabrous, first green, then grayish; buds are approx. 1 cm long, with brown scales. Needles are bright green, stiff and born in fascicles of two.

Stone pine needles length does not exceed 15 cm with critical stomata on each side. Male and female flowers are located on the same tree. Yellow pollen flowers are located in clusters. Pollen is transported by wind. Fecundation takes place 2 years after pollination and cones reach maturity in 3 years (Fady and Médail, 2004).

Mature Stone pine cones are not larger than 14 cm in length and egg-shaped with the broader end at the base, immobile and inaccessible. Pine cone bears two large seeds almost 2 cm in size. Seeds are heavy and mostly dispersed by gravity or by small mammals. Seed production begins at an early age between 15 and 20 years. Stone pine does not hybridize with any other pine and it grows mostly in pure stands and is naturally regenerated by seeds.

Stone pine are found within the Mediterranean climate zones and sub humid bio-climatic which is characterized by hot, dry summers and rainy, mild winters where the mean temperature of the coldest month is over zero and the rainfall is less than 800 mm/year. It prefers acidic or neutral sandy soils. Environmentally Stone pine is well adapted to the high temperatures and drought characteristics of Mediterranean climate. It is less sensitive to diseases and pests than other Mediterranean pines. It is not a fast growing species, nor is its timber very valuable. Its value comes mainly from its nuts (Mutke, et al., 2005a) which are the most important edible product of Mediterranean forests (Calama, et al., 2007b).

The yield of Stone pine depends on several factors such as age of the trees, site index, health, number of trees per hectare, on tree pruning, and tree thinning (Montero and Canellas, 2000). Stone pine yields annual variation has been demonstrated are due to climatic factors the most influencing one is water stress (Mutke, et al., 2005b). Nut production based depends upon the precipitation from spring to early summer of that year. Good harvest occurs in the third year when there are moderate temperatures and droughts (Calama, et al., 2007a). Stone pine kernels are used in the Mediterranean as a delicacy and have a protein value (Moussouris and Regato, 1999).

A successful management of forests would improve the economic sector by allowing the establishment of services with a high market value that encompasses tourism for all purposes such as business, agriculture and entertainment one. Stone pine forests are important in the development and protecting other natural resources and the vulnerability of this type of forests to hazards is very high. There are many researches concerning Stone pine forests the most important ones are forest fires risks and urban expansion (Masri, et al., 2003).

Choueiter and Ucenic (2007) proved that the revenues earned from the investment in Stone pine forests are from the production of nuts, wood, firewood, and resins. In addition, the authors proved that these forests face many hazards such as deforestation, over-grazing, urban development, road development, bad agricultural techniques, excessive use of chemical products, hunting and industrial development. And therefore, the degradation of the Stone pine forests has a considerable negative impact on the environment (soil erosion, induces losses of fauna and flora biodiversity, changes the microclimate).

In general there is no research about an effective and reliable suitability map for reforestation and planting of Stone pine trees. In addition, there is no accurate separation between Stone pine and other type of forests in the classification process of the multispectral image which sometime share the same area with or live beside Stone pine forests and we believe that creating suitability map can help in this process. For these reasons, the research will cover a methodology that is based on Geospatial technologies and on existing geographic database to create model for creation of the Stone pine suitability map which can be applied to any region in the world if the geographic and natural conditions are met. In addition, it can help in the management process of this important natural resource and in the separation process.

After the introduction the second section will identify the study area to verify the model later. The third section covers the data and the methodology including the suitability map. The fourth section is the discussion and finally the conclusion.

