Programa de Doctorado en Medio Ambiente y Sostenibilidad

Correcciones y restauración de espacios mineros de materiales destinados a la construcción

M.ª Ángeles Peñaranda Barba

Director de la tesis

Dr. D. Ignacio Gómez Lucas

Codirectora de la tesis

Dra. Dña. Virginia Alarcón Martínez

Universidad Miguel Hernández de Elche

- 2024 -

TESIS POR COMPENDIO DE PUBLICACIONES

La presente Tesis Doctoral, titulada "**Correcciones y restauración de espacios mineros de materiales destinados a la construcción**", se presenta bajo la modalidad de **tesis por compendio** de las siguientes **publicaciones**:

- **Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Methods of soil recovery in quarries of arid and semiarid areas using different waste types. Span. J. Soil Sci. 2020, 2, 101–122.** DOI: 10.3232/SJSS.2020.V10.N2.01
  Indicios de calidad: SJR (Scimago Journal Rank): Q3 Soil Science

- **Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas. Glob. J. Environ. Sci. Manag. 2021, 7, 565–586.**
  https://doi.org/10.22034/gjesm.2021.04.06
  Indicios de calidad: SJR (Scimago Journal Rank): Q1 Agricultural and Biological Sciences / Q2 Environmental Engineering / Q2 Environmental Science (miscellaneous) / Q2 Pollution / Q2 Social Sciences (miscellaneous) / Q2 Waste Management and Disposal

- **Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Restoration Techniques Applied in Open Mining Area to Improve Agricultural Soil Fertility. Agriengineering. 2023, 5, 1599-1613.**
  https://doi.org/10.3390/agriengineering5030099
  Indicios de calidad: SJR (Scimago Journal Rank): Q2 Agronogy and Crop Science / Q2 Engineering (miscellaneous) / Q2 Food Science / Q2 Hortoculture

El Dr. D. *"Ignacio Gómez Lucas"*, director, y la Dra. Dña. *"Virginia Alarcón Martínez"*, codirectora de la tesis doctoral titulada **"Correcciones y restauración de espacios mineros de materiales destinados a la construcción"**

INFORMAN:

Que D./Dña. *"M.ª Ángeles Peñaranda Barba"* ha realizado bajo nuestra supervisión el trabajo titulado **"Correcciones y restauración de espacios mineros de materiales destinados a la construcción"** conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo al Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmamos para los efectos oportunos, en Elche a 15 de enero de 2024.

Director de la tesis　　　　　　Codirectora de la tesis

Dr. D. ''*Ignacio Gómez Lucas"*　　　　　　Dra. Dña. *"Virginia Alarcón Martínez"*

El Dr. D. José Navarro Pedreño, Coordinadora del Programa de Doctorado en **Medio Ambiente y Sostenibilidad.**

INFORMA:

Que Dña. *"M.ª Ángeles Peñaranda Barba"* ha realizado bajo la supervisión de nuestro Programa de Doctorado el trabajo titulado **"Correcciones y restauración de espacios mineros de materiales destinados a la construcción"** conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo al Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmo para los efectos oportunos, en Elche a 15 de enero de 2024.

Prof. Dr. D. José Navarro Pedreño

Coordinador del Programa de Doctorado en Medio ambiente y sostenibilidad.

AGRADECIMIENTOS

Tras un largo camino lleno de obstáculos, desafíos y situaciones complicadas, aunque también lleno de alegría y de aprendizaje que han puesto a prueba mi fortaleza y determinación, por fin he llegado al final de esta tesis doctoral. Me quedo con la frase que dijo William Arthur Ward, 'Estar agradecido y no mostrarlo, es como tener un regalo y no entregarlo', por esto me gustaría agradecer en este apartado a todas las personas que han hecho que esta tesis sea posible.

Gracias a Raúl, mi compañero de vida, mi apoyo incondicional, que ha estado a mi lado en todo momento, especialmente en los más complicados y me ha ayudado tanto en todos los aspectos de mi vida. Gracias a mis hijos, Izan y Martín, por soportar tantos momentos que no han podido compartir conmigo y porque solo por existir, me han dado fuerzas para continuar, ser constante y valiente.

Gracias, a mi padre y a mi madre, que me dieron siempre todo lo que necesité, que me han enseñado a salir adelante y a no rendirme y por todo el apoyo que me han dado siempre en todos los ámbitos de mi vida que han hecho que fuera posible llegar hasta dónde estoy hoy.

Gracias a Virginia, mi gran amiga y codirectora de esta tesis, por embarcarme en este camino, sin ella no me hubiera planteado realizar esta tesis, y gracias por toda la ayuda que me ha prestado en todo momento.

Gracias a Jose y a Ignacio, tutor y director se esta tesis, por ayudarme todos estos años, por aportar todo su conocimiento y por estar ahí cuando los he necesitado.

Finalmente, quiero dar las gracias a todos mis familiares y amigos y a aquellas personas que han contribuido de alguna manera en esta tesis, ya sea con sus conocimientos, consejos o simplemente su amistad.

ÍNDICE

Listado de abreviaturas

UE: Unión Europea

EIA: evaluación de impacto ambiental.

EsIA: estudio de impacto ambiental.

RSU: residuos sólidos urbanos.

CIC: capacidad de intercambio catiónico.

Listado de figuras

Listado de tablas

1. Resumen

La minería a cielo abierto provoca impactos ambientales negativos en el medio ambiente. En la Región de Murcia, así como en otras zonas mediterráneas con clima árido o semiárido, existe una gran actividad minera ligada al sector de la construcción, en la que se utiliza roca ornamental y áridos calizos. Todo esto ha dado lugar a numerosas antiguas explotaciones mineras abandonadas en las que no se ha llevado a cabo un proceso de restauración, y, por tanto, ha generado importantes impactos en regiones naturales y rurales. Actualmente, las legislación europea y española sobre EIA exige que se lleve a cabo un plan de restauración en las explotaciones mineras y la aplicación de residuos puede ser una buena solución para rehabilitar los ecosistemas, además, con su utilización se contribuye a eliminar el problema de la cantidad de residuos que existen. En esta tesis se han buscado técnicas para la rehabilitación de estos espacios mineros; se han evaluado los diferentes impactos ambientales en este tipo de canteras y; se han evaluado a corto (dos y cuatro meses desde su incorporación al suelo) y medio plazo (nueve meses), diferentes enmiendas aplicadas (abono inorgánico de uso común N-K-P, purines de cerdo, restos de poda y residuos sólidos urbanos) en una zona de restauración de canteras de la Región de Murcia. En base a lo anterior, se han encontrado varias técnicas exitosas utilizando residuos para rehabilitar estas zonas mineras y, además, se han propuesto medidas preventivas y correctoras basadas en diagramas de flujo para mitigar los impactos ambientales y evitar que se generen daños significativos o irreversibles en el medio ambiente, todo ello cumpliendo perfectamente con la economía circular y la estrategia residuo cero. Además, los resultados muestran como con la aplicación de los tratamientos utilizados se incrementan los macronutrientes (N, P, K, Na, Ca y Mg) y micronutrientes (Fe y Cu) del suelo.

2. Abstract

Open pit mining causes negative environmental impacts on the environment. In the Region of Murcia, as well as in other Mediterranean areas with an arid or semi-arid climate, there is a large mining activity linked to the construction sector, in which ornamental rock and limestone aggregates are used. All of this has given rise to numerous old abandoned mining operations in which no restoration process has been carried out, and, therefore, has generated significant impacts on natural and rural regions. Currently, European and Spanish legislation on EIA requires that a restoration plan be carried out in mining operations and the application of waste can be a good solution to rehabilitate ecosystems, in addition, its use contributes to eliminating the problem of the amount of waste that exists. In this thesis, techniques have been sought for the rehabilitation of these mining spaces; The different environmental impacts in this type of quarries have been evaluated and; Different applied amendments (commonly used inorganic fertilizer N-K-P, pig slurry, pruning remains and urban solid waste) have been evaluated in the short (two and four months from its incorporation into the soil) and medium term (nine months) in an area. restoration of quarries in the Region of Murcia. Based on the above, several successful techniques have been found using waste to rehabilitate these mining areas and, in addition, preventive and corrective measures based on flow diagrams have been proposed to mitigate environmental impacts and prevent significant or irreversible damage from being generated in the environment, all perfectly complying with the circular economy and the zero waste strategy. Furthermore, the results show how with the application of the treatments used, macronutrients (N, P, K, Na, Ca and Mg) and micronutrients (Fe and Cu) of the soil increase.

1. Introducción

La minería a cielo abierto es una actividad importante para el desarrollo de la sociedad humana, pues, mejora la calidad de vida de los habitantes y genera un beneficio social y económico a la población (Zhu et al., 2017; De Silva et al., 2018; Xiang et al., 2021). Al mismo tiempo, la minería genera un gran impacto ambiental en los ecosistemas y en el medio ambiente (Sort and Alcañiz, 1996; Sheoran et al., 2010; Chatuverdi and Singh, 2017), y, además, puede afectar a las condiciones de salud de la población circundante. El nivel de destrucción causado por la minería a cielo abierto, es diez veces mayor que el causado por otros tipos de minería (Zhou et al., 2018). Una de las principales fuentes de impacto se deriva del abandono de las canteras a cielo abierto sin realizar ninguna rehabilitación o recuperar su estado inicial (Khabali and Kamal, 2013). Entre los impactos más importantes que produce este tipo de minería está: altera la morfología de la corteza terrestre, contamina el aire, el suelo, y las aguas superficiales y subterráneas, elimina la flora y destruye el biotipo, altera los hábitats de los animales y hace daño a la biodiversidad, además, provocan modificaciones en el paisaje con la consecuente degradación del mismo (Jing et al., 2018; Luo et al., 2018; Sonter et al., 2018; Liu et al., 2019; Carabassa et al., 2020; Macci et al., 2020; Opekunova et al., 2020; Wang et al., 2020; Asyakina et al, 2021; Daraz et al., 2022; Atuchin et al., 2023). En los climas áridos y semiáridos, y en particular, en los ecosistemas mediterráneos, el problema de degradación ambiental se agrava, debido a la escasez de agua y a los episodios de precipitaciones torrenciales, la elevada radiación solar y la escasa cobertura vegetal que favorece los procesos de erosión (Peñaranda et al., 2021). Minimizar los impactos ambientales es clave para la sostenibilidad en la minería (Yildiz, 2020), es por ello que se debe garantizar que las consideraciones ambientales se expresen e incluyan explícitamente en el proceso de toma de decisiones a la hora de iniciar una explotación para así, anticipar y evitar, y minimizar y compensar los efectos negativos sobre el medio ambiente (Mora-Barrantes et al., 2016). Para lograr una minería más verde y con menos impactos, España creó la Ley 21, (2013), de evaluación ambiental, modificada por la Ley 9 (2018), en dónde se indica que realizar una evaluación de impacto ambiental es esencial para la protección del medio ambiente. Esta Ley, es una adaptación a la legislación existente de la UE. La Ley, facilita la incorporación de criterios de sostenibilidad en la toma de decisiones estratégicas y garantiza una adecuada prevención de los impactos ambientales que puedan generarse, al tiempo que establece mecanismos de corrección o compensación del daño, cuya eficacia depende del tipo y características de la actividad.

