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RESEARCH ARTICLE

GIS and Remote Sensing applications for abandoned quarries rehabilitation: A case study in the Akreuch Region, Rabat, Morocco.

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Abstract

Geographic Information System (GIS) and Remote Sensing techniques are increasingly widely used tools in urban and environmental studies and help making decision in land-use planning. Generally, such projects involve a large amount of spatial data derived from several sources and provided in different formats. As an urban project, abandoned quarries rehabilitation requires a suitability evaluation based on geo-environmental information. This evaluation incorporates topography, soil characteristics, water resources and socioeconomic constraints. The diversity of parameters shows the complexity of the issue and underlines the necessity of developing a methodology supporting decision makers in choosing the most appropriate and optimal solution for quarries reuse.

Akreuch quarries have been abandoned for at least 8 years without any plan of rehabilitation or restoration and they are today subject to various forms of degradation processes. In this sense, this paper addresses quarries rehabilitation using GIS and Remote Sensing approaches combined with multi-criteria analysis.

Four major categories were studied offering different scenarios of rehabilitation. It comes to: Construction, Landfill, Revegetation and Waterbody. A multi-criteria analysis based on the Analytic Hierarchy Process (AHP) was performed taking into account different parameters and has revealed the appropriate rehabilitation alternative for each quarry. As a result, suitability maps were produced and attest the efficiency and the functionality of GIS and Remote Sensing in redevelopment projects.

Introduction:-

The increase of population, the urban sprawl and the improvement of infrastructures in Morocco have meant that quarries are progressively more exploited over the national territory. Despite the quarries contribution to the national economy, they represent a risk to the environment and the surrounding populations. In fact, after extraction activities end, and if the rehabilitation is not properly managed, many environmental aspects are disrupted; water quality can be substantially changed and altered (Ekmekçi, 1990; Hobbs, 2002; Green *et al.*, 2005; Misra, 2013) ; heavy metal concentration often exceeds the limits allowed by the WHO for drinking water (Peffer, 1982; Afeni *et al.*, 2012; Akubugwo *et al.*, 2012). In this same context, and as a part of the environmental complex, soil undergoes a drastic deterioration and transformation due to excavation works (Adewole & Adesina, 2011; Etim & Adie, 2012; Adabanijaa & Oladunjoyeb, 2014; Ayodele *et al.*, 2014; Lago-Vila *et al.*, 2015; Tiimub *et al.*, 2015; Lago-Vila *et al.*, 2016). Animals and plants are also affected by dust and noise generated by human interventions (Farmer, 1993; Vardaka *et al.*, 1995; Salami *et al.*, 2002; Ruddock & Whitfield 2007; Kumar *et al.*, 2008; Leghari *et al.*, 2013;

Rawat & Katiyar, 2015) ; natural habitats are destructed and indigenous species may be replaced by some new biological units and non-native species, causing an increased translocation (Ratcliffe, 1974; Lameed & Ayodele, 2010; Rover & Persson, 2014). The landscape is fragmented and shows irregular depressions (Hagiou & Konstantopoulou, 2010). In addition to these effects, human safety is threatened; Quarries faces represent a risk of falling and collapse (Martin Duque *et al.*, 1998) and should be stabilized during and after the extraction. For these multiple reasons, quarries' rehabilitation and the restoration are for a great interest. These will ensure the reintegration of exploited sites into their natural environment.

Legislative actions on environmental issues have been improved during the last decades all over the word (Damigos & Kaliampakos, 2003). In order to comply with the international change and in a perspective of sustainable development, recent government policy have put a great importance to environment preservation activities and have adjusted the legislative guidelines for the rehabilitation; a quarry opening project is subject to an Environmental Impact Assessment, and a financial guarantee is foreseen for the rehabilitation or restoration after closure.

There is no one and single method of rehabilitation; a variety of examples exist depending on the particularities of the quarry (Jim, 2001; Kaliampakos & Mavrikos, 2006; Darwish *et al.*, 2008; Dal Sasso *et al.*, 2012; Bottero *et al.*, 2013). However, their goals remain the same and aim to ensure the security of sites and their long-term stability, limit their negative impacts, and in the same way, reintegrate and revalorize quarries.

Many recent studies have focused on identifying the most suitable areas to open a new extraction site (Robinson Jr *et al.*, 2004; Brown, 2010; Premasiri *et al.*, 2012; Bayisa *et al.*, 2014; Karakaş, 2014), but few studies have been concerned with the post-operation to choose the most appropriate restoration method for quarries (Dal Sasso *et al.*, 2012). The use of guides is not always the most reliable way for the redevelopment of quarries. Each site is distinguished by its different characteristics (geology, geomorphology, hydrology, socioeconomics, etc.). The paper presents a planning for abandoned quarries rehabilitation using GIS and Remote Sensing techniques. The coupling of these approaches to address different environmental issues has been widely used over recent years (Pereira & Duckstein, 1993; Chenini *et al.*, 2010; Gupta & Srivastav, 2010; Jha *et al.*, 2010; Pourghasemi *et al.*, 2014; Zolekar & Bhagat, 2015; Agarwal & Garg, 2016). Indeed, Geographic Information Systems enable the collection, storage, processing, management and presentation of spatial data; they are an essential tool in the management and planning of space (Kainz 2004), while Remote Sensing approaches allow the study of earth's surface without being in direct contact with the object, area or phenomena under investigation (Kumar, 2005). These two technologies are even more useful when combined with the multi-criteria analysis. Together, they form a powerful decision aid system. In fact, the multi-criteria analysis allows the resolution of complex problems by proposing a finite number of actions from the evaluation of multiple criteria (Lootsma, 1999). Several methods of multi-criteria analysis are being adopted and their diversity lies in the realization of the information synthesis contained in each criterion (Ben Mena, 2000). Those methods are largely used in environmental scientific researches (Khalili & Duecker, 2013 ; Mosadeghi *et al.*, 2013; Guerrero-Baena *et al.*, 2015; Junior *et al.*, 2015). In this study, the Analytic Hierarchy Process (AHP) was used to determine the best method of rehabilitation for each quarry. This approach is very popular in environmental field and urban planning. Various studies have proven its effectiveness in these two disciplines (Dai *et al.*, 2001; Schmoldt *et al.*, 2001; Uyan, 2003; Tudes & Yigiter, 2010; Akıncı *et al.*, 2013; Aydi *et al.*, 2013; Srdjevic *et al.*, 2013; Moghadam *et al.*, 2014; Koç & Burhan, 2015). The method applied is built on a well-defined approach based on pairwise comparison, aggregation and weighting. It provides a framework integrating modeling and ease of use, and requires the development of a reliable hierarchical structure. This last includes factors of various forms of stakeholders' and decision makers' influence to determine the best choice to make (Saaty, 1990).

Study area:-

The study area is situated in the Akreuch Region, southeast of Rabat city (Morocco); (Figure 1). It is located in north-west of Morocco, between latitudes 33°58' and 33°55'N, and longitude 6°48' and 6°44'W, and covers 36,6km² of the Bouregreg watershed. This last covers an area of about 10597km² and extends southeast of Rabat to the Middle Atlas chain.

