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Environmental Integrated Sustainable Development During and After Mining of Sedimentary Rocks

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Summary

Sedimentary rocks are used as aggregates in various construction applications. Mining of sedimentary rocks is a temporary activity that requires rehabilitation of the affected zones into different paths, all of which search for sustainable development in an integrated way. Some of applications include agriculture, cattle raising, forestry and artificial wetlands. The question remains in determining: What sort of application should be done and where? The answer follows many aspects that include: positioning of ground control points, developing of digital elevation models, placing meteorological stations, remote sensing, modelling analysis for water balance including evaluation of the actual evapotranspiration, atmospheric correction, geostatistics and multicriteria analysis. Successful pilot projects have been developed for various applications. The results from agriculture and dairy products have taken a further step in the research by using a green and low energy consumption technology defined as Confined Zeodratation, process that uses zeolite's properties as adsorbant and as molecular sieve for volatiles substances' recovery; allowing the preservation of antioxidants, vitamins, smells, flavours and other natural properties in the processed products. Confined Zeodratation has been tested in different fields such as food industry, pharmaceutical, cosmetics, gastronomy and recovery of wasted products such as fish skin, eggs and shrimp shells, and various fruit peels.

Introduction

Mining operations have been considered detrimental to the environment. However, mining is only a temporal use of land during and after which a reintegration should take place. The reintegration will considered restoration, rehabilitation or reaffectation. The former implies to leave the zone as close as it was before the intervention. Rehabilitation on the other hand, develops other land uses that benefit the zone in social, environmental and economic aspects, but it involves applications that have some relationship with what currently exists. The latter also improves the characteristics of the zone but it does not have any relationship with what existed before. In this research all aspects are considered. In the first scenario, once mining operations took place, grass for cattle raising are introduced, as well as native trees. In the second case, agriculture, forestry and wetlands either for fish production or for birds' habitat development are generated. For reaffectation the development of a new industry by means of Confined Zeodratation is used and tested in more than 1000 products for the last 5 years.

Two general objectives are considered during the research: one from an industrial point of view and other from a scientific perspective. The former is focused on the development of new economic activities parallel to mining operations, to provide more employment in the region and reduce the environmental impacts of mining operations. The latter is conducted to find integrated land uses and their optimal distribution at ¨Guasca ¨ Municipality during and after mining operations of sedimentary rocks and their regeneration to productive land towards Sustainable Development.

Multicriteria analysis is used to determine the optimal land distribution. Three major variables are determined by different methods and models. *Evapotranspiration* by means of Sebal and Sebs algorithms. *Lithology and depth* by means of Geostatistics and *Water* (surface and groundwater) characteristics by lumped models and VisualModflow.

Theory and/or Method

Evapotranspiration can be defined as the net water loss from the earth surface. The term involves two phenomena: Evaporation that represents a mass transfer from the ground to the atmosphere and Transpiration that refers to water loss from plants into the atmosphere through stomata opening (Bandara et al, 1998). Therefore, it has an influence in the hydrologic cycle and moreover in the Water Balance Process. For the multicriteria analysis, the more evapotranspiration is present, the less desirable for artificial wetlands applications and agricultural purposes, since more water will be required to maintain them.

The SEBAL (Surface Energy Balance Algorithm for Land) model is used to determine the evapotranspiration. This model is based upon the energy balance equation:

$R_n = G + H + LE$ (1) (Bastiaanssen, 1998)

Where R_n = Net radiation, G is the soil heat flux, H is the sensible heat flux and LE is the latent heat flux. These components are considered the principal energy sources that drive the land surface flux densities. Equation (1) neglects the energy required for photosynthesis and the heat storage in vegetation. The SEBAL model is a one-source modelling approach with various advantages, on one hand it does not discriminate soil and vegetation components and on the other, is based upon the estimation of spatial variability surface energy fluxes (French 2005). However, the determination of the dry and wet points is subjective and expertise dependent from the modeller. The information required to apply the formulas come from different sources: remote sensing, meteorological stations, regression analysis and relationships among the variables.

The SEBS (Surface Energy Balance System, Zu., 2007) model is also used to determine the evapotranspiration. This model is based upon the same energy balance equation; however, it involves some additional data and additional means of obtaining it. For the optical thickness for example, it is necessary to use a sun-photometer and calculate the different transmittances of various components in the atmosphere (Ozone, Rayleigh and Mie Scattering, Water Vapour and Gases).

For the subsoil characteristics data, Geoelectric Tomography information determined the lithology and depth of the layers to be studied. Various experimental variograms fits by means of Geostatistics were used. For the multicriteria analysis, considerable depth of sedimentary rocks, would mean more material to refill the zone, therefore more cost to implement agriculture and easier to create artificial wetlands.

The groundwater recharge is found by the information provided by the divers placed in some piezometers within the studied area. The direct runoff is inferred from the software STELLA and the application of the GWLF model (Generalized Watershed Loading Functions, Haith et al., 1992) in the hydrologic components. Such model (GWLF) calculates the daily runoff of a small to medium size urban-rural watershead using the SCS-CN method.

Since various artificial wetlands are needed to maintain the other applications such as agriculture, cattle raising and forestry, it is necessary to find out if there is any impact on the groundwater flow. Different scenarios of artificial wetlands in sizes and locations are analyzed by means of Visualmodflow as shown in the following figure:

