ASSESSMENT OF ABANDONED QUARRIES FOR REVEGETATION AND WATER HARVESTING IN LEBANON, EAST MEDITERRANEAN

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Abstract. Negative impacts of abandoned quarries in Lebanon include degraded scenery, landscape fragmentation, loss of biodiversity and decreased quantity and quality of water resources. Between 1996 and 2005 the number of quarries increased from 711 to 1278 and the quarried land area increased from 2875 to 5283 ha. Recent remote sensing data (2005) showed that 21.5% were distributed on forested land and arable land while 32.4% of quarries were detected on scrubland and grassland and 3.2% of quarries were distributed inside urban zones. Due to institutional weakness and the absence of national policy, most Lebanese quarries have not been developed using environmental concepts and in preparation for post operation reclamation or restoration. Limited national resources available for reclamation must be targeted toward those quarries where the likelihood of successful reclamation, and thus the likelihood for mitigation of negative environmental impacts, is the greatest. To facilitate such decision making we developed a GIS based model that utilizes geomorphological and pedoclimatic characteristics of the site, including precipitation, slope gradient, slope aspect, rock infiltration, catchment area, the availability of soil material and soil texture to assess probability of reclamation success. Each abandoned quarry was categorized into specific classes with respect to surrounding native vegetation, rainfall and slope gradient. Deserted quarries were assessed for suitability for vegetation establishment and/or water harvesting. Potential revegetation success is strongly linked to slope aspect where southern facing slopes especially in semi-arid areas with annual rainfall below 600mm, were given lower prospects of success in relation to spontaneous revegetation processes. The quantity and quality of soil material adjacent to quarries was included in the vegetation model to evaluate the possibility of providing sufficient mineral substrate from neighboring areas with deep soils possessing good physico-chemical properties for plant establishment and survival. All attributes in the vegetation recovery model were assigned a weighted numeric score which were summed to provide a relative ranking of all quarries. These were then separated into four classes of likely revegetation success. In addition, water harvesting potential was assessed based on catchment area above the quarry and rock permeability in the quarry. The priority for reclamation was based on the comparison of vegetation success and suitability for water harvesting. The results of this model can be used to facilitate decision making concerning priority selection of sites for reclamation efforts, reclamation strategies to be attempted and possible alternative post-reclamation land use.

Additional Key Words: Quarry rehabilitation, vegetation recovery, modeling reclamation success, water harvesting

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Introduction

Urban and industrial expansion is exerting increasing pressure on limited soil and water resources in arid and subhumid Lebanon (Eswaran and Reich, 1999; Darwish *et al.*, 2004). Loss of forest cover due to fires and quarrying of productive lands exacerbate water shortage in Lebanon and other countries of the Middle East North Africa (MENA) region. Land degradation resulting from mismanagement of quarried sites affects the ecosystem and water balance in the watersheds leading to soil erosion and landslides. Mediterranean ecosystems are frequently fragile and prone to drought, making vegetation recovery a difficult and long process. Years of unregulated quarrying have left hundreds of abandoned quarries across Lebanon (USAID/ECODIT, 2002). Accelerated runoff reduces water recharge and the availability of water resources in the area and contributes to excess groundwater pumping thereby enhancing seawater intrusion into coastal aquifers (El Moujabber *et al*., 2006). Institutional weakness and the absence of policy for integrated land resources management accelerate the deterioration of the mountain soil-forest ecosystem, especially in degraded quarries (Khawlie, 1998).

Quarries, particularly those on steep slopes with unstable rocks, increase landslides and other mass movements with consequent destruction of natural habitats and biodiversity. Removing the topmost soil layer and surface rock material multiplies the vulnerability of groundwater contamination due to karst features of hard limestone and the high infiltration rate of disturbed sands. Recently, the spontaneous vegetation dynamics of deserted Lebanese quarries and the suitability of quarries as landfill sites (Khater *et al*., 2003; El-Fadel *et al*., 2001) were assessed. Sustainable quarrying activities consider conservation of the ecosystem with rehabilitation of landform and landcover to approximate the initial state. A majority of Lebanese abandoned quarries represent lasting scars on the landscape and a potential danger to the ecosystem (Atallah *et al*., 2003).