The Akreuch Region counts 10 abandoned open quarries (former marl and limestone extractions) falling under Sehoul, Hassaine and Oum Azza communes (Table 1). They are distributed along the Bouregreg River and its tributary Akreuch (at least 30m), 2km downstream from Sidi Mohamed Ben Abdellah Dam and at least 100m from agglomerations. These conditions make this area very sensitive to pollution. Furthermore, an abandoned quarry may easily be transformed into an uncontrolled landfill, which may affect surface and groundwater quality, and consequently the nearby dam quality. In addition to these threats, extraction activities have left fronts of different heights varying from 30m to 70m and presenting substantial width extensions. These excavations are visible from hundreds of meters and they are of significant concern for local communities.

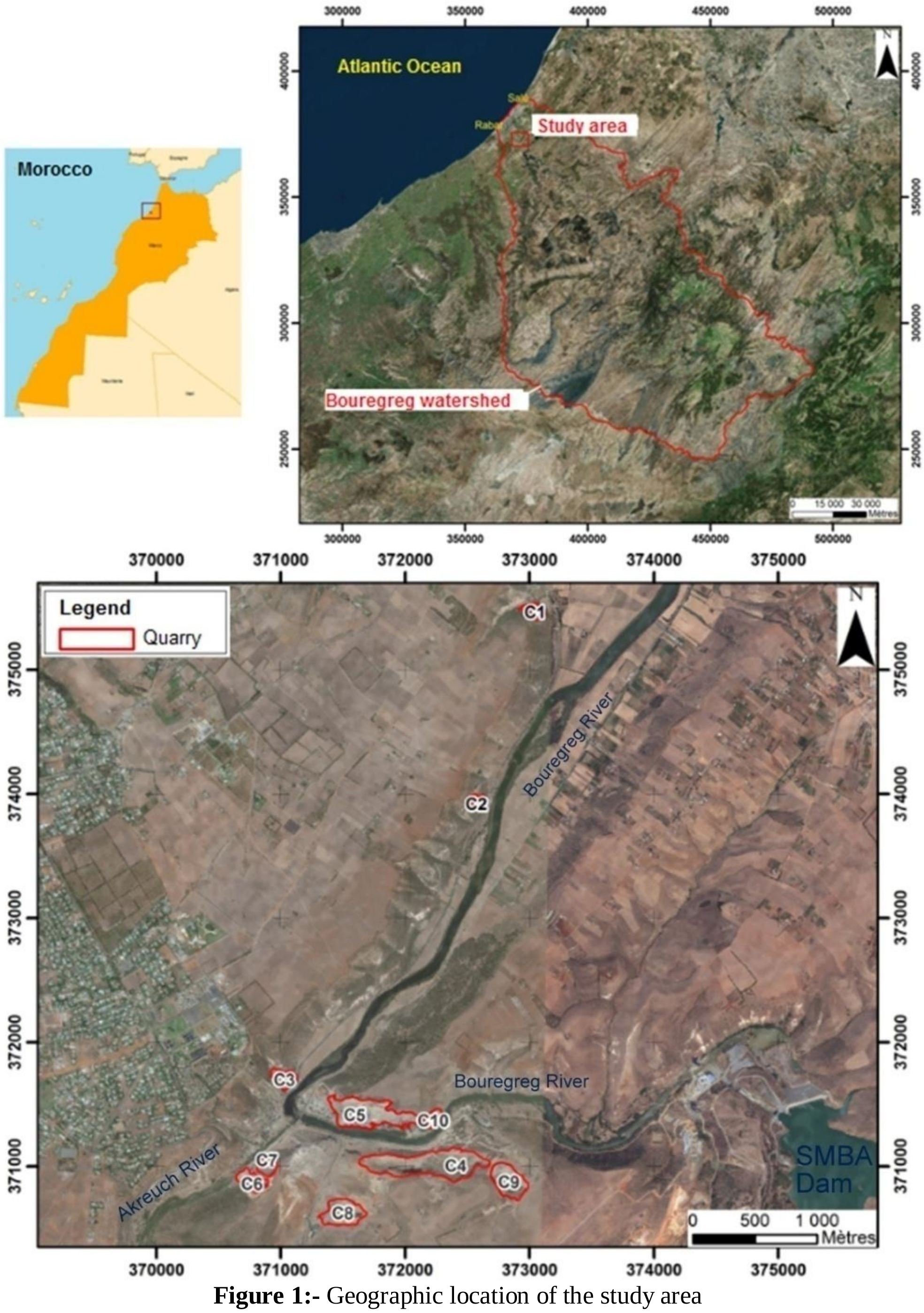

Figure 1:- Geographic location of the study area

Table 1:- Characteristics of the studied quarries

Quarry	Quarry operator	Commissioning date	Closing date	Rock nature	Area (m²)	Commune	Coordinates	
							X	Y
C1	Med Boudkhil	-	-	Marl	11510	Souissi	373041	375484
C2	Abassour	-	-	Marl	7800	Souissi	372612	373923
C3	Fadil-Dar Dmana	1978	2003	Limestone	23000	Souissi	371024	371714
C4	SDT-SOCAROA (Ste Doukkala)	1973	2007	Limestone	157500	Oum Azza	372176	371032
C5	SOGECAR	1969	2008	Limestone	103200	Hssaine	371715	371414
C6	Ste Rougani	1945	2008	Limestone	45800	Oum Azza	370795	370872
C7	Belahcen	1959	2008	Limestone	13500	Oum Azza	370907	370999
C8	El Mohami	1970	1992	Limestone	57000	Oum Azza	371508	370672
C9	SDT-SOCAROA (Ste Doukkala)	1975	2007	Limestone	57300	Oum Azza	372841	370889
C10	SDT-SOCAROA (Ste Doukkala)	1973	2007	Limestone	14500	Hssaine	372208	371348

(-) Unknown date

Materials and method:-

Rehabilitation planning is a large-scale project that cuts across several sectors. Indeed, geo-environmental and socioeconomic parameters are discussed and show an interdependent behavior; the selection of a scenario rather than another cannot be done basing on one criterion, but involves multiple factors. In this study, four major alternatives were selected (Table 2) inferred from previous works and experiences, and aligning around the same objectives.

Table 2:- Description of the different rehabilitation categories

Alternative	Description
Construction	This category includes all type of construction and buildings. Cleaning and securing the quarry site are essential steps before construction works. Partial filling of the quarry is then performed to ensure better ground stability and reduce very steep slopes.
Landfill	This alternative requires quarry cleaning and safety measures provision before starting construction works, according to regulation and hydrological, geological, geomorphological and geotechnical characteristics of the site.
Revegetation	This category involves quarry securing by eliminating blocks, and cleaning and backfilling the quarry using suitable equipments. Laying topsoil is then carried out to ensure natural evolution of vegetation. Revegetation includes any type of rehabilitation based on plantation, agriculture, reforestation, natural vegetation, etc.
Waterbody	This category requires, as its previous, cleaning and securing the quarry site. It includes: ponds, lakes, dam, retention basin, etc.