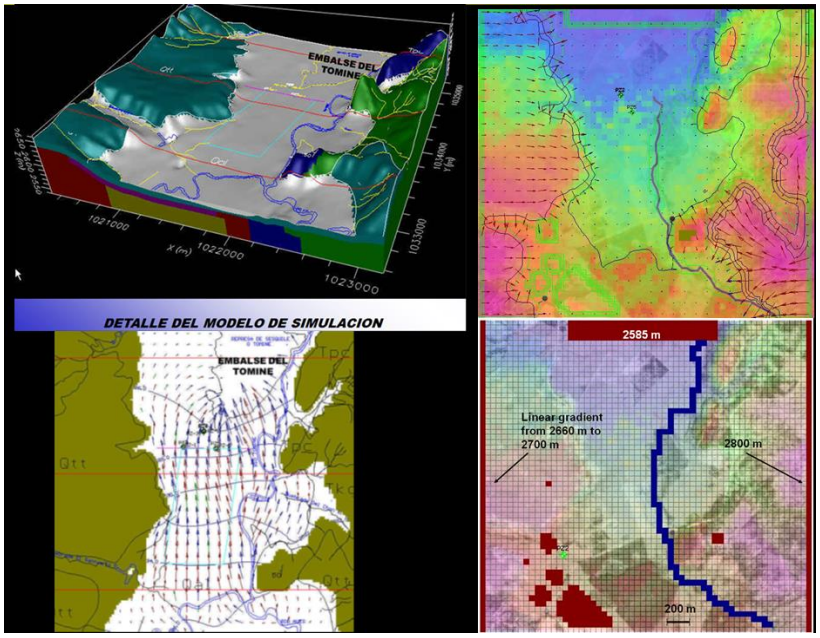


Figure 1. VisualModflow models in the studied zone

Examples

After combining the three main selection criteria (evapotranspiration, depth and lithology and water availability) to optimize the land use, the results show a preference for agriculture (46%) followed by Forestry (26%), Cattle Raising (20%) and wetlands (8%). It is important to mention that this distribution is without considering the development of a wetland of 50 Ha.

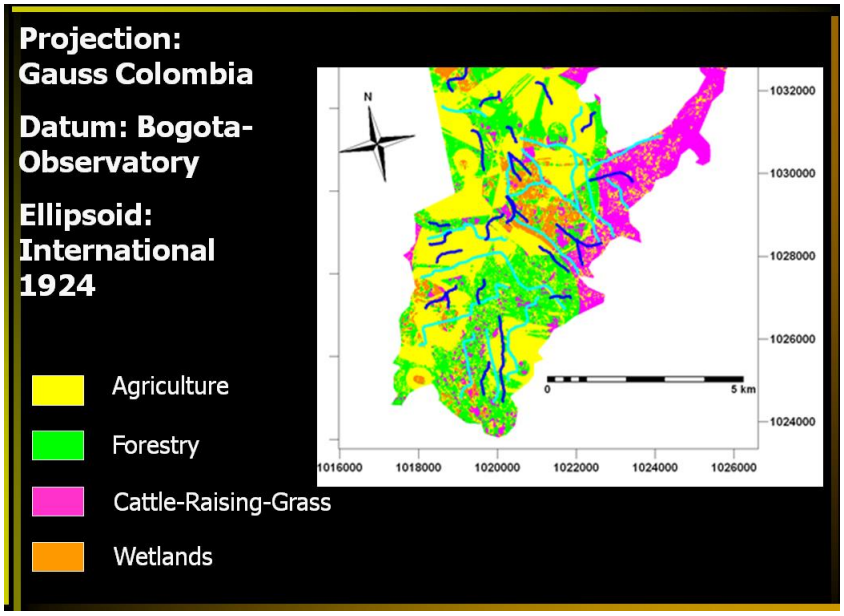


Figure 2. Multicriteria results over the studied zone

For the different land used applications, successful pilot projects have been developed over the years. For agriculture, different crops were implemented and organic certificates were obtained. For cattle raising, dairy products were produced such as yogurt, cheese and “dulce de leche”. For Forestry, native species and other species were analyzed to produce wood and for CO_2 capture. For wetlands the focus was given to the preservation of endemic species in danger of extinction (Tingua Bogotana) and other migratory birds. According to the Bogota’s Ornithology Association in 2011 more than 45 bird species were found in one of the artificial wetlands created in the study zone after mining operations.

Once the production took place, Confined Zeodratation technology was implemented. The equipment consists of a vacuum chamber, an owen, trays, zeolites, electronic equipment and software in order to dehydrate a variety of products used in pharmaceutical, cosmetics, gastronomy, agriculture, fish, dairy products and precooked food. The technology does not provide any harm to the environment. The waste products consist of water vapour and the zeolites that after a continuous use, they lose its “adsorbant” properties. The zeolites could be incorporated in a regular soil. Experiments show improvements in soil’s characteristics with zeolites.

The production consists of placing the product on a tray and introducing it in the vacuum chamber; depending upon the product, a cycle could last between 4 hours to 14 hours. The longer the time the less water available in the product and therefore the more time the product will last. The minimum time on average that a product can be preserved without adding any chemicals is 1 year. With an appropriate packing it could last even longer.

A typical Zeodratation curve is as follows:

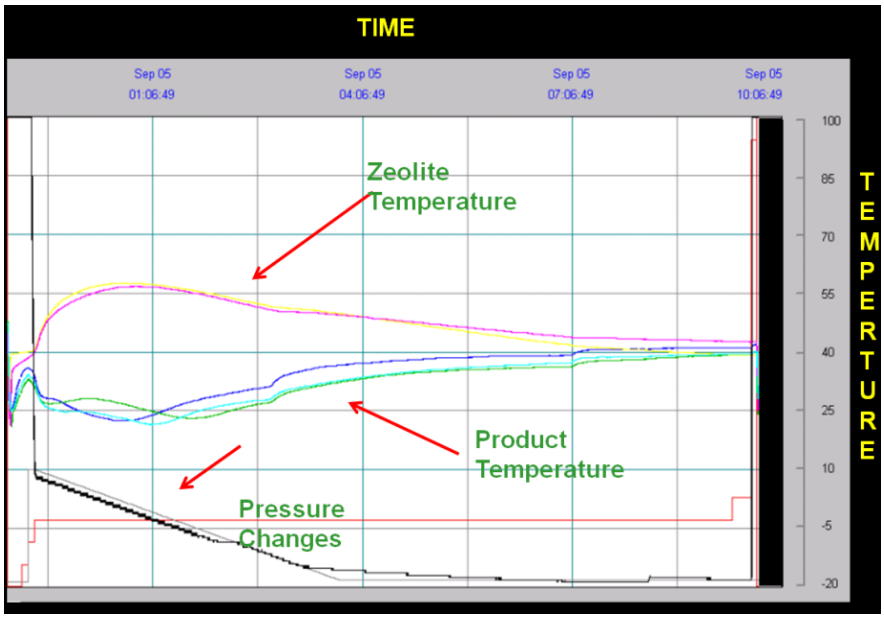


Figure 3. Typical Zeodratation curve

GiCaP Products Ltda has been engaged in the zeodratation process since 2008. More than 1000 products have been tried and some tested in various recognized laboratories from Colombia, USA and France. The participation of GiCaP Products Ltda in national and international exhibitions, as well as conferences and voluntary work around the world is opening an interest of such appropriate green technology. Export of the Mining products started in 2011 to the USA and in 2012 to France.