En la Región de Murcia, la explotación de los recursos geológicos siempre ha estado ligada a la extracción de minerales y rocas. En concreto, está representada por la extracción de mármol, caliza marmórea y áridos calizos, que son utilizados por las empresas constructoras en múltiples aplicaciones (Peñaranda et al., 2021). Existen canteras en todo el territorio de la Región de Murcia, aunque destaca la zona del Noroeste y la cuenta de Mula por la variedad de roca ornamental, y la zona de Fortuna-Abanilla por la cantidad de áridos calizos. La importancia que tiene y ha tenido esta actividad, especialmente en los siglos XIX y XX, ha dejado algunos espacios mineros que deberían ser objeto de una política medioambiental, como la sierra minera de Cartagena.

Actualmente, la normativa minera exige la realización de un plan de restauración antes del inicio de la explotación con el fin de prevenir o reducir los posibles efectos adversos sobre el medio ambiente y la salud provocados por la actividad minera, y establecer las medidas correctoras y preventivas necesarias para que estos impactos no se produzcan o que afecten en menor medida al medio ambiente. Además, el terreno deberá ser rehabilitado una vez finalizada la explotación (Peñaranda et al. 2020). La Directiva 2006/21/CE, sobre la gestión de residuos de industrias extractivas, exige la rehabilitación de las zonas en las que exista instalaciones de residuos mineros. En España, esta directiva se desarrolla por el Real Decreto 975/2009, de 12 de junio, sobre gestión de residuos de las industrias extractivas y de protección y rehabilitación del espacio afectado por actividades mineras, que tiene por objeto el establecimiento de medidas, procedimientos y orientaciones para prevenir o reducir en la medida de lo posible los efectos adversos que sobre el medio ambiente y los riesgos para la salud humana que pueden producir la investigación y aprovechamiento de los yacimientos minerales y demás recursos geológicos, y, fundamentalmente, la gestión de los residuos mineros. La restauración y la rehabilitación se encuentran entre las medidas más importantes, ya que con estas técnicas se conseguiría integrar la explotación en el entorno paisajístico y ecológico, y se podría destinar el terreno para otro uso, una vez finalizada la explotación (Escribano and Mataix, 2007).

Existen abundantes explotaciones en las que no se ha llevado a cabo un proceso de restauración y han sido abandonadas, además, existen muchas otras en las que no se ha conseguido una rehabilitación exitosa del suelo. Por tanto, la rehabilitación de estas áreas, es un desafío para mejorar la recuperación del suelo y del paisaje y combatir el calentamiento global. Los ecosistemas áridos y semiáridos cubren una superficie importante del planeta, alrededor del 45% (Bastin et al., 2017), y se espera que aumenten en el futuro debido a los efectos negativos del cambio climático. Por lo tanto, es necesario restaurar estos ecosistemas a través de metodologías que sean apropiadas y exitosas. En esta tesis, se aborda indistintamente los términos restauración y rehabilitación, ya que lo que se pretende es mostrar que el suelo debe adquirir condiciones tales que sea capaz de servir como elemento activo de un biotopo, permitiendo el desarrollo de organismos vivos, especialmente vegetación, independientemente de su naturaleza y del uso posterior al que se destine el espacio recuperado. La restauración ecológica, en estas zonas áridas y semiáridas, tiene como objetivo mejorar el desarrollo y establecimiento de ecosistemas sostenibles, saludables y con una buena cubierta vegetal a largo plazo (Burguer et al., 2020). Debido a los efectos del cambio climático, los ecosistemas áridos y semiáridos podrían aumentar en el futuro y actualmente cubre alrededor del 45% de la superficie del planeta (Bastin et al., 2017), por este motivo, se hace más necesarios restaurar estos ecosistemas a través de metodologías adecuadas y exitosas.

La degradación del medio ambiente y la generación y aglomeración de residuos, es una de las mayores preocupaciones a nivel mundial. Por este motivo, la UE ha creado una estrategia de cero residuos a través de la economía circular (Almendro-Candel et al., 2018). Para la recuperación de suelos y paisajes tras las actividades mineras, una buena opción es utilizar residuos orgánicos. De esta forma se evita su acumulación y se contribuye a la economía circular y a la estrategia europea Residuo Cero (Murray et al., 2017; Ritzén and Sandström, 2017; Peñaranda et al., 2020). La recuperación del suelo, la implementación de actividades productivas y la mejora del paisaje son objetivos derivados de la aplicación de residuos orgánicos y la implementación de la economía circular, en la restauración de canteras. Las enmiendas orgánicas, aumentan el contenido de material orgánica del suelo, mejoran la retención de agua y estimulan los microorganismos del suelo en comparación con suelos no enmendados (Soria et al., 2021). El estado nutricional del suelo, es el siguiente paso para asegurar un buen desarrollo de la cubierta vegetal.

El suelo es el pilar fundamental en toda recuperación de explotaciones mineras a cielo abierto, y junto a él, la vegetación que es factor clave en la recuperación paisajística. Si unimos a estas claves, la necesidad de reutilizar residuos sobre la base de una economía circular, se puede concluir que las tres piezas fundamentales en rehabilitación y restauración son los suelos, la vegetación, y la reutilización de residuos como principal fuente de materia orgánica y nutrientes.

1.1. Proceso para restaurar canteras en zonas áridas y semiáridas

La recuperación del suelo de canteras en zonas áridas y semiáridas es muy lenta debido a la escasez de lluvias y a la caída de lluvias torrenciales en determinadas épocas, además, se une la fuerte radiación solar, que somete a las plantas a estrés hídrico severo y contribuye en su conjunto a aumentar la erosión del suelo. La ausencia o escasa cobertura vegetal, también aumenta esta erosión (Miralles et al., 2009). Para restaurar una zona con suelos muy degradados y normalmente desestructurados, hay que acondicionar una capa superficial con unas propiedades físicas, químicas y biológicas adecuadas. La estrategia habitual en las restauraciones es la de recuperar la cubierta edáfica, creando un nuevo medio edáfico, un tecnosuelo. Así pues, tras la estabilización mecánica del suelo, es recomendable utilizar materiales orgánicos (como los residuos) y posteriormente realizar una revegetación que sea estable.

Antes de crear el tecnosuelo, hay que realizar una limpieza de la superficie, eliminando materiales de desecho que no sean útiles para la recuperación del suelo y nivelando este suelo para evitar la erosión que podrían ocasionar las aguas superficiales. Además, es importante adecuar la hidrografía del medio, cubriendo zanjas y canalizando las aguas para evitar que discurran y arrastren materiales (Zornoza et al., 2017). Tras la estabilización mecánica, se prepara el suelo mediante técnicas de laboreo para reducir la compactación y la densidad aparente, y aumentar la porosidad de la capa arable, que a su vez facilite la germinación de las semillas y el desarrollo de las plántulas (Kabas et al., 2012). También hay que recuperar la fertilidad del suelo, incorporando o cubriendo la superficie con residuos orgánicos que a su vez remedian el suelo, lo abonan y lo protegen. Al proceso general de restauración de una cantera se muestra en la figura 1.

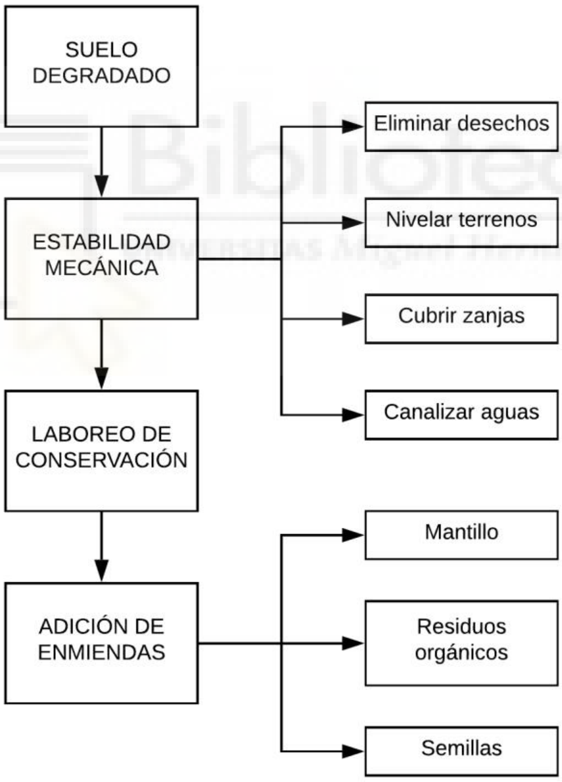

Figura 1. Proceso general de restauración de una cantera. Fuente: elaboración propia.

La aplicación de residuos orgánicos al suelo es una herramienta útil para mantener y aumentar las cantidades de materia orgánica (Kabas et al., 2014). Los residuos orgánicos, deben de tener una procedencia y composición biológica, y en ellos se encuentran los llamados bioelementos, en mayor medida el carbono, hidrógeno y oxígeno (C, H y O) y en menor medida el nitrógeno, fósforo y azufre (N, P y S).

Aumentar la materia orgánica del suelo es esencial para garantizar la rehabilitación real de los mismos, ya que mejora la estructura del suelo, la aireación, la retención y la circulación de agua, reduce la erosión, estimula la actividad biológica e incrementa la fertilidad debido a la liberación de nutrientes (Senesi et al., 2007).