The method adopted uses GIS and remote sensing to provide redevelopment proposals of abandoned quarries. As a first step, data were collected, structured, processed and then stored in a geographic database under different themes (Topography, Soil characteristics, Water resources and Socioeconomics). The second step was to exclude unsuitable surfaces and select the most decisive parameters widely tackled in land management and particularly in quarries' redevelopment. This selection was based on: previous experiences in urban planning, expertise, and local and regulatory constraints. Afterwards, multi-criteria analysis was applied to evaluate rehabilitation alternatives (Construction, Landfill, Revegetation and Waterbody) depending on factors previously selected. The final step was to create thematic maps for each alternative and assess the different propositions. A flowchart of the methodology is illustrated in Figure 2.

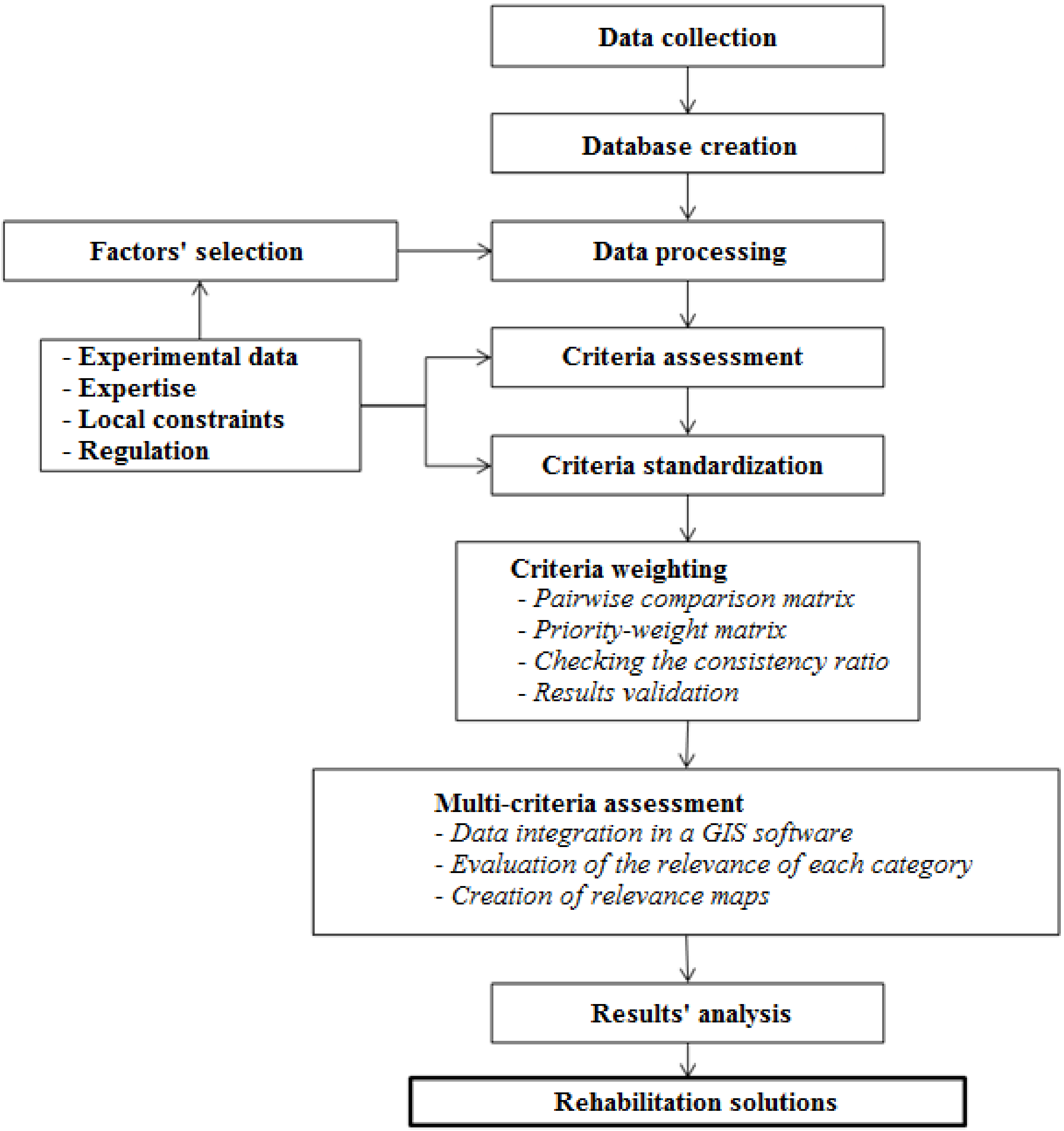

Figure 2:- Flowchart of the rehabilitation methodology

Data collection and processing:-

Various data were used and processed to assess the different rehabilitation alternatives:

- ❖ Satellite images imply radiometric correction and image enhancement to suppress atmospheric disturbances and improve visual interpretation. Scanned maps are integrated into a GIS software for georeferencing and digitizing. Data produced are then grouped in a geographic database.
- ❖ Topographic data are obtained from the Global Digital Elevation Model (GDEM) and concern the slope, the elevation and the exposure maps.
- ❖ Soil characteristics include:
    - Pedology obtained from the soil map of the study area (1/100000) and soil analysis;
    - Geological data obtained from a scanned map of the region (1/100000) and experimental data;
    - Soil loss estimation obtained from the application of the RUSLE (Revised Universal Soil Loss Equation) model. This last uses the following data: topographic map (1/25000), satellite image (30x30m resolution), soil analysis, soil map, climatic data, GDEM and data collected during field surveys;

- Geotechnical data synthesized from a literature review.
- Groundwater characteristics were acquired from national administrations, include the groundwater levels, and recharge zones.
- The different water resources (permanent and temporary watercourses, dam, sources, etc.) have been digitized from the topographic map and Google Earth imagery.
- Socioeconomic data comprise roads, trails, highways, power grids and built-up areas, and they were digitized from the topographic map and Google Earth imagery.
- Natural hazards were obtained from national regulation and reports.

Factors for suitability assessment:-

In this section, only the most significant sub-criteria were considered for each decisive factor. The above form a non-exhaustive list of sub-criteria and they are structured in table 3.

Table 3:- Assessment criteria selected

Criteria	**Sub-criteria**
Topography	Elevation (m)
	Slope (%)
	Exposure
Soil characteristics	Pedology
	Distance from faults (m)
	Geotechnics
	Erosion (t/ha/yr)
Water resources	Distance from watercourses (m)
	Distance from sources (m)
	Groundwater depth (m)
	Recharge zones (m)
Socioeconomics	Distance from roads (m)
	Distance from agglomerations (m)
Natural hazards	Seismicity
	Flooding

Elevation forms a determinant factor of suitability assessment. High areas suffer from accessibility and lack of basic infrastructure (transport, water supply and sanitation); (Dai *et al.*, 2001) which may generate additional costs in case of construction or the implementation of a landfill. Variation of altitude also affects vegetation cover change (Rogers *et al.*, 2014). However, elevation in the study area varies between 10m and 179m. This values are considered moderate and do not have a significant impact on decision making in such redevelopment project.