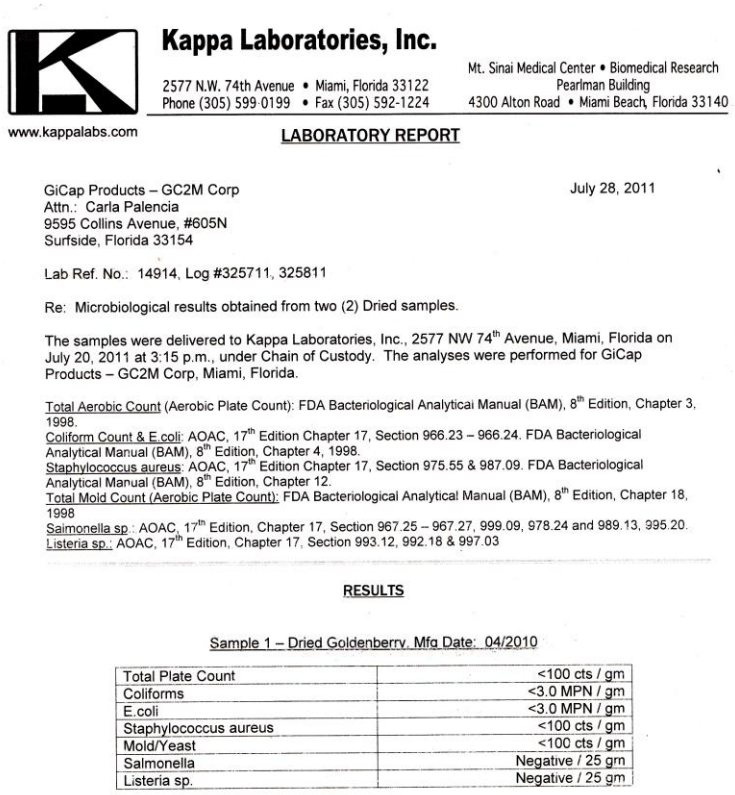
Some of the products are:

Figure 4. Zeodratated mining products with different packaging

Figure 5. Five day emergency food kit. Some of the products came from the rehabilitation of mining zones

Figure 6. Eggs, onions and tomatoes produced at the studied zone

Some of the lab results are as follows:



Kappa Laboratories, Inc.

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LABORATORY REPORT

GiCap Products – GC2M Corp
Attn.: Carla Palencia
9595 Collins Avenue, #605N
Surfside, Florida 33154

July 28, 2011

Lab Ref. No.: 14914, Log #325711, 325811

Re: Microbiological results obtained from two (2) Dried samples.

The samples were delivered to Kappa Laboratories, Inc., 2577 NW 74th Avenue, Miami, Florida on July 20, 2011 at 3:15 p.m., under Chain of Custody. The analyses were performed for GiCap Products – GC2M Corp, Miami, Florida.

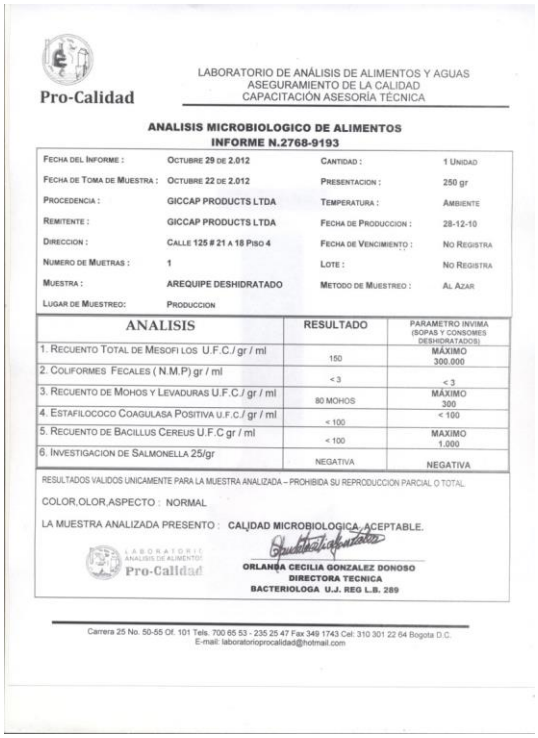
Total Aerobic Count (Aerobic Plate Count): FDA Bacteriological Analyticai Manual (BAM), 8th Edition, Chapter 3, 1998.
Coliform Count & E.coli: AOAC, 17th Edition Chapter 17, Section 966.23 – 966.24. FDA Bacteriological Analytical Manual (BAM), 8th Edition, Chapter 4, 1998.
Staphylococcus aureus: AOAC, 17th Edition Chapter 17, Section 975.55 & 987.09. FDA Bacteriological Analytical Manual (BAM), 8th Edition, Chapter 12.
Total Mold Count (Aerobic Plate Count): FDA Bacteriological Analytical Manual (BAM), 8th Edition, Chapter 18, 1998
Salmonella sp.: AOAC, 17th Edition, Chapter 17, Section 967.25 – 967.27, 999.09, 978.24 and 989.13, 995.20.
Listeria sp.: AOAC, 17th Edition, Chapter 17, Section 993.12, 992.18 & 997.03

RESULTS

Sample 1 – Dried Goldenberry, Mfg Date: 04/2010

Total Plate Count	<100 cts / gm
Coliforms	<3.0 MPN / gm
E.coli	<3.0 MPN / gm
Staphylococcus aureus	<100 cts / gm
Mold/Yeast	<100 cts / gm
Salmonella	Negative / 25 gm
Listeria sp.	Negative / 25 gm

Figure 7. Zeodratated Goldenberry (produced in mining fields) after 1 year without chemicals for preservation