Para reducir la erosión, recuperar los suelos y evitar su pérdida, es necesario establecer una cubierta vegetal estable (Zornoza et al., 2017). En zonas áridas y semiáridas, debido a las escasas precipitaciones, se produce un estrés hídrico severo en las plantas. Por ello, se necesita utilizar especies de plantas adaptadas al estrés hídrico, a los nutrientes del área restaurada y a la climatología del lugar, pues estas plantas han desarrollado adaptaciones morfológicas y fisiológicas que les permiten sobrevivir y crecer en condiciones difíciles (Clemente et al., 2004). El uso de especies nativas es de especial interés ya que estas especies se adaptan mejor a las condiciones climáticas y del suelo y tienen mayore probabilidades de supervivencia, crecimiento y reproducción (Antonsiewicz et al., 2008). Por esto, es importante disponer de un banco de semillas de las especies existentes previas al inicio de la explotación, o en su defecto, preparar uno con las plantas del entorno más próximo.

Además de la aplicación de residuos orgánicos y la revegetación de la zona, otra enmienda muy utilizada para la restauración de estos suelos degradados en zonas áridas y semiáridas, es la aplicación de mantillo formado por tierra vegetal y distintos tipos de turbas. Este mantillo actúa limitando la pérdida de agua por evaporación, mejora la filtración del agua, el crecimiento de las raíces y el establecimiento de la vegetación, reduce la erosión del suelo (Hueso-González et al., 2015). Además, los restos vegetales que constituyen el mantillo, aumentan la estabilidad de agregados del suelo. Junto con el uso de mantillo, existen otras estrategias asociadas al acolchado superficial de los suelos (mulching) como es el uso de plástico, piedras o astillas de madera, que son medidas efectivas para evitar la pérdida de agua (Bakker et al., 2012).

2. Objetivos:

2.1. El objetivo general.

La presente tesis tiene como objetivo general el estudio y análisis de las medidas correctoras y plan de restauración de espacios mineros de materiales destinados a la construcción en zonas áridas y semiáridas, como lo es la Región de Murcia.

2.2. Objetivos específicos.

Los objetivos específicos de esta tesis son los siguiente:

- Crear un sistema de gestión de mitigación de impactos basado en diagramas de flujo con medidas correctivas y preventivas que pueda aplicarse fácilmente en canteras de rocas ornamentales y áridos en zonas áridas y semiáridas.

- Recopilar la información más relevante sobre las técnicas utilizadas para la recuperación de suelos en espacios mineros a cielo abierto, que sirvan de base para futuras rehabilitaciones.

- Evaluar la mejora de la restauración de suelos en áreas mineras a cielo abierto, en zonas áridas y semiáridas, mediante el uso de residuos, como parte de la estrategia de cero residuos. Se pretende evaluar el éxito de diferentes tratamientos de restauración aplicados en una cantera del Noroeste de la Región de Murcia, mediante el uso de cuatro tratamientos (fertilizante inorgánico NPK 15-15-15, purines de cerdo, restos de poda y residuos sólidos urbanos (RSU)) sobre las propiedades fisicoquímicas y la disponibilidad de nutrientes del suelo en canteras de piedra caliza. Estos tratamientos se han aplicado puesto que hay una elevada producción en la Región de Murcia y es un problema su eliminación. Los tratamientos aplicados pretenden ser evaluados a corto plazo (dos y cuatro meses desde la adición al suelo) y a medio plazo (nueve meses), con el fin de determinar si los suelos restaurados serán aptos para la recuperación del paisaje en función de la disponibilidad de nutrientes. Además, se seleccionaron como referencia y para comparación con las parcelas tratadas, suelos degradados sin aplicación de ningún tipo de tratamiento.

3. Materiales y métodos.

3.1. Análisis de estudios de impacto ambiental (EsIA) y elaboración de diagramas de flujo.

Se analizaron 8 EIA de canteras a cielo abierto de roca ornamental (mármol y caliza marmórea) y áridos calizos de la Región de Murcia, para identificar los impactos negativos sobre el medio abiótico y biótico, el paisaje, el medio socioeconómico y sociocultural, y las infraestructuras, con el fin de aplicar técnicas para mitigar y reducir los efectos negativos provocados por la extracción minera.

Para identificar los impactos, se utilizó el método de evaluación de impactos de Conesa et al. (2010). Esta metodología es anterior a las últimas modificaciones legislativas, pero constituye una base sólida sobre la que desarrollar las EIA (Castelo et al., 2019). Después de haber analizado diversas metodologías para evaluar los impactos en la minería a cielo abierto, se comprobó que la evaluación depende de una cantidad de datos difíciles de obtener o de métodos cuantitativos generales con datos de reproducibilidad incierta, además, dependen en muchas ocasiones del evaluador y su experiencia y si se requiere mayor confiabilidad, se necesitan equipos experimentados o procesos costosos, por lo que no existe un método para responder rápidamente y que sea reproducible y confiable hasta la fecha.

Según el método de Conesa et al. (2010), en primer lugar, se identifican las acciones del proyecto que puedan causar impactos, y seguidamente, se valoran los impactos de una manera cualitativa, caracterizándose mediante una serie de atributos como son la sinergia, el efecto, la acumulación, la periodicidad y la recuperabilidad. Esta técnica se basa en el método de matrices causa-efecto. Esta matriz se basa en relacionar acciones del proyecto con los factores ambientales del mismo, identificando la magnitud y la importancia de los potenciales efectos sobre un determinado factor ambiental y el generado para cierta acción del proyecto. Una vez identificados los impactos en la matriz de identificación de impactos y las causas que los producen, se evalúan cada uno de los impactos identificados de acuerdo con una serie de parámetros, para determinar su importancia en una matriz de valoración de los impactos. La importancia toma valores entre 13 y 100 función de las valoraciones dadas a cada parámetro. La definición de estos impactos junto con su importancia se muestra en la tabla 1 y se concluye en el EsIA si el desarrollo del proyecto es aceptable o no. Para conocer los impactos más significativos, se ha calculado la importancia de la actividad en las diferentes fases de una cantera: fase I, preparación; fase II, operación; y fase III, restauración.

Una vez obtenidos los impactos más importantes que se producen en estas canteras, se analizaron las medidas preventivas y de control para reducir o eliminar dichos impactos en función de los diferentes componentes del medio ambiente. En base a todo ello, se elaboran diagramas de flujo para facilitar la aplicación de estas medidas correctoras y preventivas. Con todo esto, se establece una metodología que puede ser aplicada de manera general en otras regiones y operaciones mineras a cielo abierto, facilitando así, el monitoreo sistemático y la propuesta de medidas de mitigación de impactos.

Tabla 1: Clasificación de impactos. Fuente: Elaboración propia según Ley 9/2018 y método de evaluación de impacto de Conesa et al. (2010).

	Clasificación de impactos.	Importancia
Compatible	Es aquel cuya recuperación es inmediata tras el cese de la actividad y no precisa de medidas preventivas o correctoras.	13-25
Moderado	Es aquel cuya recuperación no precisa medidas preventivas o correctoras intensivas y en el que la consecución de las condiciones ambientales iniciales requiere cierto tiempo.	25-50
Severo	Es aquel en el que la recuperación de las condiciones del medio exige la adopción de medidas preventivas o correctoras, y en el que, aún con esas medidas, aquella recuperación precisa de un periodo de tiempo dilatado.	50-75
Crítico	Es aquel cuya magnitud es superior al umbral aceptable. Con él se produce una perdida permanente de la calidad de las condiciones ambientales, sin posible recuperación, incluso con la adopción de medidas de prevención y corrección.	75-100

3.2. Análisis de las técnicas utilizadas para la recuperación de espacios mineros a cielo abierto.

Se realizó un análisis bibliométrico, en la base de datos de Scopus, para determinar el interés de la comunidad científica sobre la restauración de espacios mineros a cielo abierto. Se encontraron 338 artículos científicos, mediante la búsqueda de ‘’restauración de canteras’’, durante en el periodo 2000-2019. El mayor número de publicaciones sobre este tema fue en España (Figura 2), siendo Murcia una de las comunidades autónomas dónde más artículos se encontraron, pues fueron 35.

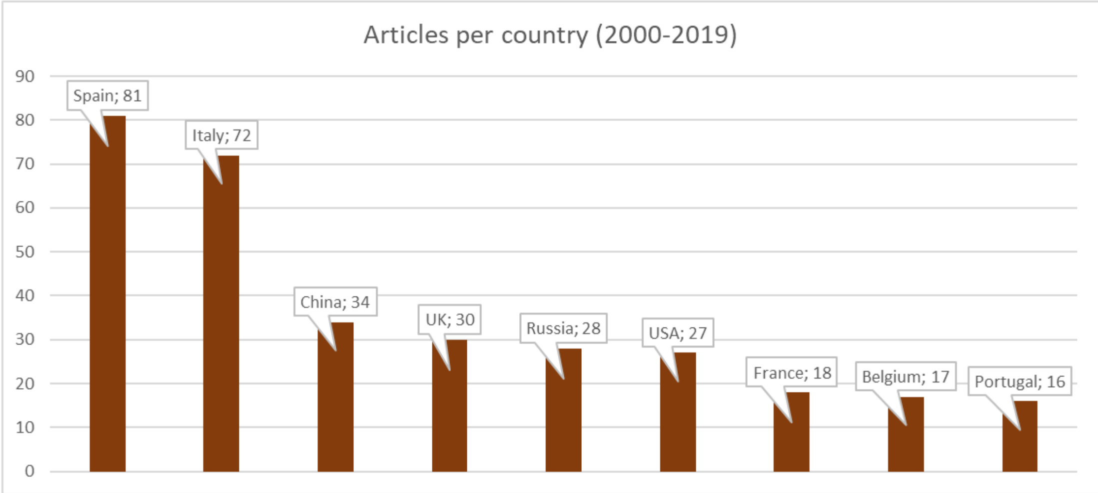

Figura 2. Número de artículos publicados sobre restauración de canteras por país, en el periodo 2000-2019. Fuente: elaboración propia.

De los estudios de autores españoles sobre residuos utilizados en la restauración de canteras, destacan aquellos en los que se utilizan lodos, especialmente en los que se utilizan biosólidos procedentes de la depuración de aguas residuales (Figura 3).