2. Area of Study

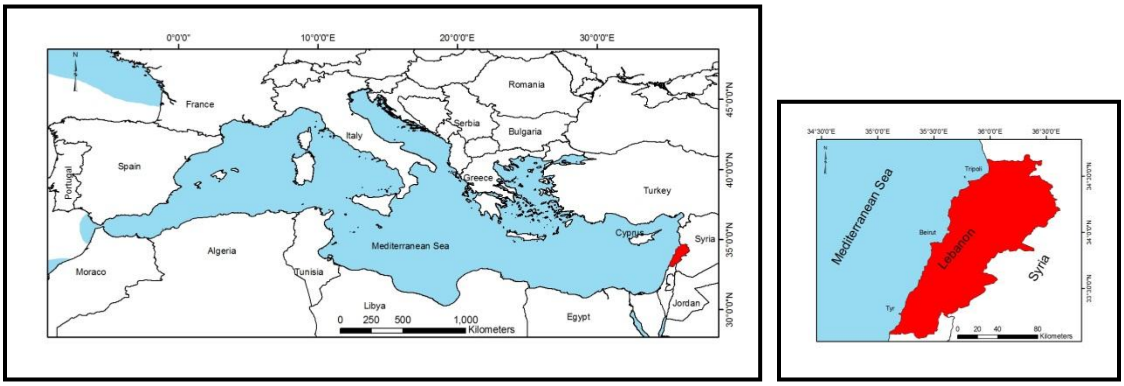
In order to create a suitability model which can be representative for the whole Mediterranean region and the world in general, Lebanon is selected as an area of study because it is located on the shoreline of the Mediterranean Sea (Figure 2). Its climate is characterized by being moderate/humid in the coastal area, wet and cold in the mountains and dry and cold in the north eastern part of the country during the winter. In the summer it is hot and humid in the coastal area, moderate in the mountains and hot and dry in the north eastern part of the country.

The slope in Lebanon ranges from flat (0-2%) to very steep (> 60%) and there are more than 135 types of soil according to the new created map for Lebanon (Darwish, et al., 2005). Soils greatly influence the landscape by determining its floristic component.

In Lebanon the Stone pine is observed associated with other type of vegetation, mainly Erica spiculifora, Gallipoli rose, Calicotome spinosa, Lavandula stoechas and juniper. This describes its abundance in areas like sandy soils (Choueiter and Ucenic, 2007).

The temporal analysis of the available information for the study area will help understand how the changes are taking place and how the changes are affecting Stone pine cover.

The delineation of the suitable areas is based on Geographic Information System (GIS) which uses up to date technology and an advanced software package for the interpretation and calculation of parameters derived from several geographical sources. Another objective is to prove the importance of using an effective source of information and tool to monitor and manage with high accuracy the changes to the Stone pine forest cover.



(a) *(b)*

Figure 2: *Study Area (a) Location in the Mediterranean Region (b) Exposed*

3. Materials and Method

In this research, several existing layers are used to create the Stone pine suitability map. These layers are based on measured data from weather stations and digitized layers from paper maps such as the climatic layers (measured temperature and rainfall), topographic (slope and elevation), soil types and their parameters (Organic Matter, pH, Texture, Depth).

3.1. Suitability Map Creation Process

To create the suitability map it is necessary to decide on the convenient method to classify climatic, soil, and topographic layers. Next, selecting the appropriate the ranges of values by which classes are created starting from the most to the least suitable area for the growth of this type of forests is another necessity for the success of the map. Finally, there is a need to create a mathematical model which can be applied using GIS software such as ArcGIS from ESRI.

3.1.1. Climatic Conditions

Knowing the climatic conditions to reforest Stone pine "*Pinus pinea"* is necessary issue for a suitability model. In general, Stone pine can tolerate temperature between -2 C° to 32 C°. According to (Trap, 1996) this kind of pine is fairly easily propagated from seed, preferably fresh seed. The optimum temperature for seed germination is between 17-19 C°. Temperature above 25 C° can inhibit seedling establishment while at temperatures below 10 C° seeds become dormant. So, drought and cold weather are the least preferable but they are tolerable. Climatic condition by Stone pine, and then the extreme temperature classes are the last categories. The least favorable temperature is the one > 25°C so it is the worst category. Temperature between -2 C° and 10° C is second worst tolerable category. The optimum temperature for seed germination is between 17 C° and 19 C° which is category 1. Stone pine can tolerate rainfall between 315 and 1400 mm, however it shows optimum performance in relation to rainfall with best sites receiving between 1000 to 1200 mm annual rainfalls (Zwolinski, 2005). Therefore we have the five classes for two parameters listed in Table 1. *T* is temperature, *R* is rain and the criteria ranges between 1 the best and 5 the worst.