Tools such as remote sensing and GIS have been used to locate quarries suitable for aggregate mining on the Lebanese coastal area (Khawlie *et al*., 1999). Other studies mapped areas prone to desertification (NAP, 2003) and exposed the dynamic factors of land degradation and the impact of chaotic urban sprawl on arable lands (Darwish *et al*., 2004). Masri *et al*. (2002) monitored land cover change over the last forty years and Zurayk *et al*. (2001) modeled land degradation as functions of farmers' perception and attitudes. However, few studies have holistically assessed the negative impact of land degradation from existing quarrying activity in the East Mediterranean and the potential revegetation success using remote sensing and GIS techniques. Accordingly, the objective of this work was to establish a model of potential revegetation success or water harvesting to orient national ecosystem restoration efforts addressing the suitability of quarries in Lebanon for rehabilitation.

Material and Methods

Two models were developed to assess and rank quarries in Lebanon according to potential for (1) successful revegetation, and (2) redevelopment as a water harvesting site. Satellite imagery of Landsat TM 5 (30 m spatial resolution) from 1996 and 2005 as well as Ikonos (2m resolution) from 2005 were used to locate the quarries. Spatial distribution of quarries was compared to the land cover map of Lebanon produced using 1998 IRS-1D (panchromatic 5 m spatial resolution). Satellite images were inspected visually on screen to identify quarry distribution and coverage patterns. This was followed by field surveys to support delineation of quarries. Distribution of quarries was examined with respect to individual thematic layers for which georeferenced data were available using the GIS facilities of ArcGIS 9.2. Thematic layers considered included landcover, soil, precipitation, geology and landform. Parameters within these layers included in the models were assigned a numeric value based on their potential to impact either revegetation or water harvesting. Both models assessed potentials associated with individual quarries based on a summation of the numeric values for each parameter included in the model. The distribution of numeric scores was then divided into ranked categories.

Input parameters used in the model assessing potential for revegetation success included precipitation, slope gradient, slope aspect, soil material availability and soil texture (Table 1). Each of these parameters was assigned a numeric impact value ranging from 0 to 4. Because of the very strong correlation between elevation and precipitation in Lebanon, elevation was not explicitly included in the model. We also recognized interactive impacts among some parameters. For example, northern aspect was considered as a negative factor in the high precipitation (high altitude, lower temperature) areas due to decreased solar radiation and cooler temperatures. Northern aspect was classified positively in the lower rainfall zones (low altitude and high temperatures) due to decreased evaporative loss and moderated temperatures. The categorization of each parameter and the associated numeric values are summarized in Table 1.

Table 1. Parameter categorization and numeric values (Val.) used to assess the potential for successful revegetation of quarries in Lebanon

<table>
<tr><th colspan="2">Annual Precipitation</th><th colspan="2">Slope aspect (within precipitation classes)</th><th colspan="2">Slope gradient (%)</th><th colspan="2">Soil material availability</th><th colspan="2">Soil texture</th></tr>
<tr><th>Range (mm)</th><th>Val.</th><th>Category (mm/year)</th><th>val.</th><th>Range</th><th>Val.</th><th>Soil type</th><th>Val.</th><th>Class</th><th>Val.</th></tr>
<tr><td>>1000</td><td>0</td><td>Flat >800
South >800
North 400-600</td><td>0</td><td><8</td><td>1</td><td>Vertisols
Luvisols
Fluvisols
Cambisols
Arenosols
Planosols</td><td>0</td><td>Loams</td><td>0</td></tr>
<tr><td>800-1000</td><td>1</td><td>Flat 600-800
North 600-800</td><td>1</td><td>8-15</td><td>2</td><td rowspan="2">Sand beach
Calcisols
Leptosols
Regosols
Andosols</td><td rowspan="2">1</td><td>Sands</td><td>1</td></tr>
<tr><td>600-800</td><td>2</td><td>Flat <400
North <400
Flat 400-600
South 600-800
North >800</td><td>2</td><td>15-30</td><td>3</td><td>Clays
Silts</td><td>2</td></tr>
<tr><td>400-600</td><td>3</td><td>South 400-600</td><td>3</td><td>>30</td><td>4</td><td></td><td></td><td></td><td></td></tr>
<tr><td><400</td><td>4</td><td>South <400</td><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