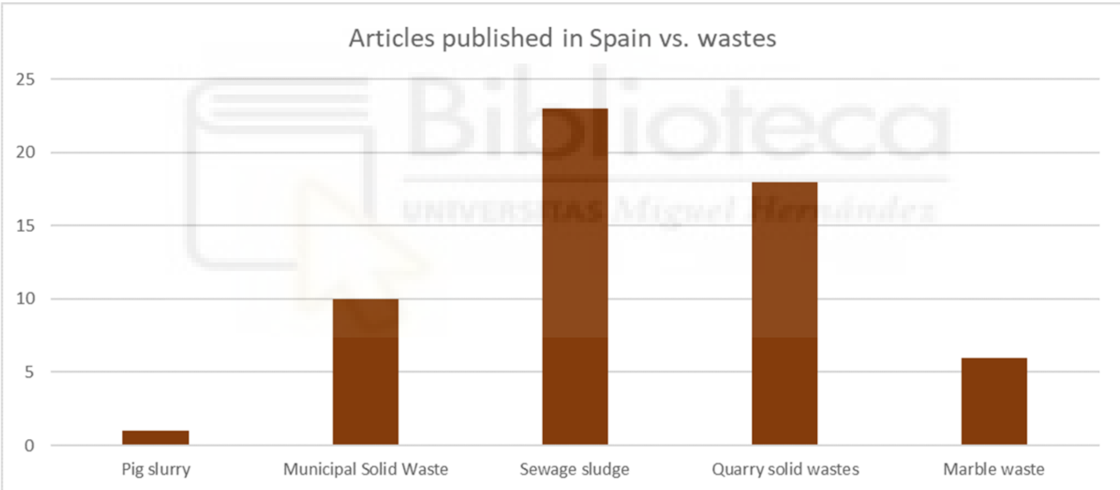

Figura 3: Publicaciones en Scopus de autores españoles en el periodo 2000-2019 según el tipo de residuo utilizado en las restauraciones de canteras. Fuente: elaboración propia.

3.3. Área de estudio.

La minería en la Región de Murcia está ampliamente ligada al sector de la roca ornamental y el árido. Según el último estudio publicado por el servicio de Minas de la Comunidad autónoma de la Región de Murcia, en 2018 había 228 explotaciones a cielo abierto de las cuáles 98 mantenían actividad. De estas explotaciones, 122 eran canteras de roca ornamental y 45 estaban activas; 74 eran canteras de árido y 32 de ellas estaban activas. En la figura 4 se muestra las zonas más representativas con canteras en la Región de Murcia.

Concretamente, la roca ornamental existente es de distintas variedades de calizas marmóreas y mármoles. La roca ornamental, en la comarca del Noroeste y el Altiplano, está asociada a las capas Jurásicas del Subbético y del Eoceno Prebético, grandes espesores de calizas y dolomías, con una extensa variedad de colores: cremas, marrones y rojos. Los mármoles, en sentido estricto, aparecen en las alineaciones béticas del Alpujárride del Cabezo Gordo en Torre Pacheco. Las canteras de áridos calizos más representativas, se encuentran en la comarca Fortuna-Abanilla, en la comarca del área metropolitana de Murcia, en Santomera, y en la comarca del campo de Cartagena, en Fuente Álamo.

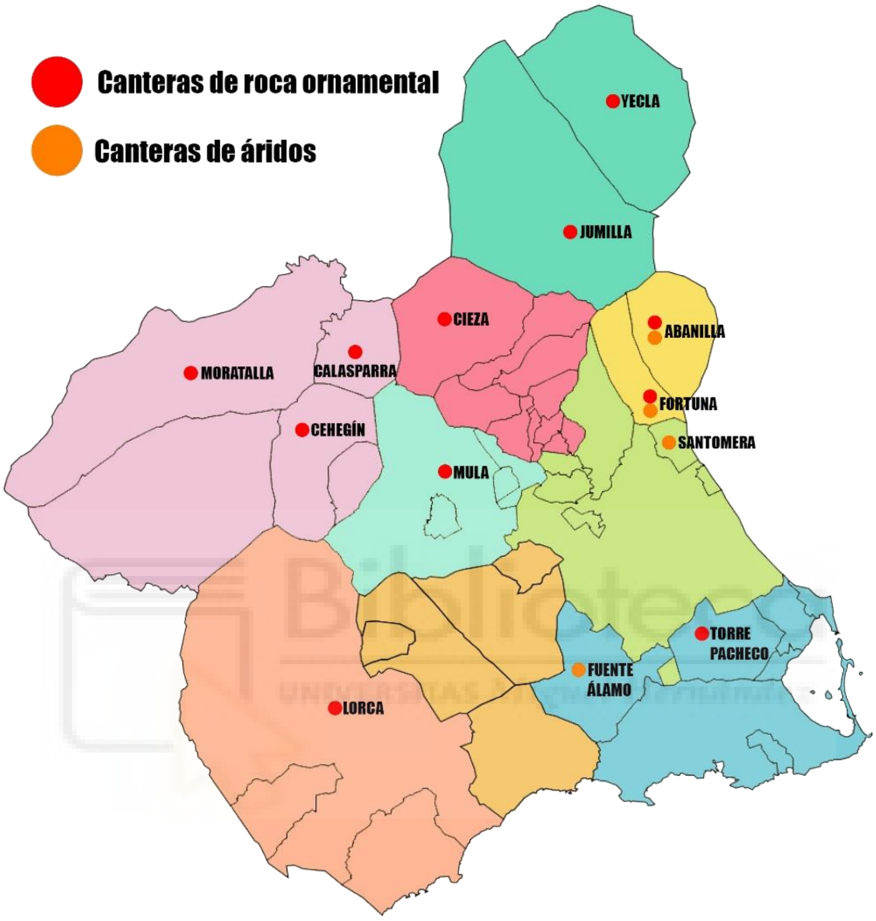

Figura 4. Municipios más representativos de la Región de Murcia con canteras de roca ornamental y áridos. Fuente: elaboración propia.

El clima de la Región de Murcia es mediterráneo con rasgos áridos: veranos cálidos y secos, inviernos suaves, aunque con frecuentes heladas en el interior, y lluvias en primavera y otoño. La característica general de este clima es su escasez de precipitaciones, concentradas en unos pocos días del año, con máximas en otoño. Estas lluvias, por lo general son torrenciales y son consideradas por el alto poder erosivo que pueden desencadenar a la hora de recuperar espacios mineros.

Según la clasificación climática de Köppen-Geiger (Peel et al., 2007), se distinguen en la Región los siguientes tipos de clima: semiárido cálido (BSh), semiárido frío (BSk), y mediterráneo (Csa). Las diferentes variedades climáticas en la Región de Murcia se muestran en la figura 5. El clima BSh es un clima caluroso y seco con precipitaciones escasas; el clima BSk es un clima frío y seco con precipitaciones escasas; y el clima CSa tiene un verano seco y lluvias estacionales.

En relación a los vientos, la orientación OSO-ENE de las grandes líneas de relieve bético canaliza los procedentes del Atlántico, mientras que los vientos de procedencia N-NO, predominante durante el invierno, son secos y fríos debido a su largo recorrido. Las borrascas del Mediterráneo asociadas a fenómenos de convección dan lugar a un régimen de vientos del Este, con características húmedas en el flanco oriental de la Región que se van desecando hacia el interior. Esta situación predomina en primavera y verano, extendiéndose al otoño. Respecto a la velocidad del viento, en líneas generales es moderada, salvo en el litoral donde es mayor debido a su exposición a vientos de levante. La radicación es un factor a tener en cuenta ya que influye sobre la distribución de los vientos.

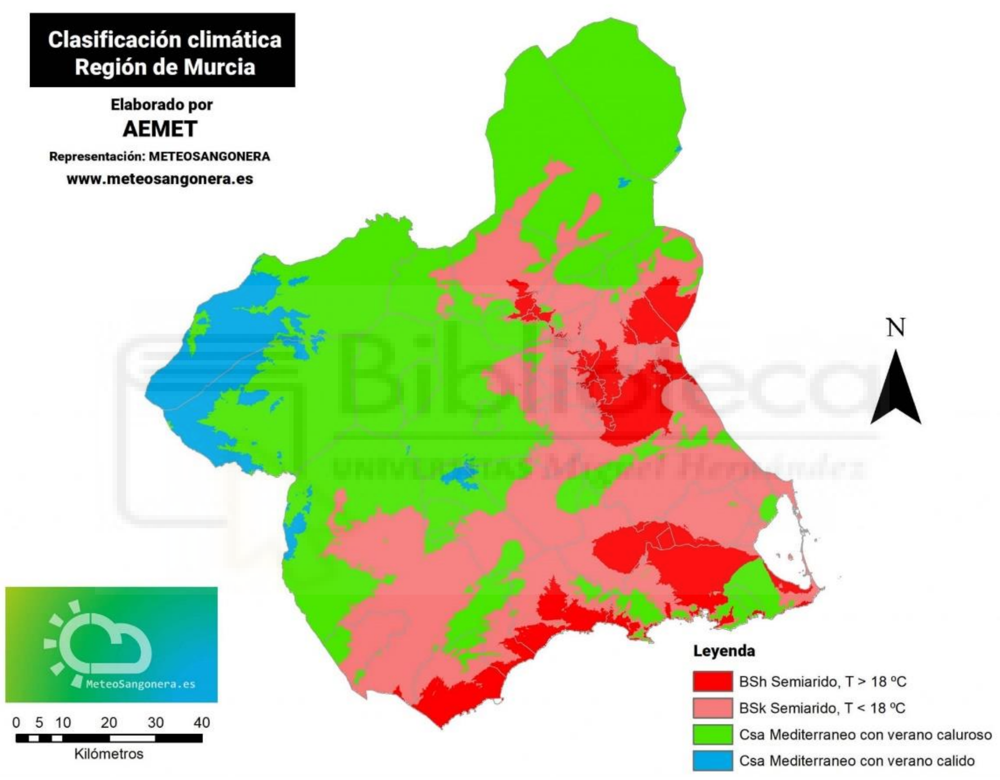

Figura 5. Variedades climáticas de la Región de Murcia. Fuente: opensource: http://www.meteosangonera.es/wp-content/uploads/2017/04/clasificacionclimatica.jpg.

La humedad relativa existente presenta diferencias en función de la proximidad al mar. En el interior varía entre el 52 y el 63% y en la costa entre el 71 y 76%. Estas características climáticas crean un fuerte índice de evapotranspiración que provoca la existencia de un permanente déficit de agua. Esta situación es generalizada en toda la Región de Murcia.

3.4. Zona de estudio de los tratamientos de residuos aplicados del artículo 3.

El estudio se ha realizado en una cantera de piedra caliza, cuya actividad es la extracción de roca ornamental y áridos carbonatados, con una pendiente media del 8%, situada en el suroeste de Cehegín, Murcia, España. La cantera está ubicada en la latitud 38º4'42.47'' N y longitud 1º48'23.65'' W (figura 6). El clima es mediterráneo (Csa) con un verano caluroso según la clasificación climática de Köppen-Geiger (Peel et al., 2007). El uso del suelo de la zona es básicamente agrícola de secano y matorral, componiendo un paisaje tradicional mediterráneo.