Table 1: *Climate Parameters Criteria for Suitability Model*

Class	*T* in C°	*R* in mm
1	*T* >= 17 and *T*< 19	*R* >= 1000 and *R* < 1200
2	*T* >= 10 and *T* < 17	*R* >= 600 and *R* < 1000
3	*T* >= 19 and *T* < 25	*R* >= 400 and *R* < 600
4	*T* < 10	*R* >= 1200
5	*T* >= 25	*R* < 400

3.1.2. Soil Parameters Conditions

According to the study conducted by Bravo, et al. (2011) Stone pine requires the following mean, maximum and minimum chemical and physical soil properties (clay, sand and silt content, organic matter amount, pH) and topographic variables (altitude, and slope) see Table 2.

Table 2: *Soil and Topographic Properties for Stone pine*

Variable	Mean	Max	Min
Sand (%)	56.75	74	23
Silt (%)	32.69	68	11
Clay (%)	10.56	19	6
Organic Matter (%)	4.3	4.57	4.07
Depth (cm)	75.0	95	60
Slope (%)	22.5	45	0
pH	8.08	8.31	7.3

According to this study the following classifications are selected for each variable (Table 3) these categories or classes will be used for the suitability model. Where *pH* is the acidity of the soil such that *pH* 1-6 is acidic, *pH* 7 is neutral, and *pH* 8-14 is basic. Soil organic matter *(OM)* is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms. Soil *OM* exerts numerous positive effects on soil physical and chemical properties, as well as the soil's capacity to provide regulatory ecosystem services (Brady and Weil, 1999). The soil depth depends on its type, if for example *Eutric Arenosols* and Lithic *Leptosol* are selected than each has its own depth characteristics. The first one has an average depth of 115 cm while the second one is 10 cm (Darwish, et al., 2005).

Soil structure is important for Stone pine, because roots prefer well aired soils with loose textures such as sand, sandy loam or gravel (with water-holding capacity of at least 60 mm. In compact clay or silt soils (with less than 40% sand and more than 40% silt or more than 30% clay), root development is restricted. Especially in the first phase of seeding establishment, and can delay flowering for many years (Janick, 2012).

Soils are classified according to their texture in classes, and each textural class has a given range of sand, silt and clay. Sands contain at least 80% sand particles and 15% or less clay particles by weight. Silts contain at least 80% silt and 12% clay particles, respectively. Clays contain at least 35% of clay particles. Loams are mixtures of sand, silt and clay particles that exhibit the properties of those particles in equal proportions. Loam soils have the best combination of physical and chemical properties in terms of cultivation and crop growth (Kosmas, et al., 1999). The texture map is created from the soil map of Lebanon 1:50000 based on the USDA textural triangle. Then the map is divided into 5 categories in order to use it in the suitability model.

Table 3: *Soil Parameters Criteria for Suitability Model*

Class	Soil pH	Soil OM	Soil Depth	Soil Texture
1	*pH* >= 7.3 and *pH* < 7.5	*OM >= 4.57*	*Depth >= 95*	*Loamy sand*
2	*pH* >= 7.5 and *pH* < 7.6	*OM >= 4.4 and OM < 4.57*	*Depth >= 75 and Depth < 95*	*Sandy clay loam*
3	*pH* >= 7.6 and *pH* < 7.9	*OM >= 4.2 and OM < 4.4*	*Depth >= 60 and Depth < 75*	*Sandy clay*
4	*pH* >= 7.9 and *pH* < 8.0	*OM >= 4.07 and OM < 4.2*	*Depth >= 20 and Depth < 60*	*Loam*
5	*pH* >= 8.0 or *pH* < 7.3	*OM < 4.07*	*Depth < 20*	*others*

3.1.3. Topographic Conditions

Topographic factors are usually utilized in combination with edaphic factors to estimate species-specific measure of actual or potential forest productivity (Pacheco, 1991). According to an investigation conducted by our team which covered almost all Stone pine existence in the area of study it is identified that Stone pine can live at altitude between 0 and 1500m. In addition, the investigation indicated that the following are the 5 categories for the suitability model (Table 4).