To assess availability of soil material in the vicinity of degraded quarries, an updated soil map of Lebanon at 1:200,000 scale was used (Darwish *et al*., 2002). Soil taxonomic groups were categorized into two classes based on potential soil productivity and depth. Soil textural classes were separated into three groups on the basis of potential water holding capacity and susceptibility to compaction. On the basis of assigned value ranges, precipitation class was given the greatest weight in the model, slope factors intermediate weight, and soil factors the lowest weight.

The model to assess potential for redevelopment of quarries for water harvesting was developed using a GIS approach similar to the revegetation model. Parameters included in the water harvesting model were slope, catchment area above the quarry, and rock permeability. Rock permeability was evaluated on the basis of the porosity associated with the types of basaltic, sandstone, marl and hard limestone bedrock at the quarry location. These parameters and associated values are presented in Table 2.

Table 2. Parameter categorization and numeric values used to assess the potential redevelopment of quarries for water harvesting in Lebanon

Slope gradient		Rock infiltration		Catchment area (ha)	
Class %	value	Class	Value	Class	Value
<8	3	Extreme	3	320-1745	4
8-15	2	High	2	1745-4095	3
15-30	1	Medium	1	4095-15150	2
>30	0	Low	0	15150-24470	1

Catchment area categories were designed with respect to calculation of average area of catchment basins in Lebanon and the 4 quartiles calculated to define class limits.

Precipitation was not included in the water harvesting model because even in regions with low annual precipitation, water harvesting is feasible since much of the rainfall comes in intense, infrequent storms that generate significant runoff and flash floods. Furthermore, it is precisely these regions of the country that would benefit most from water harvesting.

By overlaying the output from revegetation and water harvesting models, a combined model was developed that can be used to facilitate priorization of quarry rehabilitation and inform decisions of the rehabilitation strategy to be implemented. In the combined model, water harvesting classes were assigned a numeric value and revegetation classes were assigned a letter value (Table 3). The resulting alphanumeric code thus contains an assessment concerning both potential rehabilitation approaches for quarries.

Table 3. Modeling the potential rehabilitation success of quarries in Lebanon

Suitability for Water harvesting \ Revegetation success	Very High (A)	High (B)	Medium (C)	Low (D)
High (1)	1-A	1-B	1-C	1-D
Medium (2)	2-A	2-B	2-C	2-D
Low (3)	3-A	3-B	3-C	3-D

Results and Discussion

Between 1996 and 2005, the number of quarries increased by 55.6% (from 711 to 1278). During the same time, the quarried land area increased by 54.4% (from 2875 to 5283 ha). Based on recent remote sensing data (2005) 75.18% of these quarries were located on dense and sparse grassland-bare rocky lands, which significantly affected the sustainable management of rangeland in the country (Fig. 1). A total of 4.97% of quarries were distributed on forestland-scrubland while 16.96% of quarries were detected on arable lands and 3.19% of quarries were distributed inside urban zones. Shown in Fig. 2 and 3 are two examples of abandoned quarries in Lebanon. This situation can pose severe problems for air quality and possible deterioration of soil and water quality. Lebanon has a shortage of fertile arable lands and yet is experiencing unprecedented expansion of urban areas on fertile lands (Darwish *et al*., 2004) as well as increased forest fire events and recession of vegetation cover (Masri *et al*., 2006). Current policy and legislation controlling the distribution of licenses for new quarries in Lebanon only exacerbates these trends and is clearly in need of reconsideration.