Slope is considered because it represents a very important factor when it comes to construction and landfills. Steep slopes are difficult to access and generate additional costs for excavation and widening the traffic aisles to ensure transportation of materials and equipments (Chowdury, 1987), as they are more susceptible to erosion when they exceed 50% (Tudes & Yigiter, 2010). They also promote the leachate drainage toward flat areas and cause waterbodies contamination (Eskandari *et al.*, 2015) ; Number of studies have limited the angle to 20% for landfill sites (Lin *et al.*, 2005; Akbari *et al.*, 2008; Kara & Doratli, 2012).

Steep slopes also represent a great challenge for the conservation and preservation of vegetation; slope degree influences soil nutrients and vegetation dynamics (Thomas *et al.*, 1999; Bochet & Garcıa-Fayos, 2004; El Kateb *et al.*, 2013). Revegetation on slopes greater than 24% is complex: seeds are exposed to the direct action of precipitation and the high erosion risk (Van der Meer *et al.*, 2014). Nevertheless, the vegetation on gentle slopes favors soil stability and reduces erosion risk (Norris & Greenwood, 2006; Fattet *et al.*, 2011; Osman & Barakbah, 2011; Ali *et al.*, 2012).

Exposure is taken into account because in the Northern Hemisphere north-facing slopes receive very little heat unlike south-facing slopes. The latter tend to receive more direct rays, and therefore they are sunniest and most favored for buildings (James & LaGro, 2007). East-facing slopes receive the sunlight in the morning when temperatures are low, while west-facing slopes receive sunlight in the afternoon when temperatures are higher. Consequently, west-facing slopes are warmer and more preferred (Kumar & Biswas, 2013).

Slope aspect has also an impact on the selection of landfill sites. Combined with the prevailing winds direction, this criterion controls the direction of winds in hilly areas. The wind direction should be hindered to prevent the transmission of odors from landfills to residential areas (Eskandari *et al.*, 2013; Sar *et al.*, 2015).

Vegetation dynamics is no exception to the effect of slopes exposure. South-facing slopes accentuate the natural aridity in Mediterranean regions (Lansiart & Odent, 1999). The colonization of plants varies in the northern hemisphere, from north to south (Bochet *et al.*, 2009). North-facing slopes are wetter, and their soils are characterized by greater organic matter content (Poesen *et al.*, 1998; Kutiel & Lavee, 1999; Hammada *et al.*, 2004).
Pedology: Soil analysis is essential to effective revegetation management. Organic matter is the basis of soil fertility. It provides nutrients (nitrogen, phosphorus, potassium, sulfur, etc.) through the mineralization process. It regulates the humidity of clay soils by improving their porosity, which facilitates the penetration of water and oxygen, and promotes the evacuation of excess water. During quarry exploitation, the topsoil is removed. If materials are not properly stored, they lose their intake of water and organic matter. The handling of the topsoil must be done with great caution (Lansiart & Odent, 1999).

Studied quarries were abandoned between 1992 and 2008 without any planning for a possible redevelopment. Field surveys have confirmed the lack of arable land in these sites. In case of revegetation, external arable materials will be used (sewage sludge, compost, etc.).

Faults are among the most significant factors in triggering landslides (Feizizadeh *et al.*, 2011; Gemitzi *et al.*, 2011; Shahabi & Hashim, 2015) and thus pose a risk of collapse in case of construction (Hall *et al.*, 1995; Champion & Liel, 2012). Their detection is one of the most used criteria in territory management and planning (Dai *et al.*, 2001; Sumathi *et al.*, 2008; Youssef *et al.*, 2011; Ali *et al.*, 2012).

In the case of landfills, the existence of faults promotes rock permeability which makes the infiltration of leachates easier and could cause damage to the water table (Eskandari *et al.*, 2015). Studies have selected a distance of 200m from faults, as the favorable for the implementation of a landfill (Eskandari *et al.*, 2013; Eskandari *et al.*, 2015; Safavian *et al.*, 2015).

A fractured zone is characterized by low permeability allowing a strong flows channeling (Pouya *et al.*, 2011; Meier *et al.*, 2015). Non-fractured zones, characterized by massive rocks, are more favored for the establishment of a water body. A distance of at least 50m from faults has been designated as appropriate. These conditions will ensure water control and conservation.

Geotechnics:-

The elaboration of a geotechnical study would be of a great contribution. However, conducting geotechnical investigation is very expensive. Soil classification was made on the basis of their resistance and stability defined by the professional practice. They can be divided into three main categories (Vittone, 2013) :

- Poor Land: Unsuitable for construction (peat, silt, chalk, backfilling etc.).
- Average quality Lands: Fine and medium wet sand with low cohesion.
- Good quality Lands: Coarse sand and gravel, dry marl and clay.

Erosion:-

Uncontrolled erosion can cause structural damage to retaining walls, foundations and infrastructure, as it may cause flooding (Pham, 2009; Agyarko *et al.*, 2012; Ferrer *et al.*, 2015). For these reasons, control measures must be implemented to prevent possible collapse risks.
Erosive potential of abandoned sites will help choosing the most effective control methods and anticipate costs of their implementation. Lands with high erosion risk will therefore be less favored.

Watercourses:-

For environmental and safety reasons, in case of a landfill implantation, a distance of 100m must be excluded around water resources. The more remote areas are more preferred. This same distance was applied by (Sumathi *et al.*, 2008) and (Eskandari *et al.*, 2015).

Regarding water bodies, areas closest to water resources are favored. Pond filling is done either by a source, runoff (rainwater) or by diverting a stream. The last practice could disrupt aquatic wildlife and negatively impact the ecosystem. In this sense, closest distances to sources are favored. In the other hand, to facilitate the discharge of water bodies in the river and avoid additional costs in canal construction, buffer zones were created around watercourses with a preference of the nearest distances.

Groundwater characteristics play an extremely important role in soil mechanics (Hansbo, 1994) and should be considered before initiating foundation design and construction. Those characteristics concern the groundwater depth, recharge and corrosive potential, and may represent threats against buildings. Foundations can lose almost half of their load-bearing capacity, and compaction risks become more important and can be accompanied by loss of buildings' stability (Bergeron *et al.*, 1983). Conversely, urban development has a direct impact on groundwater quality and may increase pollutants level that undermine the human health and the environmental quality (Carmon *et al.*, 1997).

In order to provide sufficient security of buildings, the groundwater level must be at a distance of twice the width of the flange, or once the width of the raft (Bergeron *et al.*, 1983). In this view, to ensure the foundations' protection against humidity and avoid compaction risk and collapse, the most important values were assigned to areas with a low groundwater level.
According to information acquired, no recharge zone was identified in the study area.

Distance from roads is one of the most important parameters in urban planning (Mao, 2005). An existing road will save construction extra costs, and provides accessibility and ease of transport. In this respect, a distance of less than 100m is considered very favorable in the case of a construction or landfill implementation, with a preference of the nearest distances.
Regarding water bodies, a distance of 50m is discarded around the roads; Areas distant from urban elements are best suited for eco-tourism and give a natural look to the landscape. However, water bodies must remain accessible for public in case of creation of a promenade site.