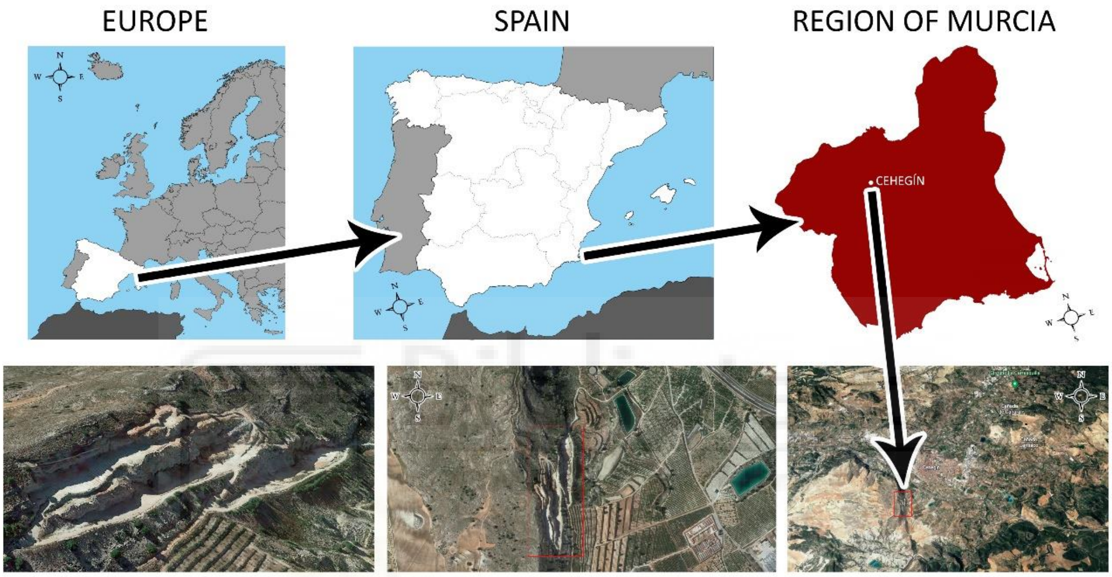

Figura 6. Localización de la cantera de estudio de piedra caliza. Fuente: elaboración propia.

3.5. Diseño experimental en el área de estudio de los tratamientos de residuos aplicados.

El estudio se realizó en uno de los cuatro frentes de cantera explotados en la zona sobre un banco de 8,2 m de altura (pared) y 105 m de largo (frente). Se acondicionó el terreno y se niveló, el área se rellenó con relaves y se agregó tierra vegetal con una profundidad de unos 20cm. Una vez lista el área, se dividió en 55 parcelas experimentales de 5 × 4 m, dejando una separación de 1 m entre ellas. Los tratamientos fueron establecidos y aleatorizados en banco. Cada uno de los tratamientos se aplicó en 11 parcelas y 11 parcelas control quedaron sin ningún tratamiento. Los tratamientos aplicados fueron los siguientes:

I. La adición de fertilizante inorgánico granulado (NPK 15-15-15) en una cantidad de 1 kg por parcela.
II. La adición de purines de cerdo en una cantidad de 5,4 kg por parcela en función del aporte de nitrógeno equivalente al fertilizante inorgánico.

III. La incorporación de residuos sólidos urbanos (RSU) compostados del centro de tratamiento de residuos de Cañada Hermosa, en el noroeste de la Región de Murcia, en una cantidad de 60 kg por parcela.
IV. La aplicación de residuos de poda leñosos (de tamaño variable superior a 5 a 20 cm de largo), procedentes de olivo, vid y almendro de la comarca, en la cantidad de 60 kg por parcela.

El resto de parcelas, se dejaron sin enmiendas y fueron tomadas para control.

Se tomaron muestras de suelo a 10 cm de profundidad para cada parcela y tratamiento (11 muestras por tratamiento), a los dos, cuatro y nueve meses desde el inicio de los tratamientos de fertilización (a corto y mediano plazo). Se tomaron muestras para conocer el estado del suelo en las primeras etapas y al final de un período prudencial para lograr cierta estabilidad previa a la siembra de los cultivos. Los muestreos se realizaron a los dos, cuatro, y nueve meses tras la aplicación de los tratamientos.

3.6. Métodos de análisis de los suelos en los que se aplicaron los tratamientos.

Las muestras de suelo secadas a temperatura ambiente se tamizaron a 2 mm. Después de eso, se determinó el pH en una extracción de suelo/agua (relación de 1:2,5 p/v) [29,30]. El equivalente de CaCO3 se determinó utilizando el método del calcímetro volumétrico de la FAO [31]. La arcilla, el limo y la arena se midieron con el método de Bouyoucos basado en la ley de Stokes [32]. El nitrógeno del suelo se determinó mediante el método de Kjeldahl y el fósforo mediante el método de Olsen [33,34].

K, Ca, Mg y Na se determinaron en el suelo mediante extracción con acetato de amonio 1 N, y Fe, Cu y Zn se determinaron mediante el método DTPA-TEA [35]. Después de la extracción, Ca, Mg y micronutrientes se midieron mediante espectrometría de absorción atómica y Na y K se midieron mediante espectrometría de emisión atómica.

3.7. Análisis estadístico del área estudiada.

Para cada tratamiento se calcularon las estadísticas descriptivas, el valor medio y la desviación estándar. Los datos se probaron para determinar la homogeneidad de la varianza y las diferencias entre las medias individuales se evaluaron mediante la prueba post hoc de Tukey en $p < 0,05$. Posteriormente, se aplicó una prueba ANOVA unidireccional para comparar los tratamientos [36].

4. Resultados y discusión.

Las respuestas a los objetivos planteados, tanto el objetivo general como los específicos, quedan reflejadas en esta tesis a través de los artículos que se presentan:

- "Methods of soil recovery in quarries of arid and semiarid areas using different waste types". Que responde al objetivo general y al segundo objetivo específico.

- "Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas". Que da respuesta al objetivo general indicado y al primer y segundo objetivo específico.

- "Restoration Techniques Applied in Open Mining Area to Improve Agricultural Soil Fertility". Que responde al objetivo general y al tercer objetivo específico.

A continuación, se presentarán los resultados obtenidos más relevantes para cada uno de los artículos y su discusión.

4.1. Methods of soil recovery in quarries of arid and semiarid areas using different waste types.

4.1.1. Impactos ambientales en canteras y diagramas de flujo.

Tras analizar diversos estudios, se obtienen los impactos medioambientales negativos más importantes que se producen en canteras de áridos y roca ornamental en la Región de Murcia, atendiendo a los efluentes que pueden afectar en las distintas fases en la explotación de una cantera. Se han elaborado unos esquemas representativos de los principales efluentes en la fase I, de preparación (figura 7); en la fase II, de explotación (figura 8); y en la fase III, de restauración (figura 9); y sus impactos negativos más representativos

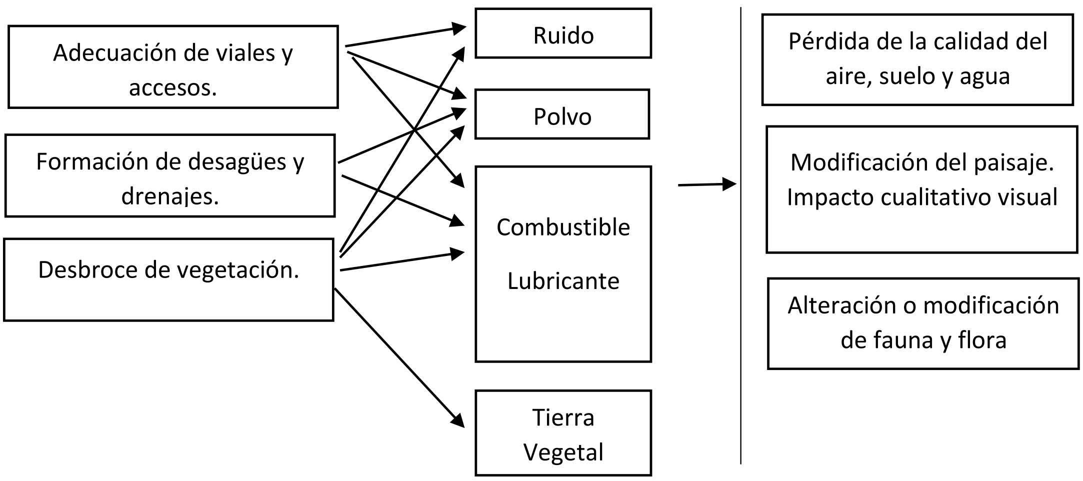

Figura 7. Principales efluentes de las actividades en la Fase I de una cantera de roca ornamental y áridos de la Región de Murcia y sus impactos más representativos. Fuente: elaboración propia.

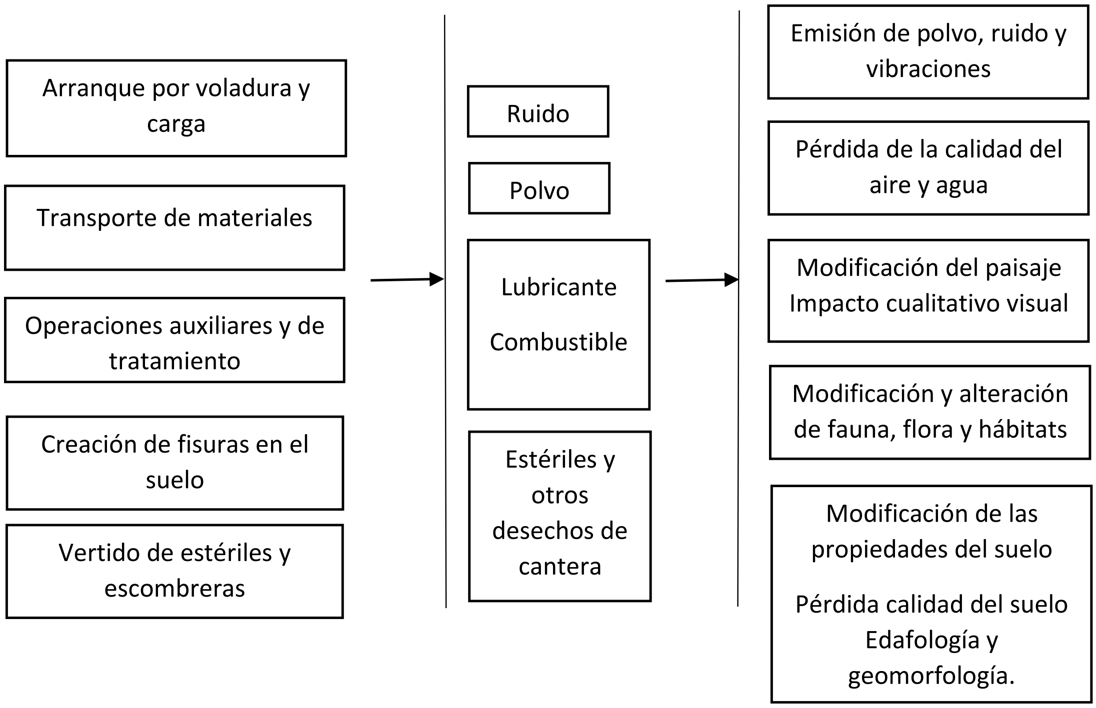

Figura 8. Principales efluentes de las actividades en la Fase II de una cantera de roca ornamental y áridos de la Región de Murcia y sus impactos más representativos. Fuente: elaboración propia.