Relatively few quarries were assessed as having a very high or high probability of revegetation success (Fig. 4). These classes are concentrated in the mountain sub humid area and western aspects of Mount Lebanon including the coastal area with a long dry period. Some of them occurred on the eastern aspects of Mount Lebanon facing the semiarid Bekaa area and on the southern mountain range. These results reflect the difficulty in establishing vegetative cover in lower rainfall, high temperature regions. They also result from the fact that quarries in higher rainfall zones also tend to be located in steeply sloping areas where transporting soil material, spreading and incorporating soil amendments, planting, and controlling erosion would be difficult. A large number of abandoned quarries in Lebanon contain steep highwalls with slope gradients exceeding 90%. Revegetation of these sites requires extensive reshaping of these walls possibly through allowing controlled additional exploitation, blasting or transporting rock and soil material from close locations to prepare the area for reclamation. Operations such as these become increasingly difficult and infeasible in steeply sloping areas. Quarries ranked as medium and low probability of revegetation success are found throughout the country reflecting how the complex morphology of Lebanon. We propose that these quarries should be assessed for alternative future uses such as water harvesting.

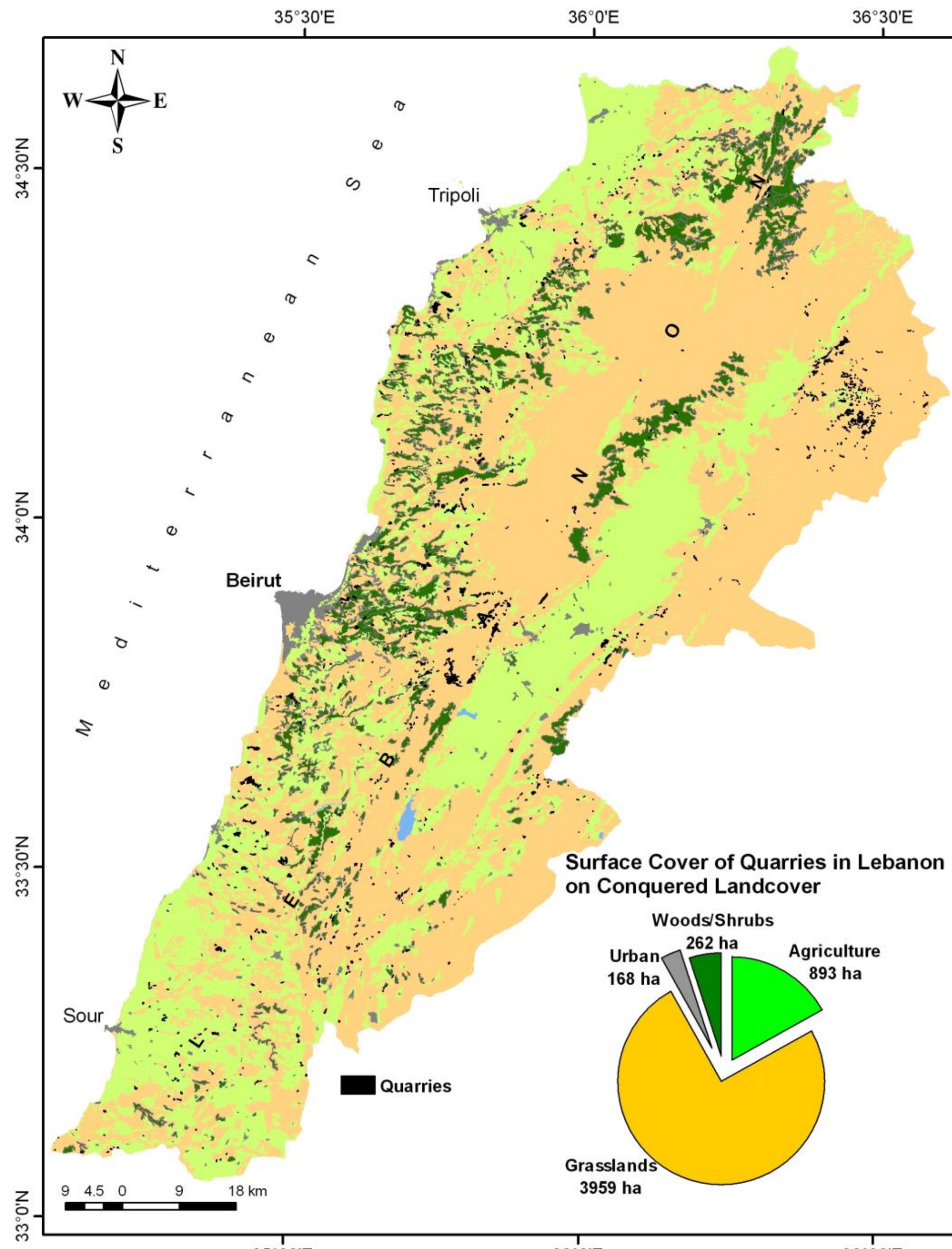
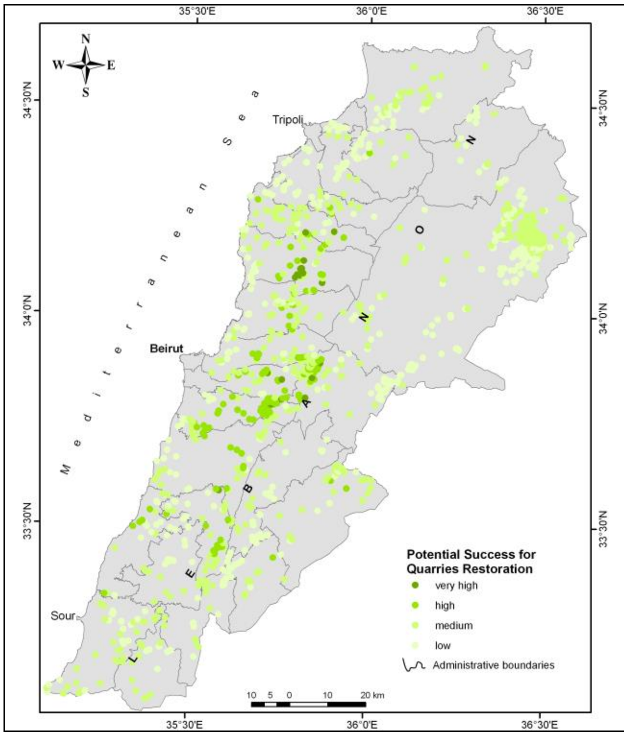