Pro-Calidad

LABORATORIO DE ANÁLISIS DE ALIMENTOS Y AGUAS
ASEGURAMIENTO DE LA CALIDAD
CAPACITACIÓN ASESORÍA TÉCNICA

ANALISIS MICROBIOLOGICO DE ALIMENTOS
INFORME N.2768-9193

Fecha del Informe :	Octubre 29 de 2.012	Cantidad :	1 Unidad
Fecha de Toma de Muestra :	Octubre 22 de 2.012	Presentacion :	250 gr
Procedencia :	GICCAP PRODUCTS LTDA	Temperatura :	Ambiente
Remitente :	GICCAP PRODUCTS LTDA	Fecha de Produccion :	28-12-10
Direccion :	Calle 125 # 21 A 18 Piso 4	Fecha de Vencimiento :	No Registra
Numero de Muetras :	1	Lote :	No Registra
Muestra :	AREQUIPE DESHIDRATADO	Metodo de Muestreo :	Al Azar
Lugar de Muestreo:	Produccion		

ANALISIS	RESULTADO	PARAMETRO INVIMA (SOPAS Y CONSOMES DESHIDRATADOS)
1. Recuento Total de Mesofilos U.F.C./ gr / ml	150	MAXIMO 300.000
2. Coliformes Fecales (N.M.P) gr / ml	< 3	< 3
3. Recuento de Mohos y Levaduras U.F.C./ gr / ml	80 MOHOS	MAXIMO 300
4. Estafilococo Coagulasa Positiva U.F.C./ gr / ml	< 100	< 100
5. Recuento de Bacillus Cereus U.F.C gr / ml	< 100	MAXIMO 1.000
6. Investigacion de Salmonella 25/gr	NEGATIVA	NEGATIVA

RESULTADOS VALIDOS UNICAMENTE PARA LA MUESTRA ANALIZADA – PROHIBIDA SU REPRODUCCION PARCIAL O TOTAL

COLOR,OLOR,ASPECTO : NORMAL

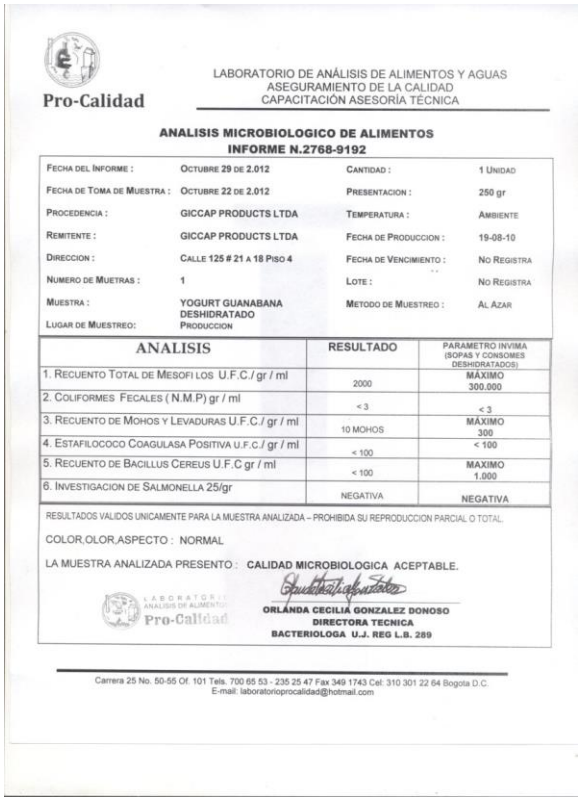
LA MUESTRA ANALIZADA PRESENTO : CALIDAD MICROBIOLOGICA ACEPTABLE.

Laboratorio de Analisis de Alimentos Pro-Calidad

ORLANDA CECILIA GONZALEZ DONOSO
DIRECTORA TECNICA
BACTERIOLOGA U.J. REG L.B. 289

Carrera 25 No. 50-55 Of. 101 Tels. 700 65 53 - 235 25 47 Fax 349 1743 Cel: 310 301 22 64 Bogota D.C.
E-mail: laboratorioprocalidad@hotmail.com

Figure 8. Zeodratated Dulce de leche after almost 2 years without chemicals for preservation



Pro-Calidad

LABORATORIO DE ANÁLISIS DE ALIMENTOS Y AGUAS
ASEGURAMIENTO DE LA CALIDAD
CAPACITACIÓN ASESORÍA TÉCNICA

ANALISIS MICROBIOLOGICO DE ALIMENTOS
INFORME N.2768-9192

Fecha del Informe :	Octubre 29 de 2.012	Cantidad :	1 Unidad
Fecha de Toma de Muestra :	Octubre 22 de 2.012	Presentacion :	250 gr
Procedencia :	GICCAP PRODUCTS LTDA	Temperatura :	Ambiente
Remitente :	GICCAP PRODUCTS LTDA	Fecha de Produccion :	19-08-10
Direccion :	Calle 125 # 21 A 18 Piso 4	Fecha de Vencimiento :	No Registra
Numero de Muetras :	1	Lote :	No Registra
Muestra :	YOGURT GUANABANA DESHIDRATADO	Metodo de Muestreo :	Al Azar
Lugar de Muestreo:	Produccion		

ANALISIS	RESULTADO	PARAMETRO INVIMA (SOPAS Y CONSOMES DESHIDRATADOS)
1. Recuento Total de Mesofi los U.F.C./ gr / ml	2000	MÁXIMO 300.000
2. Coliformes Fecales (N.M.P) gr / ml	< 3	< 3
3. Recuento de Mohos y Levaduras U.F.C./ gr / ml	10 MOHOS	MÁXIMO 300
4. Estafilococo Coagulasa Positiva U.F.C./ gr / ml	< 100	< 100
5. Recuento de Bacillus Cereus U.F.C gr / ml	< 100	MAXIMO 1.000
6. Investigacion de Salmonella 25/gr	NEGATIVA	NEGATIVA

RESULTADOS VALIDOS UNICAMENTE PARA LA MUESTRA ANALIZADA – PROHIBIDA SU REPRODUCCION PARCIAL O TOTAL.