Distance from agglomerations:-

A landfill cannot be installed near urban areas because of foul odors and traffic noise. Previous studies have recommended a minimum distance of 1000m from agglomerations to avoid odor pollution (Sener *et al.*, 2010; Eskandari *et al.*, 2013; Eskandari *et al.*, 2015). This same distance is applied in this study with a preference of remote areas.

Natural hazards include seismicity and flooding and concern the whole study area. Therefore, these two sub-criteria are discussed separately without integrating them in the AHP method. In fact, Akreuch Region is located in an area with acceleration approximately 10% of gravity, which does not require soil liquefaction analysis, while flooding represents a major issue in the region and some precautions must be taken during rehabilitation works.

Criterion standardization:-

The evaluation factors are generally non-commensurate. In order to make factors comparable, standardization is required. The latter offers a uniform suitability rating scale by assigning values to class boundaries of each factor.
According to criteria description, standardization of criteria was conducted. Table 4 shows the importance level for each sub-criterion, divided by alternatives and noted from 1 to 5. Highest values are the most significant and least important values are the least significant.

Table 4:- Criteria standardization

Criteria	**Sub-criteria**	**Alternative**	**Grading**				
			1	**2**	**3**	**4**	**5**
Topography	Slope	C	>15	10 - 15	8 - 10	4 - 8	0 - 4
		L	>20, <1	20 - 15	15 - 10	8 - 10	1 - 8
		R	>40	35 - 40	30 - 35	24 - 30	0 - 24
		W	>26, <2	20 - 26	14 - 20	8 - 14	2 - 8
	Exposure	C	N	NE	NW/E	W/SE/SW	S
		L	N	NW	W	NE/SW	S/SE/E
		R	S	SE/SW	E	W/NW/NE	N
Soil characteristics	Distance from faults	C	<120	120 - 200	200 - 500	500 - 1000	>1000
		L	<200	200 - 300	300 - 500	500 - 1000	>1000
		W	<50	50 - 60	60 - 70	70 - 80	>80
	Geotechnics	C	Vase	Marl / Clay	Alluvium / Conglomerates	Sandstone	Rocks
		L	Vase	Marl / Clay	Alluvium / Conglomerates	Sandstone	Rocks
		W	Vase	Marl / Clay	Alluvium / Conglomerates	Sandstone	Rocks
	Erosion	C	>35	30 - 35	20 - 30	7 - 20	<7
		L	>35	30 - 35	20 - 30	7 - 20	<7
		W	>35	30 - 35	20 - 30	7 - 20	<7
Water resources	Distance from watercourses	L	<100	100 – 250	250 - 500	500 - 1000	>1000
		W	>500	400 – 500	300 - 400	200 - 300	<200
	Distance from sources	L	<100	100-300	300 - 600	600 - 1000	>1000
		R	>600	500 – 600	400 - 500	300 - 400	<300
		W	>100	60 – 100	40 - 60	20 - 40	<20
	Groundwater depth	C	<10	10 - 20	20 - 30	30 - 40	>40
		L	<30	30 - 40	40 - 50	50 - 60	>60
		R	<5	-	-	-	>5
Socioeconomics	Distance from roads	C	>1000	500 – 1000	250 - 500	100 - 250	<100
		L	>1000	500 – 1000	250 - 500	100 - 250	<100
		W	>2000, <50	1000 – 2000	500- 1000	200 - 500	50 – 200
	Distance from agglomerations	L	<1000	1000 – 2000	2000 - 3000	3000 – 4000	>4000

C: Construction, L: Landfill, R: Revegetation, W: Waterbody

Development of weights:-

This step involves the construction of pairwise comparison matrices of sub-criteria according to the scale of Saaty (Saaty & Vargas, 1991); (Table 5). Pairwise comparison provides a rating for alternatives based on qualitative factors. The procedure focuses on two sub-criteria and their relation to each other. Their relative importance is rated by assigning a value between 2 and 9 and provides numerical judgments.

The value of 1 is assigned when both factors are equally important. This procedure is explained as follows:

w_{ij} is the quantitative judgment of the pair of sub-criteria,
C_i and C_j form a pair of sub-criteria,
If $W_{ij} = \alpha$, so $W_{ji} = 1/\alpha$, $\alpha \neq 0$

If C_i has a relatively equal importance to C_j, so $W_{ij}=1$, $W_{ji}=1$ and $W_{ii}=1$, for any i.

Admitting that W_i is the eigenvector of the matrix and n is the number of sub-criteria, the eigenvector can be calculated using the following formula:

$Wi = (\prod_{j-1}^{n} W_{ij})^{1/n}$ (Saaty, 1980)

Table 5:- Saaty's fundamental scale

Scale	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

The pairwise comparison of the various factors allows the construction of square matrices. The tables 6 to 9 represent these matrices.
Weights are obtained by the standardization of columns. The calculation is as follows:
W is the normalized eigenvector called Weight,

$W=\left|\frac{W_1}{\sum W_i} \frac{W_2}{\sum W_i} \frac{W_3}{\sum W_i} \dots \frac{W_n}{\sum W_i}\right|$ (Saaty, 1983)

The normalized eigenvector W allows calculating the index of consistency in the next step.

Table 6:- The comparison matrix for the "Construction" alternative

Sub-criteria «C»	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**Weight**
Slope (1)	1	9	1	3	5	3	7	**0,2799**
Exposure (2)	1/9	1	1/9	1/7	1/7	1/9	1/5	**0,0193**
Geotechnics (3)	1	9	1	5	5	5	7	**0,3335**
Distance from faults (4)	1/3	7	1/5	1	3	1	5	**0,1232**
Erosion (5)	1/5	7	1/5	1/3	1	1/3	3	**0,0727**
Groundwater depth (6)	1/3	9	1/5	1	3	1	5	**0,1293**
Distance from roads (7)	1/7	5	1/7	1/5	1/3	1/5	1	**0,0420**
Sum	3,12	47,00	2,85	10,68	17,48	10,64	28,20	**1**

Table 7:- The comparison matrix for the "Landfill" alternative

Sub-criteria «L»	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**Weight**
Slope (1)	1	3	1/7	1/5	1/3	1/7	1/5	1/7	1	1/5	**0,0241**
Exposure (2)	1/3	1	1/9	1/7	1/5	1/9	1/7	1/9	1/3	1/7	**0,0139**
Geotechnics (3)	7	9	1	5	5	1	5	3	7	7	**0,2424**
Distance from faults (4)	5	7	1/5	1	1	1/5	1/3	1/5	5	3	**0,0724**
Erosion (5)	3	5	1/5	1	1	1/5	1/3	1/5	3	1/3	**0,0492**
Groundwater depth (6)	7	9	1	5	5	1	5	3	7	7	**0,2424**
Distance from sources (7)	5	7	1/5	3	3	1/5	1	1/5	3	1	**0,0815**
Distance from watercourses (8)	7	9	1/3	5	5	1/3	5	1	7	7	**0,1794**
Distance from roads (9)	1	3	1/7	1/5	1/3	1/7	1/3	1/7	1	1/5	**0,0249**
Distance from agglomerations (10)	5	7	1/7	1/3	3	1/7	1	1/7	5	1	**0,0698**
Sum	41,33	60	3,47	20,88	23,87	3,47	18,34	8,14	39,33	26,88	**1**