Figure 1. Distribution of quarries on different landcover/use in Lebanon.

Figure 2. An abandoned hard limestone quarry located in the Qartada region of Lebanon.

Figure 3. An abandoned sandstone quarry located in the Safa region of Lebanon.

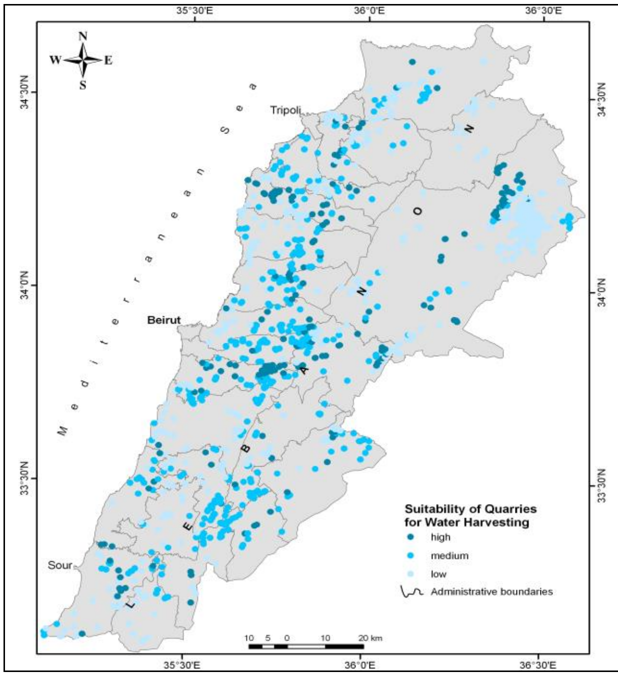


Potential revegetation success	Number	Area, ha
very high	20	175.42
high	144	513.45
medium	603	2149.83
low	511	2427.78

Figure 4. Spatial distribution, number and area of quarries classified according to their potential for revegetation success.