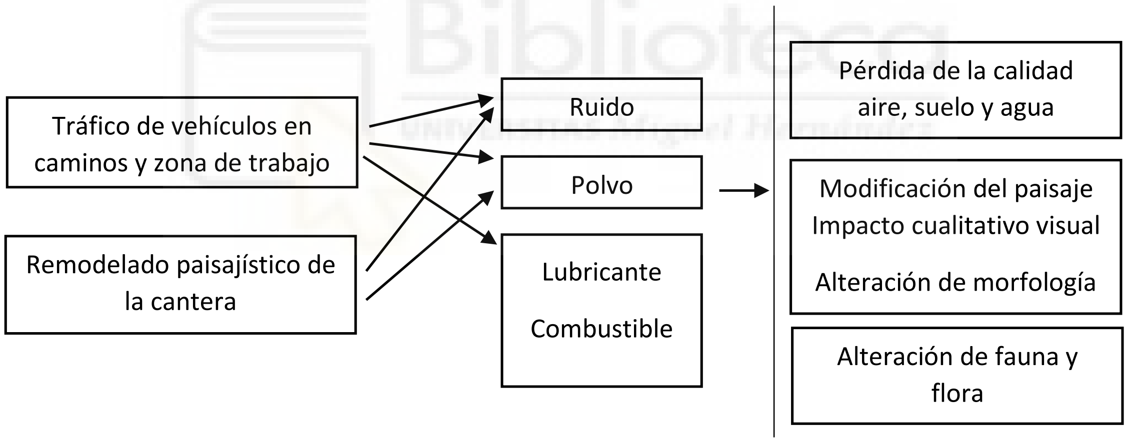

Figura 9. Principales efluentes de las actividades en la Fase III de una cantera de roca ornamental y áridos de la Región de Murcia y sus impactos más representativos. Fuente: elaboración propia.

Al observar las medidas que habitualmente se aplican para controlar y reducir dichos impactos, se comprueba que el 90% de las medidas preventivas y correctoras aplicadas para controlar los diferentes factores ambientales negativos, son siempre las mismas. Por ello, se han desarrollado diagramas de flujo que pueden ser ampliamente aplicados en actividades mineras a cielo abierto, y con ello permitir eliminar o reducir los impactos en esta actividad. Además, sirven como herramienta antes de iniciar la explotación y ayudan a prevenir posibles efectos negativos. Las medidas preventivas y correctoras tenidas en cuenta, han sido considerando los componentes del medio ambiente que intervienen o que potencialmente podrían verse afectados por la minería: medio físico y biótico, entorno perceptivo, entorno socioeconómico y entorno sociocultural.

Los diagramas de flujo derivados de los efluentes descritos anteriormente se muestran en las imágenes 10-15:

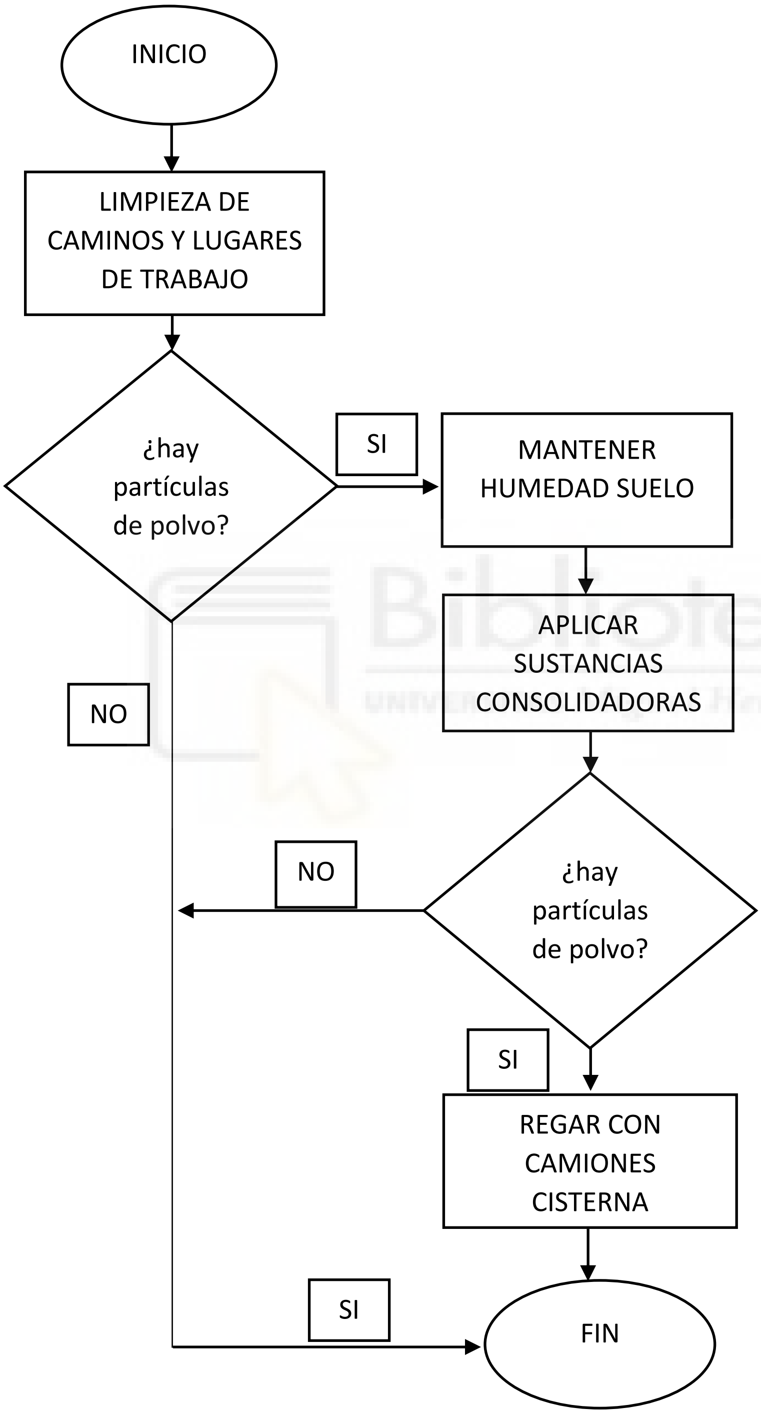

Figura 10. Diagrama de flujo para reducir el polvo en carreteras y lugares de trabajo. Fuente elaboración propia.

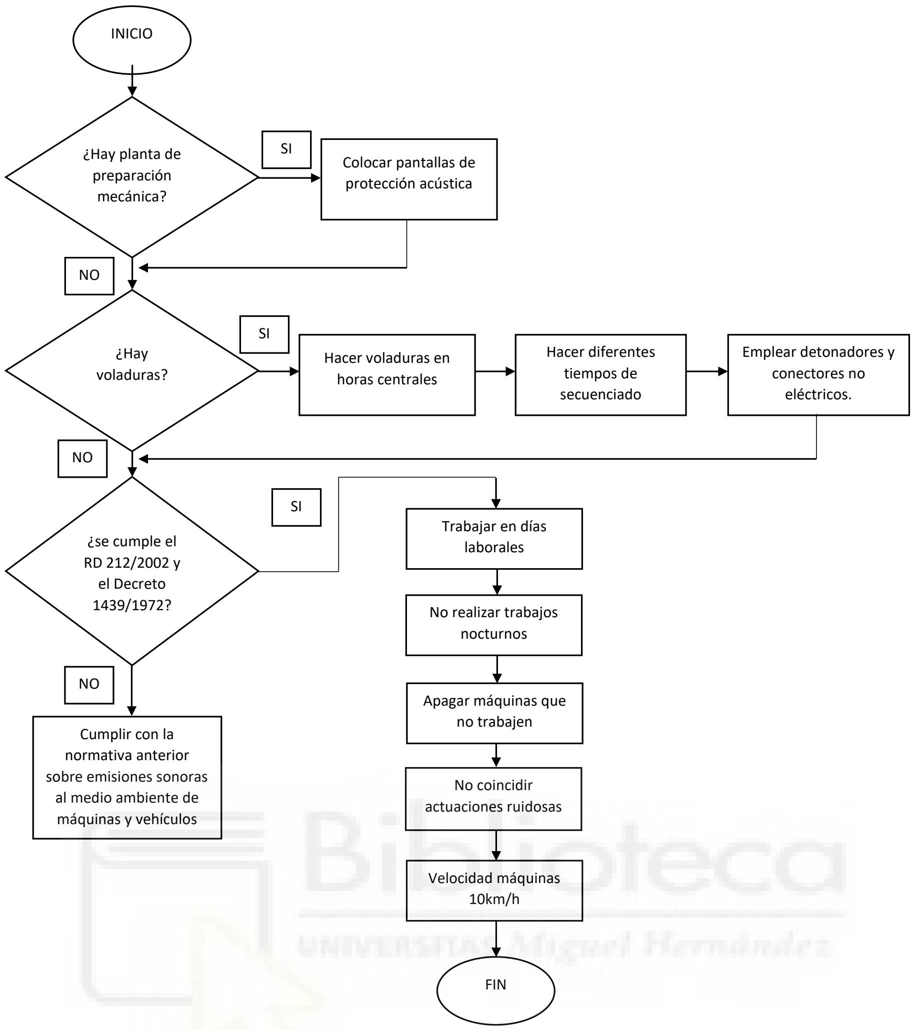

Figura 11. Diagrama de flujo para reducir el ruido y las vibraciones en las actividades de minería. Fuente elaboración propia.