The slope gradient is an important factor which can greatly affect the growth of Stone pine. Most of the trees prefer slope between 0 to 45% (Bravo, et al., 2011) and this leads to the following categories or classes (Table 4).

Table 4: *Topographic Parameters*

Class	Altitude (Al) in meter	Slope (S) in %
1	*Al* >= 500 and *Al* < 1000	*S* >= 0 and *S* < 10
2	*Al* >= 0 and *Al* < 500	*S* >= 10 and *S* < 20
3	*Al* >= 1000 and *Al* < 1300	*S* >= 20 and *S* < 30
4	*Al* >= 1300 and *Al* < 1500	*S* >= 30 and *S* < 45
5	*Al* >= 1500	*R* >= 45

3.1.4. The Mathematical Model

A model is created based on the sum of the weighted parameters representing the physical characteristics of the geographic area. The model (Equation 1) can be tuned to emphasize the most influential geographic parameter(s) by changing the weight values whose total summation should be equal to 1.

$$\textbf{Suitability\_Degree} = \sum_{i=1}^{K} W_i * P_i \qquad (1)$$

K is the number of parameters which are explained above (Texture, pH, Altitude, Slope Gradient, Climate, and Organic matter). W_i is the weight of each i^{th} parameter P_i.

The model is created using ArcGIS where each step is represented graphically in a simplified way (Figure 3). The weights can be varied such that the total weights of all parameters are equal to 1. Several cases with different weights combinations are created (Table 5).

Table 5: *Different Weights Combinations for Different Suitability Map*

Weights	Texture	pH	OM	Depth	S	Al	T	R
Case I	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.1
Case II	0.15	0.15	0.15	0.15	0.05	0.05	0.15	0.15
Case III	0.15	0.15	0.15	0.15	0.15	0.15	0.05	0.05
Case IV	0.2	0.2	0.2	0.2	0.05	0.05	0.05	0.05

In order to compare quantitatively the differences between the four cases the area of each class is calculated in hectares and a comparison between the classes is done (Table 6). One can notice that the area slightly and equally decreases when the weights of topographic and climate parameters increase (case II and III) which means that the effect of topography and temperature is insignificant. However, in case the weights of the soil parameters are increased (case IV) the area is subject to significant change. Another important issue that can be concluded from the four cases is that only about 18% of the Lebanese territories are highly suitable and about 44% are moderately suitable for afforestation with Stone pine.

The outputs of the model after varying the weights are shown in a graph (Figure 4) horizontal axis represents the different suitability classes (1-High; 2- Medium; 3- Low). The differences between the suitability maps are very negligible in the first three cases such that case 3 is covered completely by case 2. While in the fourth case the area size changed because the soil parameters are given higher weights. According to this analysis any of the first three cases can be approved as a suitability map for Lebanon. However, due to the rugged mountainous nature of Lebanon and the existence of moderate climate system with four seasons in Lebanon convinced us to use almost equal weights to all parameters with slightly small emphasis on soil parameters. The suitability map of the first case is shown in Figure 5a.

Table 6: *The Three Maps Suitability Different Classes with Area Size*

Case/ Class area in Km^2	High	Medium	Low and not suitable
1	2056	4567	3627
2	1976	4511	3763
3	1976	4511	3763
4	1824	4824	3602

It is clearly proved from the experiments using the model above, we can easily conclude that changes to the weights of all parameters should not be used unless if there is necessity to enphasize the role of one natural factor in the suitability issue (climate is more important than topography). Otherwise, the weigts should be almost comparable as it is in case I.

Finally, the selected suitability map must be verified and tested for accuracy of the results. A field survey is carried out using Global Positioning System (GPS) for some accessible areas (Mid-south of Lebanon “Jezzine”, and Mid-West “El-Meten”). Other missing points were collected from Google Earth’s very high resolution images (Google, 2014). The selected samples represent the location of dense Stone pine trees (Figure 5b). One can notice that the collected samples (200 samples) are well distributed and cover the most important location of the Stone pine forests.