Output from the water harvesting assessment model produced a somewhat more even distribution of quarries within the three classes. A large number of quarries was ranked as having a high potential for redevelopment as water harvesting sites due to their position in the catchment and relatively low rock infiltration (Fig. 5). Water is an increasingly limiting resource in Lebanon, and there is increasing competition for water among domestic, industrial, and agricultural users. Given the torrential nature of rainfall in Lebanon and its uneven distribution, many areas experience a severe shortage of fresh water in dry months. Despite the fact that rainfall is more abundant in the western mountain chain, the country lacks large water harvesting structures. The eastern mountain chain having arid and semiarid climate showed large area of quarries convenient for water harvesting to collect water from recurrent flush floods, mainly in spring and fall. These water reservoirs will contribute to reduce the impact of devastating floods and provide additional water in highly water deficit area.

Another alternative use that has been suggested for abandoned quarries in Lebanon is redevelopment into landfills. In fact, many are being illicitly used for this purpose. However, such practices could have devastating impact on groundwater quality if improperly managed. A key feature would be bedrock permeability and stability, factors included in the water harvesting model. Thus, quarries ranking high for water harvesting could also represent potential sites for landfill development. However, other factors such as proximately to urban areas, transportation, and size would also need to be considered.



Water harvesting	Number	Area, ha
high	220	1007.05
medium	442	2129.82
low	616	2129.62

Figure 5. Spatial distribution, number and area of quarries classified according to suitability for water harvesting.

By combining the outputs of the revegetation and water harvesting models, an overall assessment of quarry rehabilitation was generated (Fig. 6). There is relatively little overlap of quarries given a high ranking by both of the assessment models. Thus the models were effective in segregating quarries into clear rehabilitation alternatives. Only three quarries in Lebanon were ranked in the highest categories for both revegetation and water harvesting. Of the 220 quarries ranked high for water harvesting; only 40 were also ranked high or very high for revegetation. Similarly, of the 124 quarries ranked high or very high for revegetation, only 40 were also ranked high for water harvesting.