Table 8:- **The comparison matrix for the "Revegetation" alternative**

Sub-criteria «R»	**(1)**	**(2)**	**(3)**	**(4)**	**Weight**
Slope (1)	1	1/5	1/7	1/3	**0,0569**
Exposure (2)	5	1	1/3	3	**0,2633**
Groundwater depth (3)	7	3	1	5	**0,5579**
Distance from sources (4)	3	1/3	1/5	1	**0,1219**
Sum	13,00	4,20	1,48	9,33	**1**

Table 9:- The comparison matrix for the "Water body" alternative

Sub-criteria «W»	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**Weight**
Slope (1)	1	1/3	5	7	5	5	9	**0,2683**
Geotechnics (2)	3	1	7	7	5	5	9	**0,3865**
Distance from faults (3)	1/5	1/7	1	3	1/3	1/3	5	**0,0632**
Erosion (4)	1/7	1/7	1/3	1	1/5	1/5	2	**0,0329**
Distance from watercourses (5)	1/5	1/5	3	5	1	1	7	**0,1138**
Distance from sources (6)	1/5	1/5	3	5	1	1	7	**0,1138**
Distance from roads (7)	1/9	1/9	1/5	1/2	1/7	1/7	1	**0,0215**
Sum	4,85	2,13	19,53	28,50	12,68	12,68	40,00	**1**

Calculating the Consistency Ratio:-

Previous steps allowed weights' calculation. The AHP method provides the ability to validate the reliability of the obtained results by calculating the consistency ratio. Indeed, a potential inconsistency may be due to an incoherent judgment between two or more factors. To ensure a logical relationship between data and facilitate the detection of defects, the consistency ratio was calculated following the procedure proposed by Saaty (Saaty, 1977):
RC=CI/RI (Saaty, 1977)

Where RI is the average of the resulting consistency index depending on the matrix given by Saaty, and CI is the consistency index expressed as follows:
$IC = (\lambda_{max} - n)/(n - 1)$(Saaty & Vargas, 1991)

Where λ_{max} the principal eigenvalue of the matrix, and n is the matrix order.

RI is defined by Saaty according to the scale presented in Table 10.

Table 10:- Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51

If the value of CR is less than 10%, the consistency of the matrix is considered acceptable (Saaty, 1980); otherwise, the pairwise comparison matrix must be revised.
The consistency ratio RC was calculated for the four alternatives (Table 11). Results obtained show the reliability of the analysis; all the RC values are less than10%.

Table 11:- Consistency Ratio calculation

Alternative	**Number of factors**	**CI**	**RI**	**RC=IC/CA**
C	7	0,11	1,32	8,1%
L	10	0,15	1,49	9,9%
R	4	0,04	0,90	4,4%
W	7	0,11	1,32	8,2%

C: Construction, L: Landfill, R: Revegetation, W: Water body

Results and discussion:-

The AHP method was used to evaluate the importance of criteria and sub-criteria for each alternative and check the consistency of the analysis. Table 12 shows the most significant criteria for each alternative.

Weights of factors related to construction:-

Soil characteristics are most important with a weight of 53%, and include geotechnical characteristics (34%), the distance from faults (12%) and the erosion rate (7%). The most representative sub-criteria are Geotechnics (34%) and Slope degree (28%). These sub-criteria limit technical contingencies that may arise during or after the receipt of a building.

Distance from roads and slope exposure are less important with respectively a weight of 4% and 2%. These two sub-criteria do not represent a potential for adverse effects on human life (geotechnical hazard for example) or affecting natural resources quality; this explains their low contribution to decision making in this case.
Distance from roads is a socioeconomic factor. It is taken into account to minimize implementation costs and ensure accessibility to the public. On the other hand, slope exposure can be considered as a comfort factor; Slopes with south orientation are the most appreciated as they allow benefiting of natural sunlight and provide a passive heat.

Weights of factors related to Landfill:-
Landfill site selection is primarily based on the criterion "Water resources" with a weight of 50%. Water resources concern the sub-criteria: Groundwater depth (24%), Distance from sources (8%) and Distance from watercourses (18%). Another sub-criterion is also important in this category: Geotechnics (24%). The importance of these sub-criteria lies in their impact on the water resources protection from possible contamination and their importance for human security. Indeed, a landfill site represents several risks related to natural resources contamination, construction activity, trucks movement, collapse or compaction, etc. Good site location allows geotechnical stability to the new landfill. This will reduce the likelihood of hazards and limit their severity in case of occurrence.

Table 12:- Synthesis of criteria weights

Criteria «C»	**Weight**	**Sub-criteria**	**Weight**
Topography	30%	Slope	28%
		Exposure	2%
Soil characteristics	53%	Geotechnics	34%
		Distance from faults	12%
		Erosion	7%
Water resources	13%	Groundwater depth	13%
Socioeconomics	4%	Distance from roads	4%

Criteria «L»	**Weight**	**Sub-criteria**	**Weight**
Topography	4%	Slope	3%
		Exposure	1%
Soil characteristics	36%	Geotechnics	24%
		Distance to faults	7%
		Erosion	5%
Water resources	50%	Groundwater depth	24%
		Distance from sources	8%
		Distance from watercourses	18%
Socioeconomics	10%	Distance from roads	3%
		Distance from agglomerations	7%

Criteria «R»	**Weight**	**Sub-criteria**	**Weight**
Topography	32%	Slope	6%
		Exposure	26%
Water resources	68%	Groundwater depth	56%
		Distance from sources	12%

Criteria «W»	**Weight**	**Sub-criteria**	**Weight**
Topography	27%	Slope	27%
Soil characteristics	48%	Exposure	39%
		Distance from faults	6%
		Erosion	3%
Water resources	23%	Distance from watercourses	12%
		Distance from sources	11%
Socioeconomics	2%	Distance from roads	2%

Weights of factors related to Revegetation:-
Revegetation is the least demanding in terms of criteria; only topography and water resources are taken into consideration with respectively a weight of 32% and 68%. This category is easier to achieve technically, and also the less requiring in terms of cost; it does not take into account geotechnical and socio-economical aspects.
The most critical sub criteria for this category are: Groundwater depth (56%) and Slope exposure (26%); the first sub-criterion avoids plants waterlogging that could occur at the presence of a shallow water table, and the second sub-criterion controls the degree of sun exposure.

The least significant sub-criteria for this category are the distance from sources having a weight of 16% and the slope degree with a weight of 6%. The proximity of a source facilitates watering young plants so they can develop their root systems. While slope degree is not of great importance; Gentle slopes are favorable for planting, but otherwise, and in case of steep slopes, using climbing species would be the right solution.