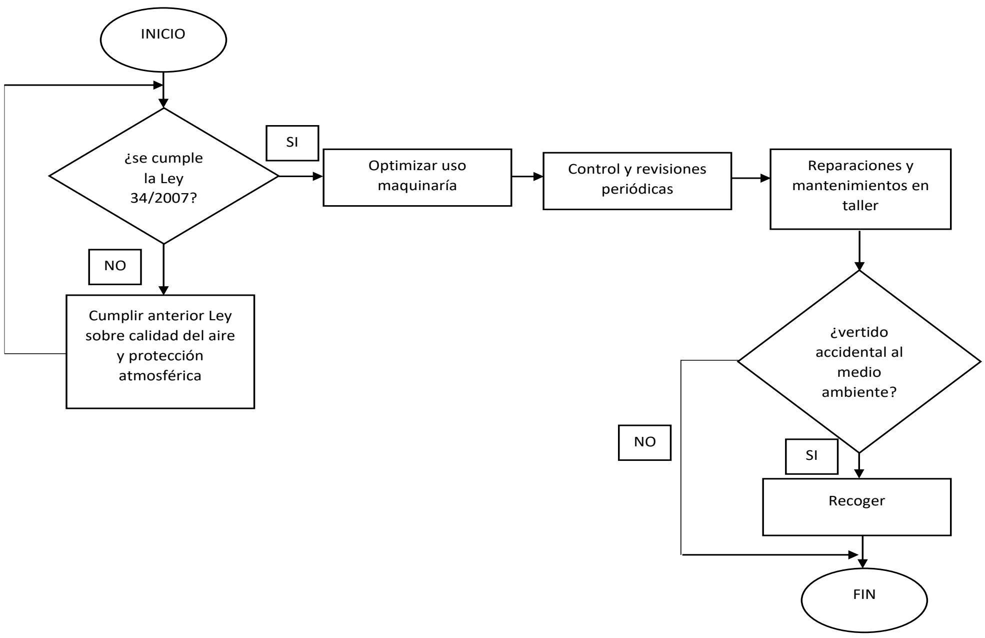

Figura 12. Diagrama de flujo para reducir combustibles y lubricantes en las explotaciones. Fuente elaboración propia.

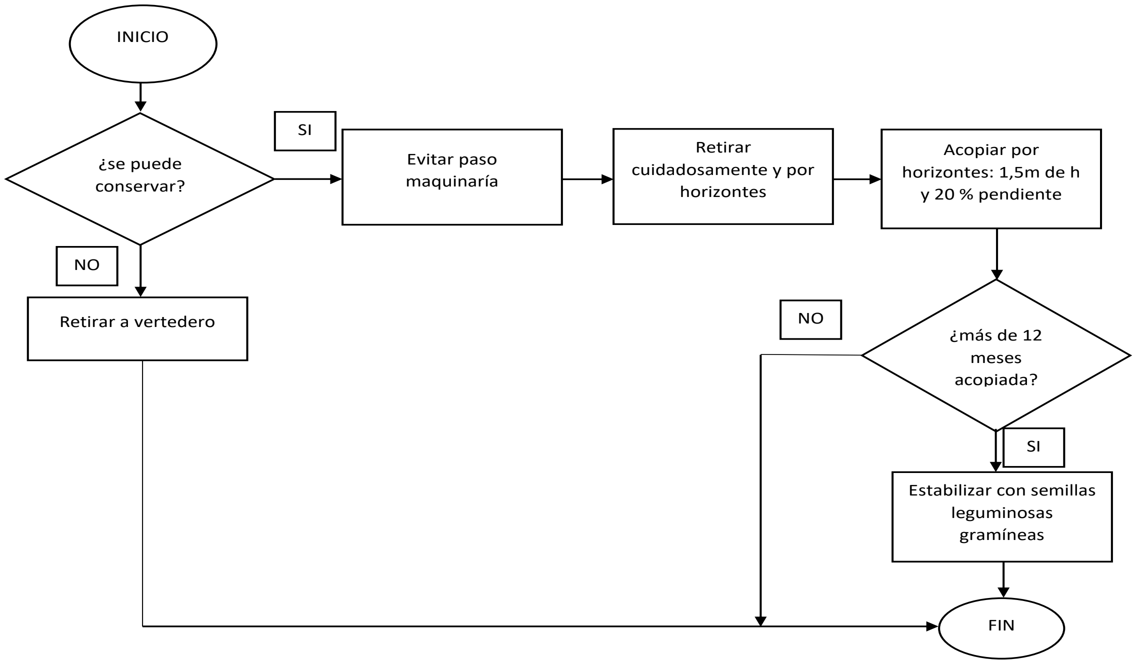

Figura 13. Diagrama de flujo para controlar la capa superficial del suelo. Fuente elaboración propia.

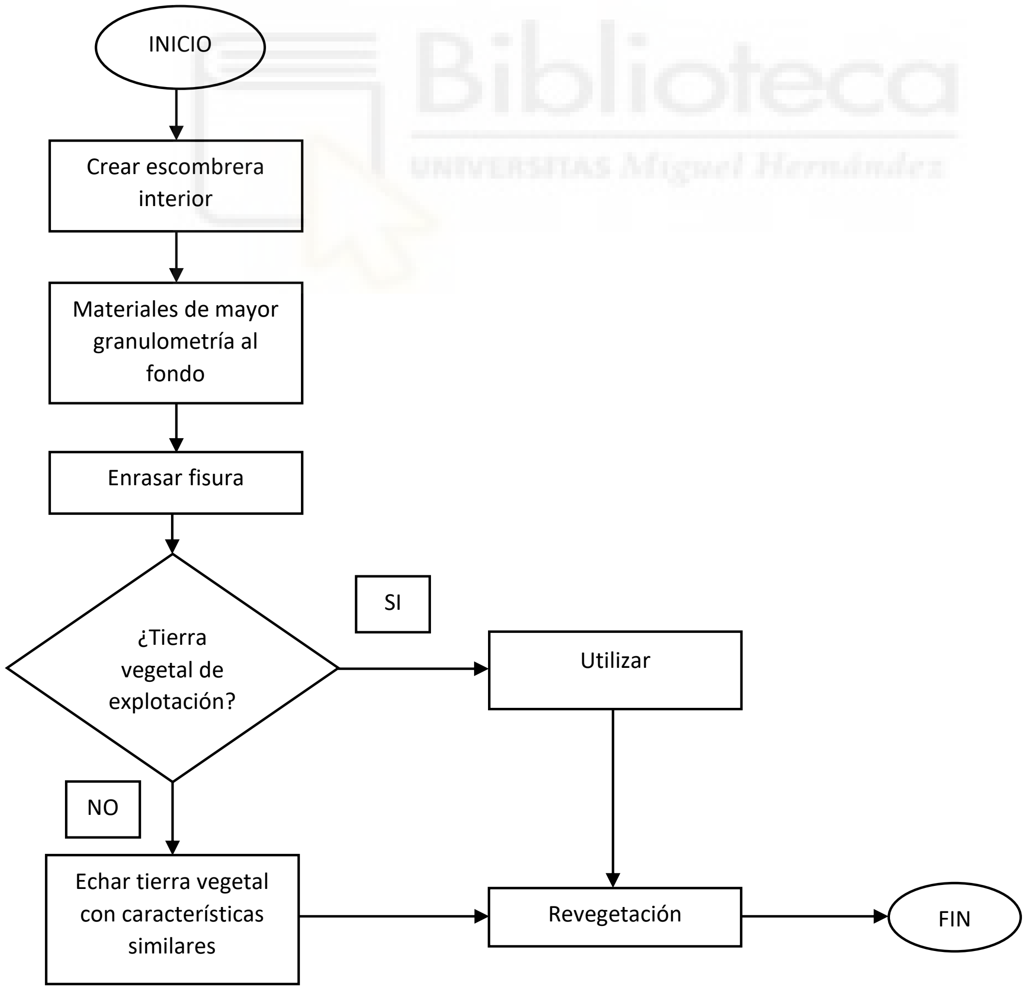

Figura 14. Diagrama de flujo para controlar el material de rechazo en las explotaciones. Fuente elaboración propia.