Use topography, soil and climate maps

1-Extract using selection in ARCGIS
a- Altitude and Slope from Digital Elevation Model (DEM)
b- Depth, Texture, Organic matter content and pH from Soil
c- Rainfall and Temperature from Climatic layers
2- Intersect extracted layers
3- Apply a mathematical model with assigned weight to each geographic parameter
4- Classify and create the suitability map

Figure 3: *The GIS Model for Creating “Pinus pinea” Suitability Map of Lebanon*

The following graph (Figure 6) shows the distribution of the selected points according to suitability classes. Moreover, it indicates clearly that most of the current Stone pine is located on the high and medium suitability classes (more than 96%) which give more credibility to the created suitability map.

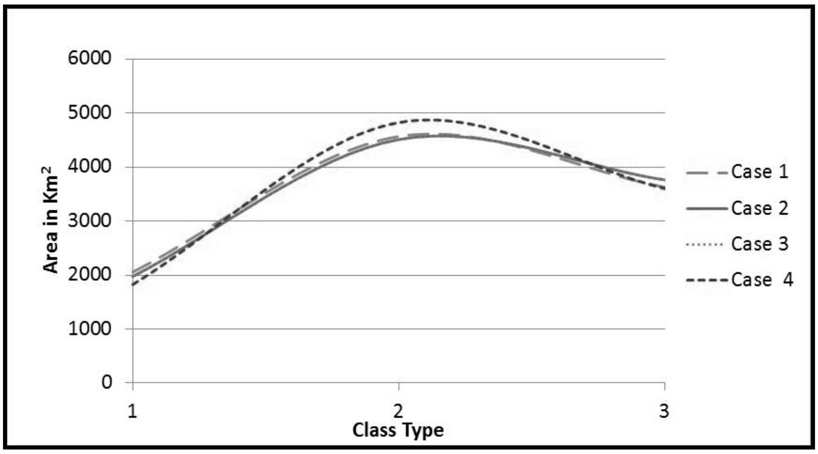
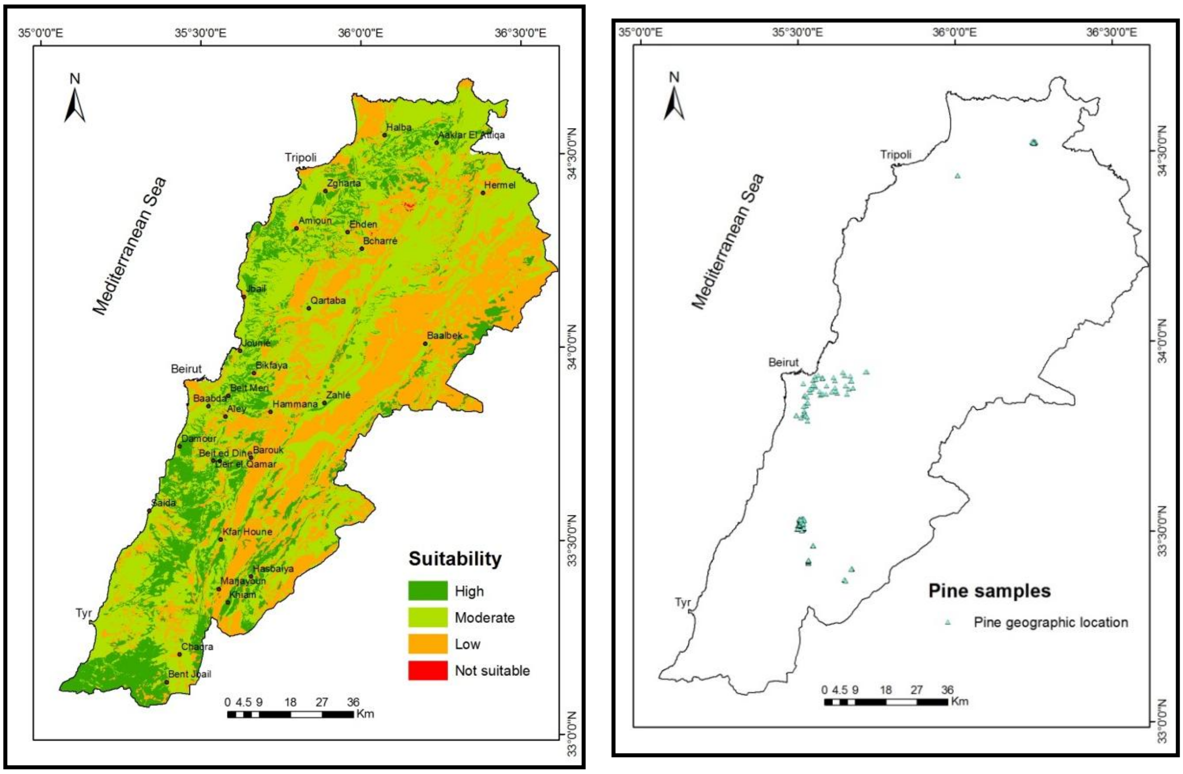