COLOR,OLOR,ASPECTO : NORMAL

LA MUESTRA ANALIZADA PRESENTO : CALIDAD MICROBIOLOGICA ACEPTABLE.

LABORATORIO ANALISIS DE ALIMENTOS Pro-Calidad

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Figure 9. Zeodratated Yogurt after 2 years without chemicals for preservation

Comparing the Confined Zeodratation with other techniques it is found that the vitamins are better kept, as well as smells, as shown in the following figure:

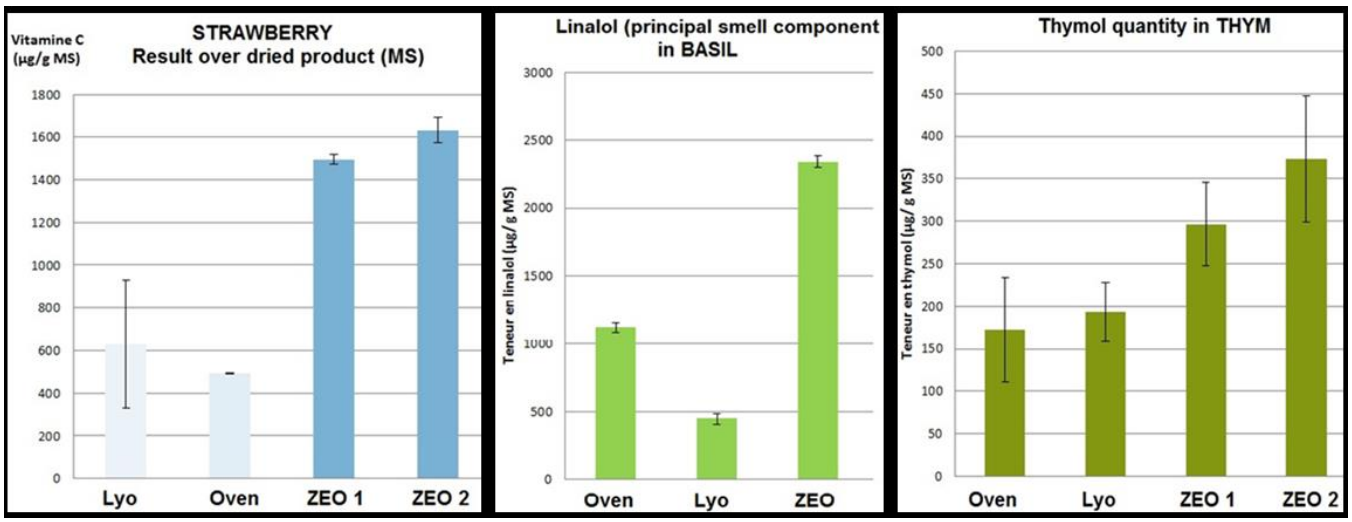


Figure 10. Comparison among Zeodratation and other techniques at certain products' characteristics

The positive impact of mining to the environment over the region was analyzed by means of remote sensing with Aster and Modis satellite images and the NDVI index. The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indexes not only because it is easy to obtain but also because it can determine biophysical vegetation parameters and understands the

transformation process over the surface of mining sites. It could also indicate the quantity of biomass (t/Ha) and the quality of vegetation (Kerle et all 2004). The index derives from the relationship between the surface reflectances averaged over the visible and near infrared regions of the spectrum (Jiang et all 2006, Liang 2004, Timmermans 1995) as follows:

$$NDVI = \frac{R_{nir} - R_{red}}{R_{nir} + R_{red}}$$

Where R_{nir} is the reflectance of the near infrared and R_{red} is the reflectance of the red in the visible spectrum. The reflectance of vegetation is low in the visible zone and the absorption is high (primarily because of the chlorophyll). The opposite occurs in the infrared zone where reflection and transmission are high while absorption is at minimum (Timmermans 1995, Verhoef 2000). It is precisely this difference of response at the studied wavelengths that allows characterizing the interest area.

The NDVI could vary between -1 and 1. For water the value is generally 0 or it could be even negative (Zhou at all 2007). NDVI less than 0.2 is selected as bare soil. NDVI between 0.2 and 0.5 is a mixture between bare soil and vegetation. NDVI greater than 0.5 is vegetation (Julien et all 2006). The higher the NDVI value, the greater the Fyto-mass, therefore, more photosynthetic activity in the studied zones (Timmermans 1995). The major pitfall of the index is the seasonal changes; yellowish leaves could be misled for bare soils. However, the studied zone does not have seasonal effects only the dry and wet seasons in a tropical area.

The NDVI was calculated with bands 2 and 3 of Aster images with 15 m resolution. The wavelengths in µm are as follows:

VNIR band 2	0.630-0.690
VNIR band 3N	0.760-0.860

The same procedure was used with Modis images from 2001 to 2008 and using the software Geomatica (PCI) combined with ILWIS. In a selected zone, the results are as follows:

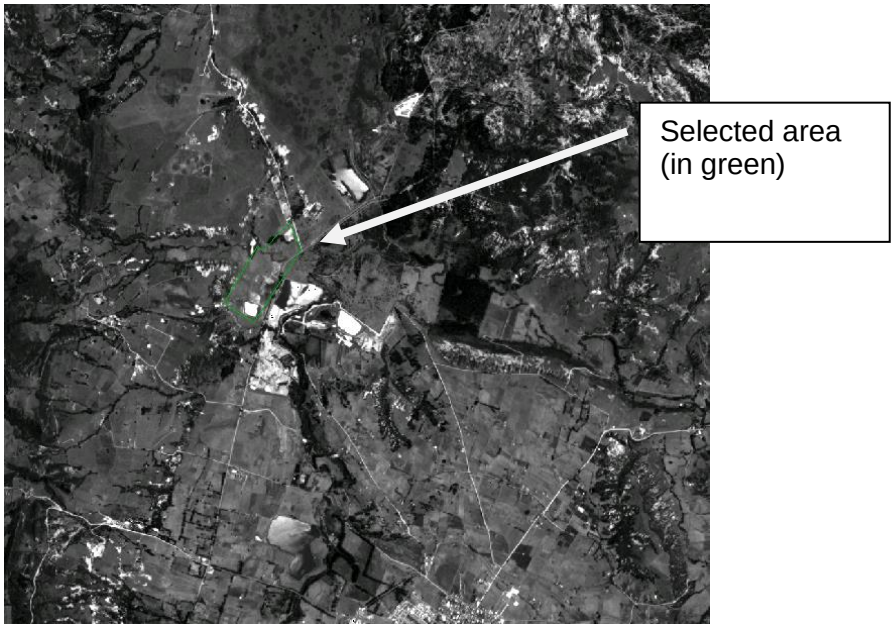


Figure 11. Selected studied zone for NDVI comparison

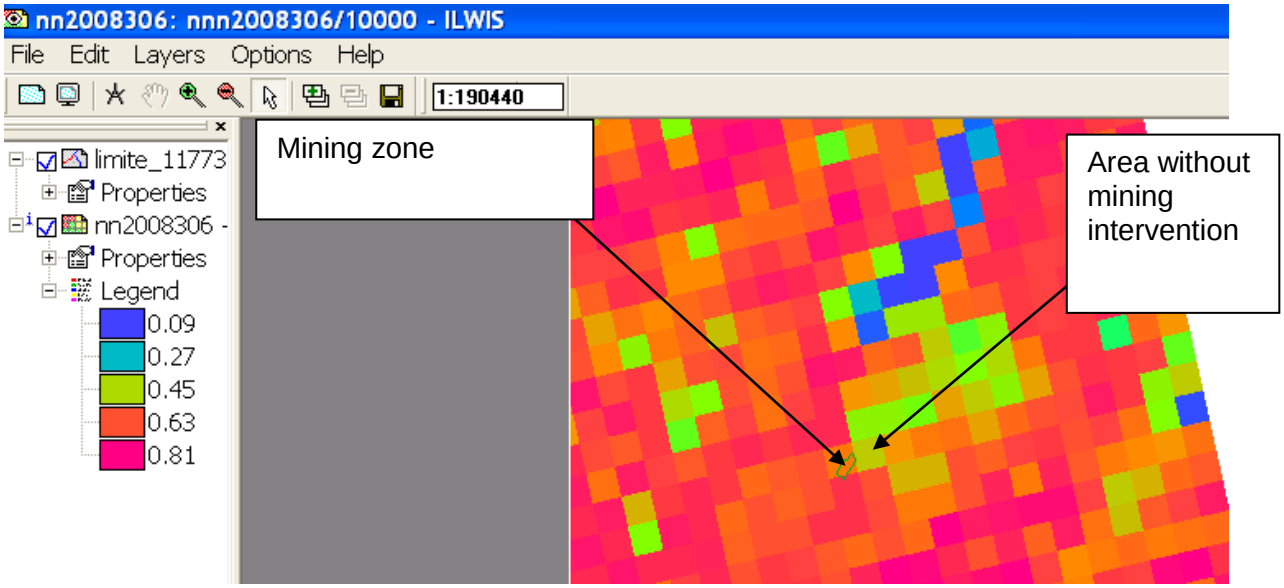


Figure 12. Selected Modis area

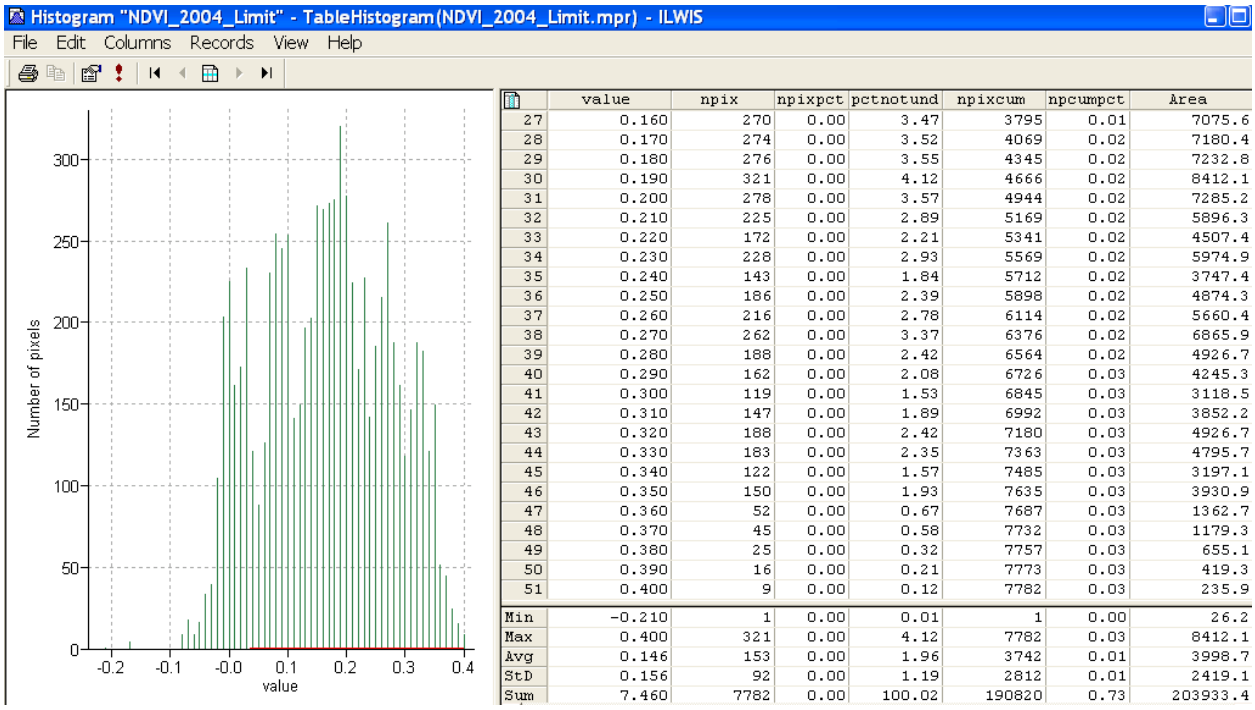
Year		January	February	March	April	May	June	July	August	September	October	November	December	Average	
2001	Mining Zone	0,57	0,47	0,52	0,52	0,65	0,53	0,57	0,44	0,44	0,50	0,52	0,64	Mining Zone	0,53
	Zone without intervention	0,50	0,42	0,47	0,48	0,58	0,43	0,47	0,24	0,50	0,50	0,56	0,51	Zone without intervention	0,47
Difference		0,07	0,05	0,05	0,04	0,07	0,10	0,10	0,20	-0,06	0,00	-0,04	0,13	Difference	0,06
2002	Mining Zone	0,62	0,54	0,47	0,63	0,42	0,68	0,74	0,75	0,64	0,64	0,65	0,61	Mining Zone	0,62
	Zone without intervention	0,50	0,47	0,44	0,57	0,58	0,58	0,61	0,66	0,53	0,53	0,58	0,51	Zone without intervention	0,55
Difference		0,12	0,07	0,03	0,06	-0,16	0,10	0,13	0,09	0,11	0,11	0,07		Difference	0,07
2003	Mining Zone	0,56	0,50	0,55	0,58	0,56	0,66	0,66	0,40	0,61	0,65	0,65	0,67	Mining Zone	0,59
	Zone without intervention	0,42	0,44	0,48	0,50	0,65	0,65	0,53	0,53	0,39	0,62	0,56	0,57	Zone without intervention	0,53
Difference		0,14	0,06	0,07	0,08	-0,09	0,01	0,13	-0,13	0,22	0,03	0,09	0,10	Difference	0,06
2004	Mining Zone	0,61	0,58	0,53	0,54	0,73	0,67	0,59	0,59	0,64	0,63	0,68	0,67	Mining Zone	0,62
	Zone without intervention	0,59	0,52	0,47	0,49	0,64	0,60	0,54	0,54	0,55	0,55	0,58	0,57	Zone without intervention	0,55
Difference		0,02	0,06	0,06	0,05	0,09	0,07	0,05	0,05	0,09	0,08	0,10	0,10	Difference	0,07
2005	Mining Zone	0,68	0,58	0,60	0,46	0,63	0,45	0,71	0,34	0,53	0,44	0,77	0,77	Mining Zone	0,58
	Zone without intervention	0,53	0,51	0,56	0,49	0,58	0,43	0,69	0,28	0,46	0,27	0,76	0,77	Zone without intervention	0,53
Difference		0,15	0,07	0,04	-0,03	0,05	0,02	0,02	0,06	0,07	0,17	0,01	0,00	Difference	0,05