Weights of factors related to Water bodies:-
The water body category is mainly represented by Soil characteristics and Topography with respectively a weight of 48% and of 27%. These two criteria are the most critical; Geotechnics define whether ground materials are suitable for ensuring embankments stability and measuring their compaction degree, while topography limits the size of ponds and helps anticipating possible flooding.

The least decisive sub-criteria are Distance from roads and Erosion rate with respectively a weight of 2% and 3%.The distance from roads is considered to improve the aesthetic appearance of the water body, remove all anthropogenic pollution, and at the same time, ensuring public accessibility. These sub-criteria have no influence on the security and safety of surrounding populations.

Erosion rate is a representative factor in redevelopment project. However, site preparation for rehabilitation requires slope stability and quarries' securing. These operations will minimize erosion and issues arising from it.

Decisive factors in quarry rehabilitation:-
From this analysis, it can be concluded that factors having a direct impact on human security and natural resources quality were the most favored. The other sub-criteria were less decisive but should not be overlooked in such a redevelopment study. To better present these results, a criteria weighting for the different alternatives was performed (Table 13).

Table 13:- The most decisive criteria in quarry rehabilitation

Criteria	**Weight**	**Sub-criteria**	**Sum of weights**	**Weight**
Topography	23%	Slope	64%	16%
		Exposure	29%	7%
Soil characteristics	34%	Geotechnics	97%	24%
		Distance from faults	25%	6%
		Erosion	15%	4%
Water resources	39%	Groundwater depth	93%	23%
		Distance from watercourses	30%	8%
		Distance from sources	31%	8%
Socioeconomics	4%	Distance from roads	9%	2%
		Distance from agglomerations	7%	2%
Sum	**100%**		**400%**	**100%**

Table 13 shows great importance of Water resources (39%) followed by Soil characteristics (23%) and Topography (23%). The Socioeconomics criterion has a very low impact and shows a weight of 4%. The most influential sub-criteria are: Geotechnics (24%), followed by Groundwater depth (23%) and the Slope degree (16%). Weights of other sub-criteria do not exceed 8%.

Data exploration and processing using a GIS software:-
After obtaining criteria and sub-criteria weights, assessment indices were calculated for each alternative using the SAW method (Simple Additive Weighting). This method is based on the weighted average(Afshari *et al.*, 2010). An evaluation score is calculated for each alternative by multiplying the weight by the sub-criterion given scale. The addition of the resulting products is then performed. This procedure is expressed according to the following formula:

$A = \sum a_{i \times W_i}$ for i = 1,2,…,n (Churchman *et al.*, 1957)
A: Alternative assessment
w_i: Sub-criterion weight
a_i: Sub-criterion given scale
A GIS software following the SAW method and using the «Weighted Overlay» tool processed sub-criteria weights previously calculated. This process is repeated for each alternative separately to create suitability maps. The scale used, ranges from one to five and shows an ascending appreciation order: Unfavorable, Slightly favorable, moderately favorable, Favorable and Very favorable.
These steps have identified the best locations for each alternative in the abandoned quarries. These have been divided into two categories according to their material type.

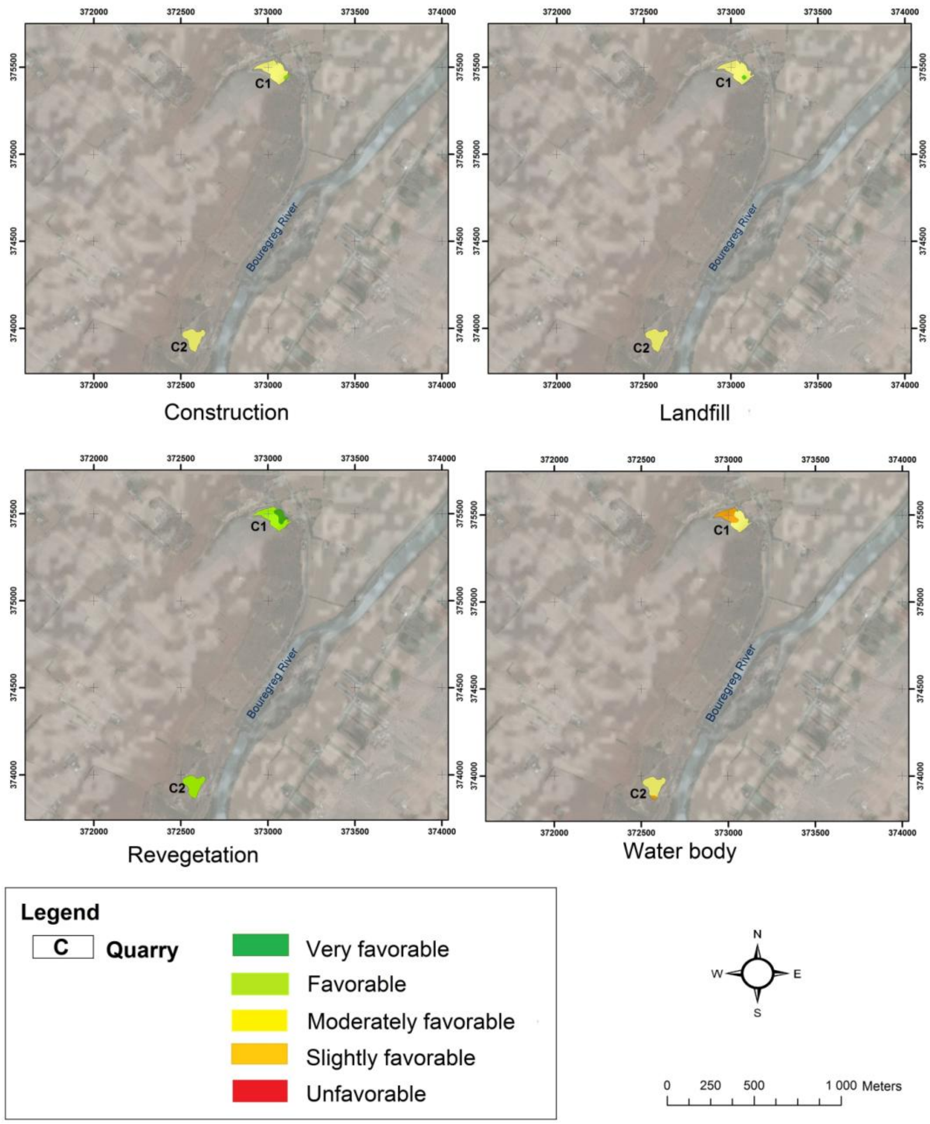

Figure 3:- Suitability map for marl quarries

Marl quarries:-

C1 and C2 quarries show a preference for "Revegetation" category (Favorable and Very favorable) with an average appreciation of other alternatives (Moderately favorable and slightly favorable). Rehabilitation by revegetation would therefore be the most reliable and least expensive in these quarries. Nevertheless, other alternatives could be adopted subject to incur additional implementation costs and anticipate more advanced engineering work.