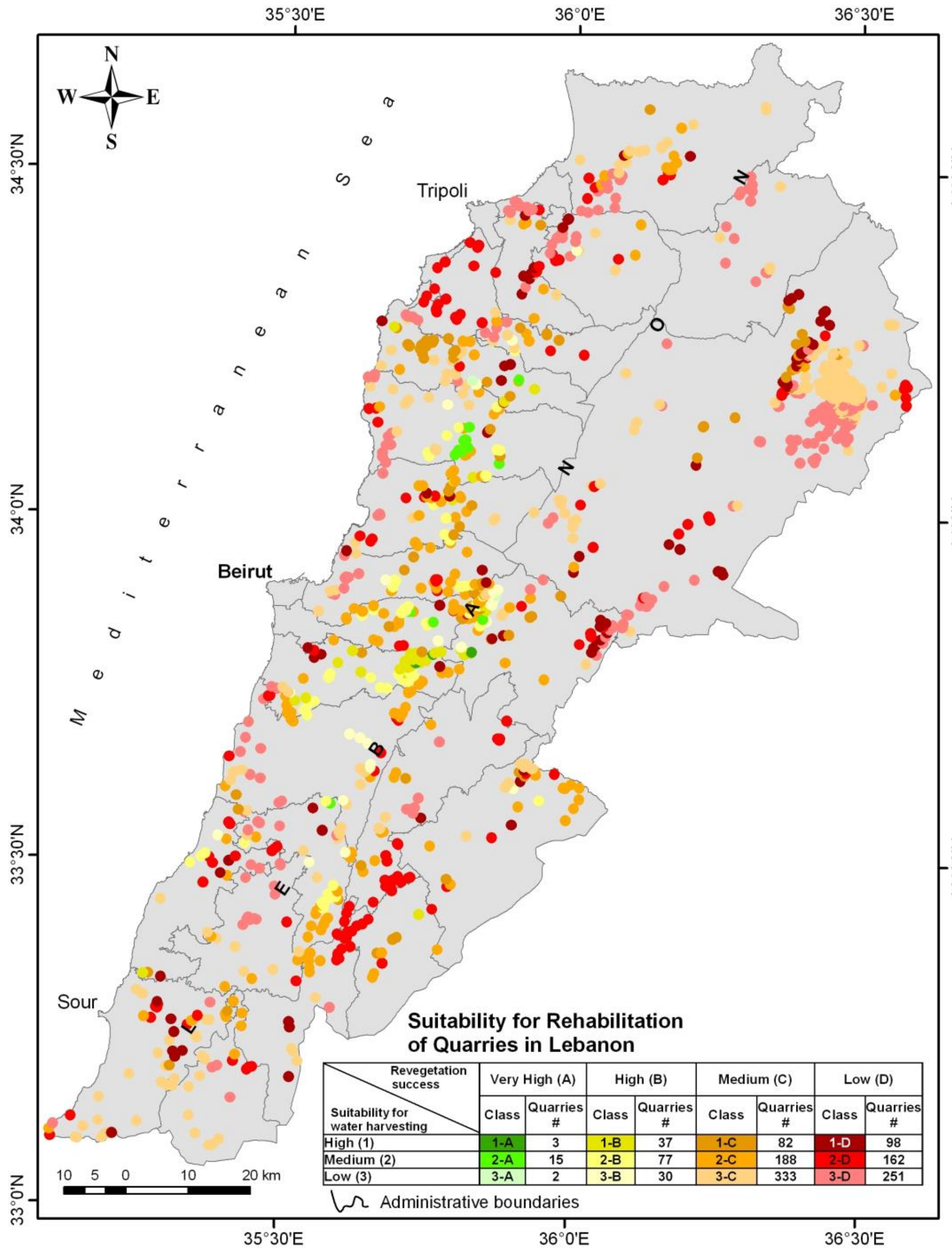


Figure 6. Combined model output of quarry suitability for rehabilitation in Lebanon

The combined model also demonstrates that quarries with a very high potential for revegetation (A) are mostly located in the Mount Lebanon mountain range (20 quarries), while those with high suitability for water harvesting (1) are more numerous (220) and are spread all over the territory.

Well segregated quarries (high rankings in one model and low in the other) should be considered for rehabilitation following their high ranking. Quarries with high rankings in both models in all likelihood would be well suited for a combined approach of revegetation and development of reservoirs.

This rehabilitation success model can be used as a tool to help with future prioritization of quarry rehabilitation, locating quarries for rehabilitation, and to guide rehabilitation strategies. Although final decisions would clearly require extensive site investigations, this model can limit such investigations to those quarries with the highest probability of success.

Conclusion

Lebanon is rich in agro-ecological zones representing complex orography, variable climate and rich biodiversity. However, the chaotic and uncontrolled expansion of quarry sites and limited rehabilitation of quarries is affecting vegetation cover, causing forest fragmentation and loss of arable lands. Given the large number of quarries and limited availability of resources for rehabilitation, a national priority for Lebanon is to direct those resources to those sites with the greatest likelihood of successful rehabilitation. The GIS based models presented in this paper have ranked all quarries in Lebanon with respect to their potential for successful revegetation and their potential for redevelopment as water harvesting sites. Both models produced a wide distribution of preferred uses for the quarries and effectively identified those that should be high priority candidates for rehabilitation. Detailed site investigations would be required to confirm the model output and to develop specific reclamation plans. However use of these models can help to target such investigations to sites with high potential for successful reclamation. Overlaying the output of the two models demonstrated a strong segregation of sites suitable for revegetation and those more suitable for water harvesting. Thus these models can also be used to help direct reclamation strategies.

Prioritization of quarries for reclamation should also consider the present environmental impact of the quarry and the potential for mitigation of that impact by reclamation. We are in the process of developing a third model that will assess potential environmental impact of existing quarries. The proposed model could also be used to limit future quarrying activity to sites with minimal potential environmental impact. Overlaying this model with the combined model output presented in this paper will result in a further refinement of the tool to help direct national policy and limited resources toward those sites where the greatest benefits will be realized. Assessing the environmental and health risk impact from current and future quarrying activities within a national policy for quarry exploitation and reclamation is essential to meet the needs of the growing population, while maintaining the sustainable use of natural resources for future generations. Legislation must consider not only licensing quarry exploitation but also their rehabilitation during the process of work. Monitoring of the potential effect on vegetation cover and water resources is a continuous task serving the ecosystem and public health.

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