2006	Mining Zone	0,71	0,63	0,72	0,72	0,75	0,64	0,60	0,65	0,70	0,53	0,41	0,60	Mining Zone	0,64
	Zone without intervention	0,66	0,58	0,61	0,70	0,76	0,58	0,52	0,53	0,57	0,62	0,53	0,57	Zone without intervention	0,60
Difference		0,05	0,05	0,11	0,02	-0,01	0,06	0,08	0,12	0,13	-0,09	-0,12	0,03	Difference	0,04
2007	Mining Zone	0,58	0,47	0,45	0,55	0,37	0,57	0,64	0,67	0,52	0,39	0,70	0,67	Mining Zone	0,55
	Zone without intervention	0,56	0,49	0,47	0,50	0,47	0,54	0,59	0,59	0,42	0,64	0,61	0,59	Zone without intervention	0,54
Difference		0,02	-0,02	-0,02	0,05	-0,10	0,03	0,05	0,08	0,10	-0,25	0,09	0,08	Difference	0,01
2008	Mining Zone	0,64	0,55	0,60	0,61	0,60	0,69	0,69	0,57	0,68	0,61	0,55		Mining Zone	0,62
	Zone without intervention	0,56	0,50	0,51	0,52	0,49	0,62	0,57	0,50	0,61	0,46	0,46		Zone without intervention	0,53
Difference		0,08	0,05	0,09	0,09	0,11	0,07	0,12	0,07	0,07	0,15	0,09	0	Difference	0,09

Figure 13. NDVI results from Mined and Non Mined zones

The results show that in all the years the average NDVI are greater for the mining zone than for the zone with no intervention. In the years 2006 and 2007 some land preparation took place and NDVI for certain months were lower. Interesting to see major average differences of NDVI that took place in 2008 (0.09); at that time, agriculture was changed to organic production. The importance of implementing organic agriculture could also be proven by the Vitamin A content in Goldenberry production for the same area. In 2006 the Vitamin A content was 644 U.I/100 g. For 2008, the value increased to 2157 UI/100g. And even more interesting to see how the Confined Zeodratation for the same product almost triples the Vitamin A and C content.

The results for ASTER images to compare the impact of mining over a non-intervened zone based upon histograms are as follows:

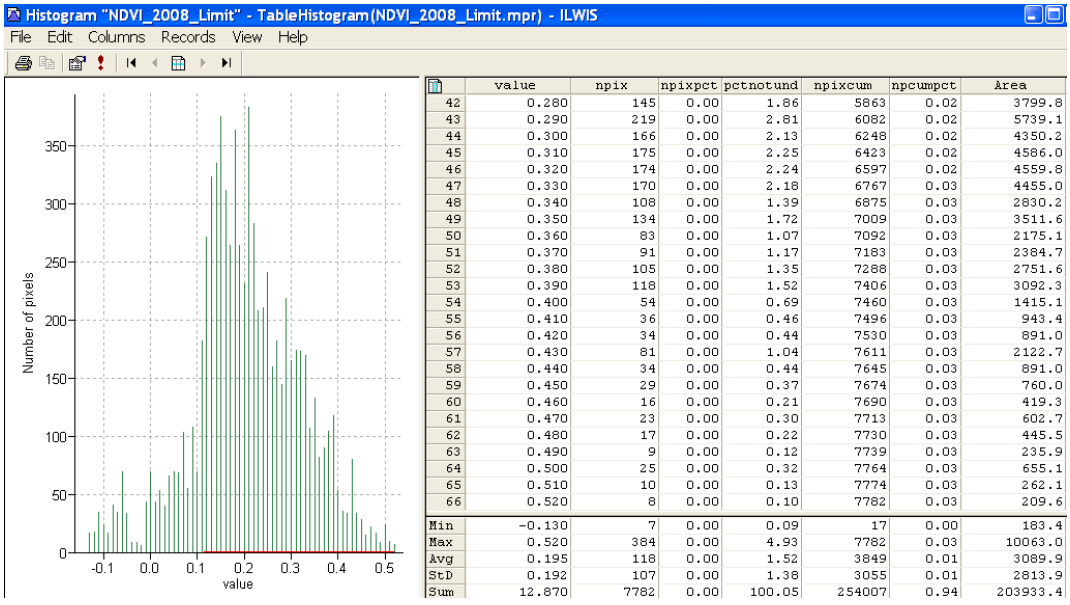
For February 8 2004



	value	npix	npixpct	pctnotund	npixcum	npcumpct	Area
27	0.160	270	0.00	3.47	3795	0.01	7075.6
28	0.170	274	0.00	3.52	4069	0.02	7180.4
29	0.180	276	0.00	3.55	4345	0.02	7232.8
30	0.190	321	0.00	4.12	4666	0.02	8412.1
31	0.200	278	0.00	3.57	4944	0.02	7285.2
32	0.210	225	0.00	2.89	5169	0.02	5896.3
33	0.220	172	0.00	2.21	5341	0.02	4507.4
34	0.230	228	0.00	2.93	5569	0.02	5974.9
35	0.240	143	0.00	1.84	5712	0.02	3747.4
36	0.250	186	0.00	2.39	5898	0.02	4874.3
37	0.260	216	0.00	2.78	6114	0.02	5660.4
38	0.270	262	0.00	3.37	6376	0.02	6865.9
39	0.280	188	0.00	2.42	6564	0.02	4926.7
40	0.290	162	0.00	2.08	6726	0.03	4245.3
41	0.300	119	0.00	1.53	6845	0.03	3118.5
42	0.310	147	0.00	1.89	6992	0.03	3852.2
43	0.320	188	0.00	2.42	7180	0.03	4926.7
44	0.330	183	0.00	2.35	7363	0.03	4795.7
45	0.340	122	0.00	1.57	7485	0.03	3197.1
46	0.350	150	0.00	1.93	7635	0.03	3930.9
47	0.360	52	0.00	0.67	7687	0.03	1362.7
48	0.370	45	0.00	0.58	7732	0.03	1179.3
49	0.380	25	0.00	0.32	7757	0.03	655.1
50	0.390	16	0.00	0.21	7773	0.03	419.3
51	0.400	9	0.00	0.12	7782	0.03	235.9
Min	-0.210	1	0.00	0.01	1	0.00	26.2
Max	0.400	321	0.00	4.12	7782	0.03	8412.1
Avg	0.146	153	0.00	1.96	3742	0.01	3998.7
StD	0.156	92	0.00	1.19	2812	0.01	2419.1
Sum	7.460	7782	0.00	100.02	190820	0.73	203933.4

Figure 14. Histogram of Aster image and NDVI values of selected studied zone for 2004

For February 3 2008



	value	npix	npixpct	pctnotund	npixcum	npcumpct	Area
42	0.280	145	0.00	1.86	5863	0.02	3799.8
43	0.290	219	0.00	2.81	6082	0.02	5739.1
44	0.300	166	0.00	2.13	6248	0.02	4350.2
45	0.310	175	0.00	2.25	6423	0.02	4586.0
46	0.320	174	0.00	2.24	6597	0.02	4559.8
47	0.330	170	0.00	2.18	6767	0.03	4455.0
48	0.340	108	0.00	1.39	6875	0.03	2830.2
49	0.350	134	0.00	1.72	7009	0.03	3511.6
50	0.360	83	0.00	1.07	7092	0.03	2175.1
51	0.370	91	0.00	1.17	7183	0.03	2384.7
52	0.380	105	0.00	1.35	7288	0.03	2751.6
53	0.390	118	0.00	1.52	7406	0.03	3092.3
54	0.400	54	0.00	0.69	7460	0.03	1415.1
55	0.410	36	0.00	0.46	7496	0.03	943.4
56	0.420	34	0.00	0.44	7530	0.03	891.0
57	0.430	81	0.00	1.04	7611	0.03	2122.7
58	0.440	34	0.00	0.44	7645	0.03	891.0
59	0.450	29	0.00	0.37	7674	0.03	760.0
60	0.460	16	0.00	0.21	7690	0.03	419.3
61	0.470	23	0.00	0.30	7713	0.03	602.7
62	0.480	17	0.00	0.22	7730	0.03	445.5
63	0.490	9	0.00	0.12	7739	0.03	235.9
64	0.500	25	0.00	0.32	7764	0.03	655.1
65	0.510	10	0.00	0.13	7774	0.03	262.1
66	0.520	8	0.00	0.10	7782	0.03	209.6
Min	-0.130	7	0.00	0.09	17	0.00	183.4
Max	0.520	384	0.00	4.93	7782	0.03	10063.0
Avg	0.195	118	0.00	1.52	3849	0.01	3089.9
StD	0.192	107	0.00	1.38	3055	0.01	2813.9
Sum	12.870	7782	0.00	100.05	254007	0.94	203933.4

Figure 15. Histogram of Aster image and NDVI values of selected studies zone for 2008

The results indicate that for 2004 the average NDVI was 0.146 (including artificial wetlands). For 2008 the average NDVI was 0.195 (low values, but still positive results). For vegetation and bare soil alone, the maximum NDVI for 2004 was 0.4 and for 2008 it was 0.52, showing that mining intervention acted positively over the zone.

Conclusions

Mining of sedimentary rocks had improved the characteristics of the zone in different aspects, it developed new job opportunities, generated new industries, added aggregate value to the products, increased the eco-tourism and contributed to scientific research in various applications, all of which are possible to be introduced at Guasca Municipality and proved to be sustainable by the pilot projects executed.

Based upon remote sensing indicators it is possible to determine quantitatively the positive impact of mining in the studied zone. Examples show an increment in NDVI values for agriculture, during the reintegration programs that had been taken place over the years.

Determination of optimal land use during and after mining operations is a tool to develop models that facilitates decision making and that could be implemented in other mining operations with some adjustments according to the characteristics of the zone and the type of mineral.

This integrated mining project allows developing an industrial symbiosis towards sustainable development with environmental consciousness and social responsibility.

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