From an environmental perspective, the implementation of a landfill in these quarries is not appropriate. The proximity of the Bouregreg River and Sidi Mohamed Ben Abdellah Dam makes the area very sensitive to pollution, and one of the most attractive areas for ecotourism projects. Further, that urban development of Rabat city may constitute a future conflict between the two entities (urbanization / landfill).

Results show moderately positive assessment for the categories Construction and Water body. This opens new redevelopment opportunities that could enhance the Bouregreg valley, in particular through social and economic projects. However, special focus should be put on flooding. Despite the establishment of protection systems by authorities, the valley is not immune. Indeed, studies carried out on the effects of the 100-year floodplain frequency in the Bouregreg valley have shown that in case of occurrence, and taking account of the dam heightening, the latter would pour a volume of 2000m^3/second of water into the valley (AAVB, 2003). These binding conditions underline the necessity of a backfilling above the maximum level of high water.

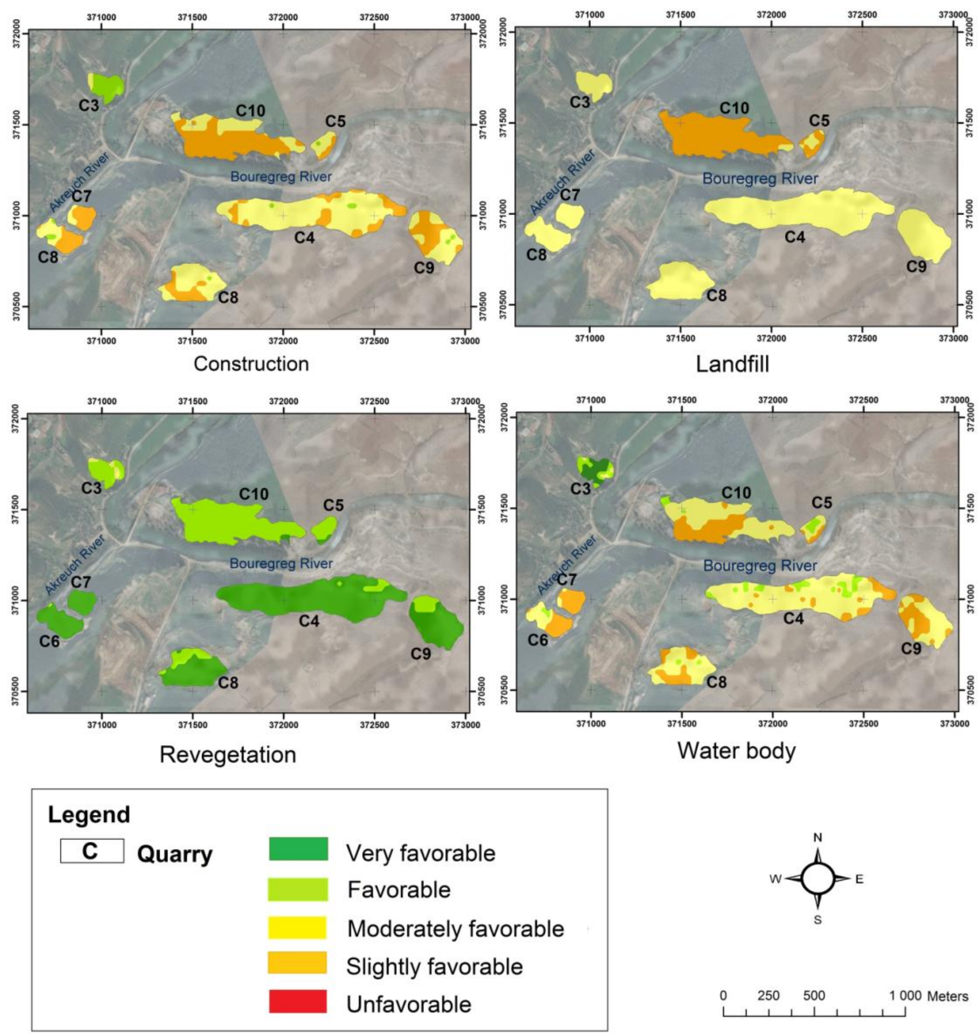

Figure 4:- Suitability map for limestone quarries

Limestone quarries:-

Limestone quarries are all favorable to rehabilitation by revegetation, but show differentiation in terms of other alternatives.

C3 quarry is very favorable for the creation of a water body, and favorable for construction and revegetation. It therefore offers a variety of choice to implement. The combination of two to three alternatives at once is also possible. Based on field visits, it has been noted that the quarry is of great geomorphological interest and can accommodate various activities.

C5 and C10 quarries are favorable for revegetation, and slightly or moderately favorable to rehabilitation by a landfill site, a water body or a construction. These quarries are located in a fractured zone with a piezometric level reaching 10m.Very steep slopes (up to 130%) and an elevation varying between 10m and 80m above sea level mark the topography. These circumstances make choosing another alternative difficult and costly.

It has understood that only the C3 quarry is the most favorable for establishing a development project unlike C4, C5, C6, C7, C8, C9 and C10 quarries. As in the case of C1 and C2 quarries, and for the same reasons, landfill installation must be avoided despite its classification as moderately favorable. Furthermore, an engineered structure (at least 1.4km of quarries) is been realized. It concerns the Bouregreg cable-stayed bridge, the largest in Africa with a length of 950 meters. The latter is part of the Rabat motorway bypass project and gives a view over the abandoned quarries of Akreuch.

Conclusion:-

Quarry rehabilitation is based on a multidisciplinary work requiring technical and regulatory knowledge and should be assessed throughout the quarry operations. In fact, rehabilitation during quarry operation is the most effective way to ensure its smooth integration in the natural environment while minimizing costs and ensuring environmental protection. Indeed, a coordinated redevelopment provides the opportunity to gradually reshape the quarry and at the same time take advantage of the topsoil availability. Late rehabilitation will be complex and costly.
In order to reconcile the negative impacts left by quarrying in the Akreuch region, and from an environmental protection perspective, this study is to propose remedial solutions that fit under the socioeconomic development of the region as well as the protection of natural resources.

Combining GIS and remote sensing approaches with multi-criteria method showed their complementarities to solve complex problems having multiple input data. Results obtained after applying these techniques have yielded consistent and logical solutions for abandoned quarries rehabilitation. It is found that rehabilitation through revegetation is the best way to limit environmental impacts of quarrying while other alternatives have shown varying levels of importance depending on sites characteristics. This analysis led to recommend and forecast the following points when planning the rehabilitation:

- Revegetation of C1, C2, C4, C5, C6, C7, C8, C9 and C10 quarries would be the most optimal solution;
- Rehabilitation of the C3 quarry by a pond to enjoy the morphology of the site and create a strolling zone;
- C1, C2 and C3 quarries can also accommodate socioeconomic projects to promote and develop the Akreuch Region. Nevertheless, backfilling sites would be expected to avoid any flooding risk;
- The establishment of a landfill site in one of the abandoned quarries is moderately favorable from a technical point of view but remains inadvisable to avoid degradation of water resources quality and prevent any visual pollution.

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