Figure 4: *Four Different Cases of Parameters Weight Variation*



(a) *(b)*

Figure 5: *Stone pine (a) Suitability Map (b) Collected Sample Locations*

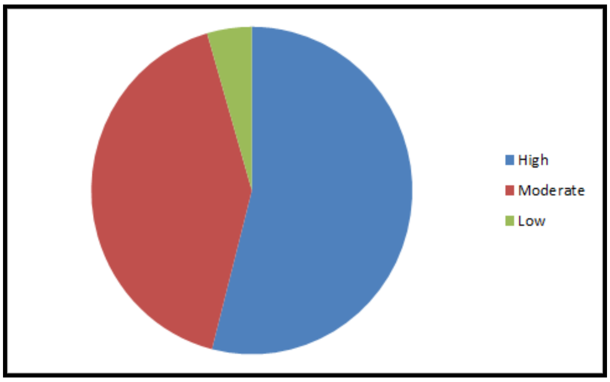


Figure 6: *Stone pine Sample Locations on Different Suitability Classes*

4. Discussion

Any forest management system relies on an efficient provision of information which can help in all the tasks related to the management of this important natural resource. The system should be able to provide accurate agricultural information which can help in the afforestation process and which can help in reducing the degradation caused by many natural and human influences. In our case a suitability modeling system is created which relies on several geographic layers and on several GIS processes such as intersect and union processes. The suitability map is created based on several layers and on the geographic characteristics of the area. This is what make the system adjustable based on the assigned weights for each variable which represents the contribution of a specific geographic layer.

In addition, the system should be able to give a clear view of the pine forest status in the past, present and the possible scenarios in the future. It should be able to monitor the progress of the afforestation. This will help in reducing deforestation, land degradation, and environment deterioration. The research can be enhanced to create a system to monitor changes and the progress of reforestation based on remote sensing images such as Landsat ETM+, Landsat 8, and other more complicated images such as hyperspectral satellite or airborne one such as EO-1 Hyperion. Moreover, the research can include a system able to interact with the available free of charge source of information such as Google Earth which can be used to verify existing information as it has been done in this research to remove irrelevant and misclassified information.

5. Conclusion

Geographic Information System (GIS) plays an important role in the management of the forest cover specifically in monitoring changes and in the inventory tasks. The decision makers lack the ability to improve the current status of the forest cover or to reduce the risks imposed on the forests such as deforestation, and the degradation due to the use of the forests for dumping and sometime due to diseases and insects attack. Add to these problems the risk of forest fires which occur repeatedly every year, the urban expansion and the sand quarries. For all these reasons coupling GIS with remote sensing to monitor and to map the forests, specifically the Stone pine forest is considered an important step in forest management. Especially that is known in the Mediterranean countries the direct and indirect importance of the Stone pine in improving different economic sectors such as health sector, tourism sector including many environmental issues. The use of GIS will increase the efficiency of forest management such as pine forests and will decrease losses.

In this research the GIS plays an important role in indicating the area which can be reforested based on a suitability map and in magnifying the issue of deforestation (the use of temporal comparison in the future). It has been proved that the created suitability map is of high reliability (more than 96%) after testing 200 collected points representing locations of current Stone pine covers.

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