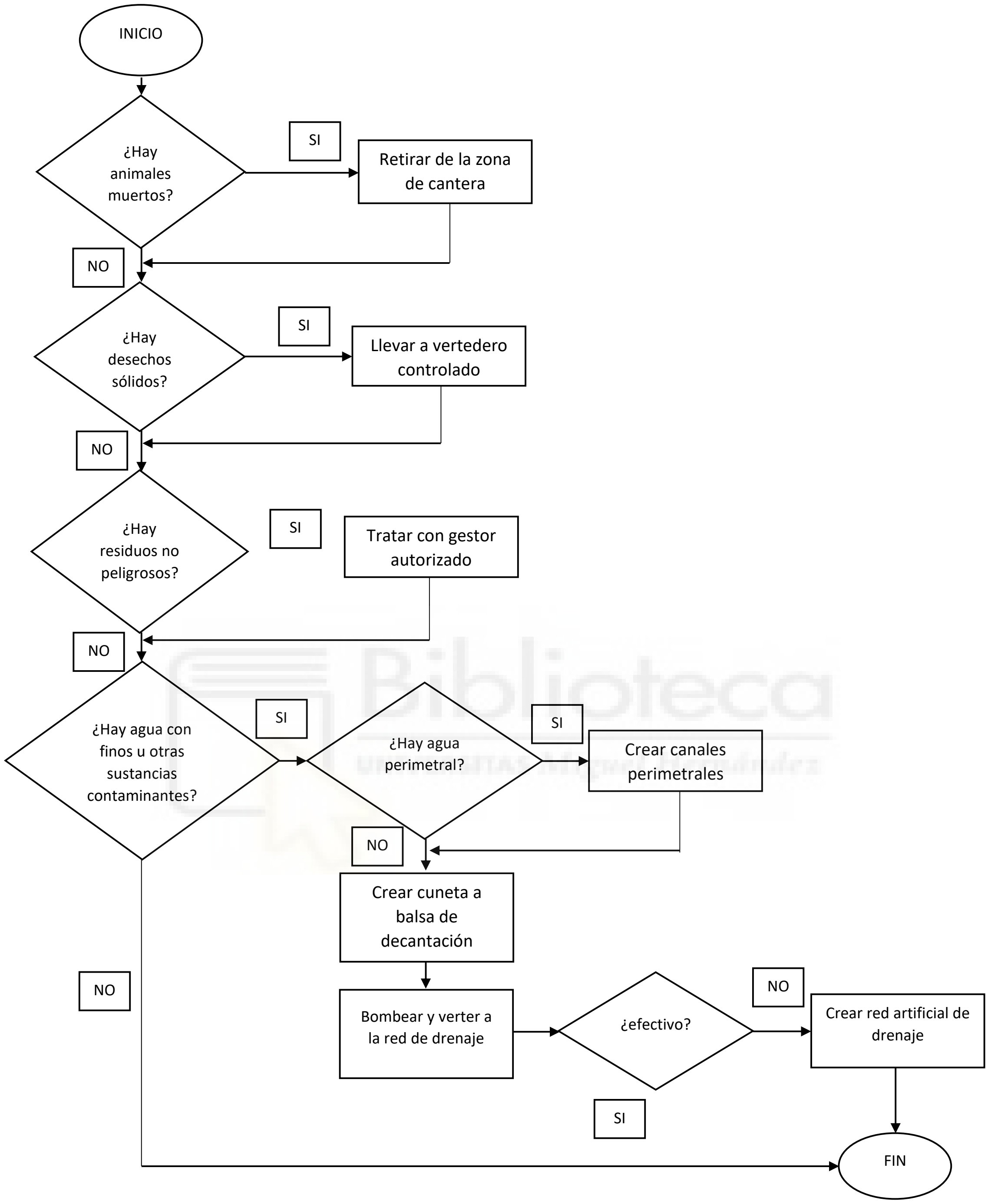

Figura 15. Diagrama de flujo para controlar y reducir otros residuos de cantera. Fuente elaboración propia.

Es crucial considerar la salud ambiental y la humana, por ello, además de los diagramas de flujo derivados de los efluentes, se han creado dos diagramas más, uno para mejorar la seguridad y salud de los trabajadores (figura 16) y otro para mejorar las superficies alteradas por la actividad en las canteras y reducir la afección del paisaje, fauna y flora (figura 17).

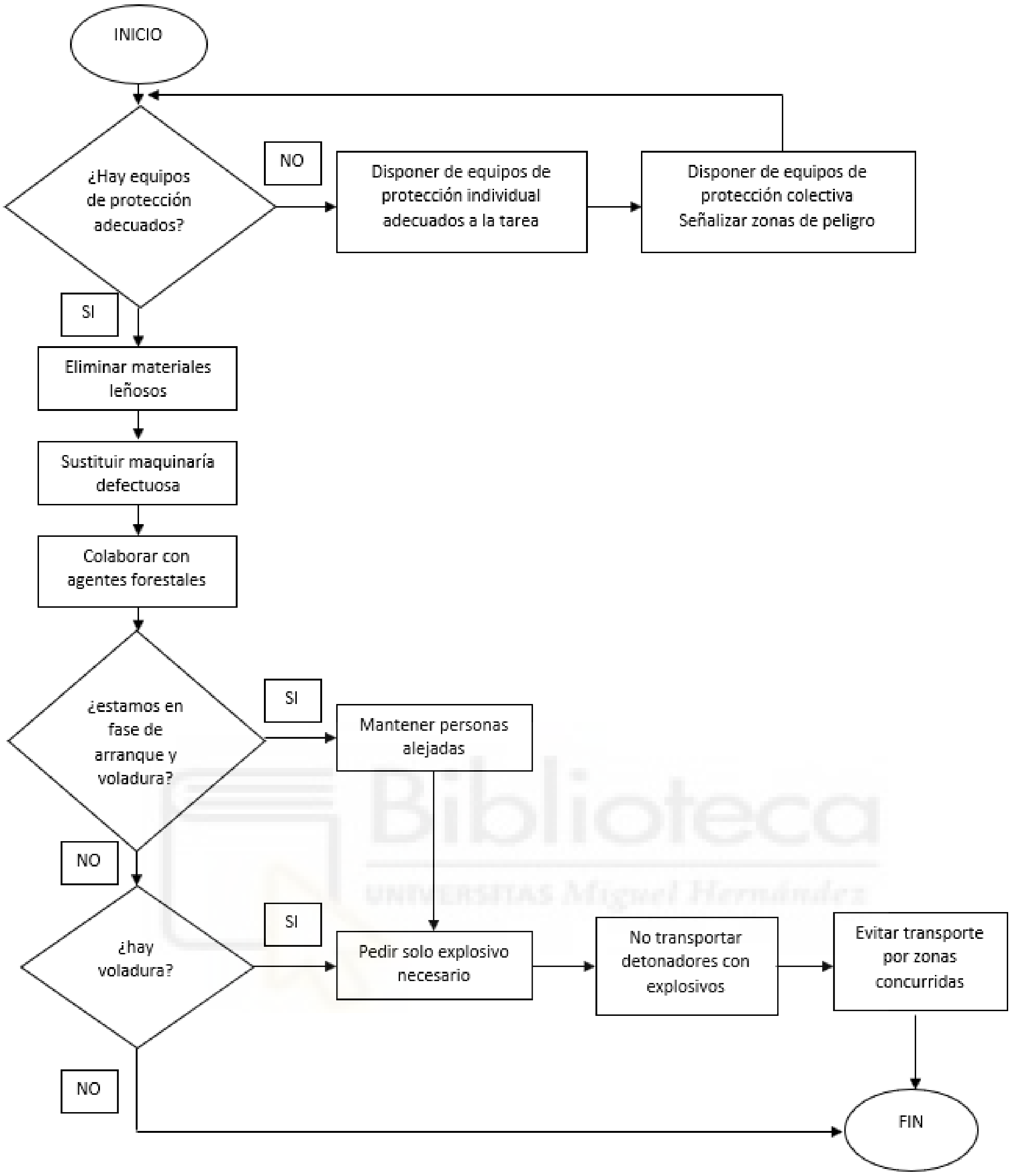

Figura 16. Diagrama de flujo para mejorar la seguridad y salud de los trabajadores en los trabajos en canteras. Fuente: elaboración propia.

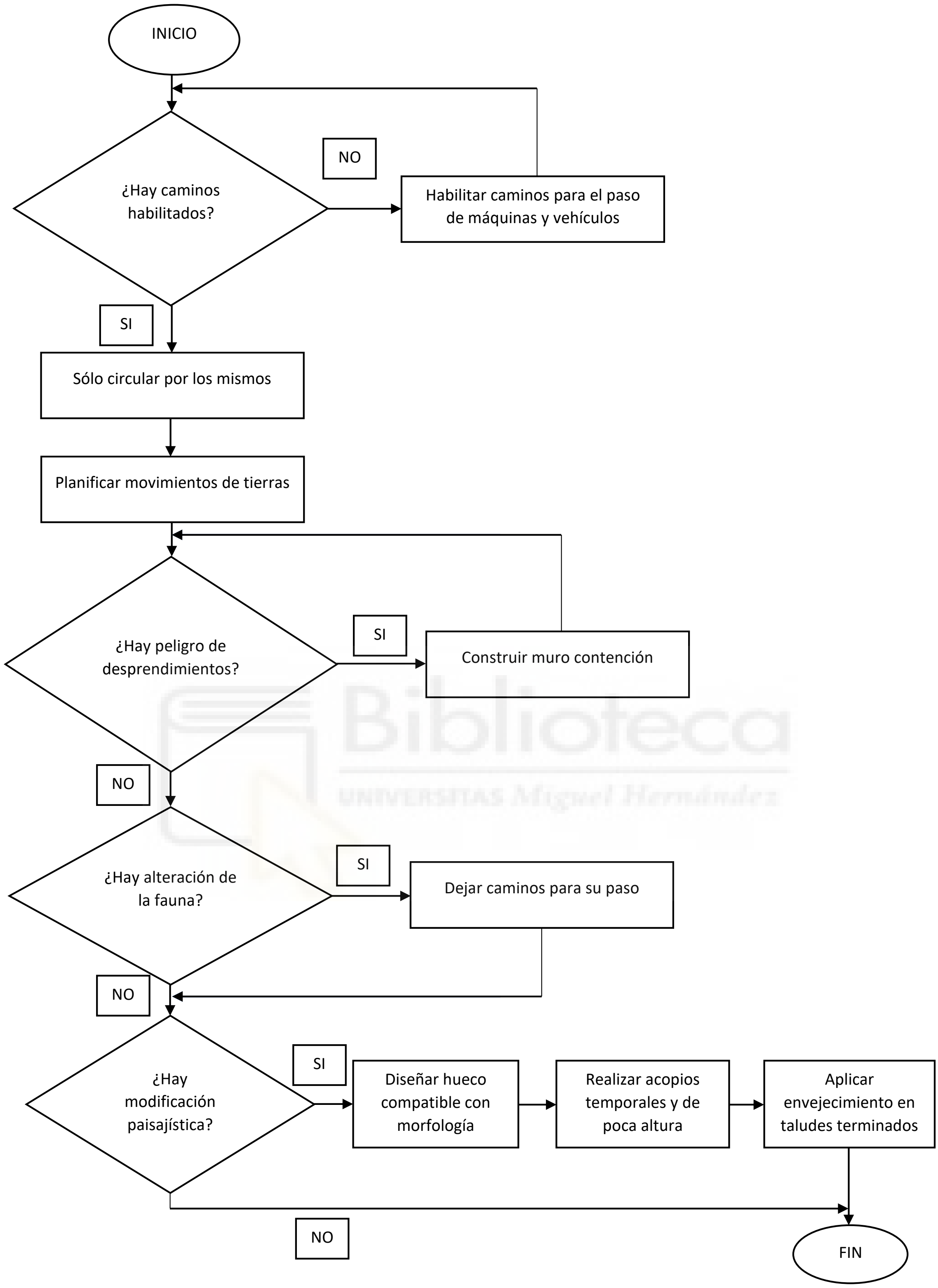

Figura 17. Diagrama de flujo para mejorar las superficies alteradas en las explotaciones y reducir la afección del paisaje, fauna y flora. Fuente: elaboración propia.

4.2. Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas". Que da respuesta al objetivo general indicado y al primer y segundo objetivo específico.

4.2.1. Técnicas de rehabilitación encontradas que se utilizan en canteras en la Región de Murcia.

La mejora de las propiedades del suelo mediante la aplicación de materia orgánica está ligada a la historia de la agricultura. Actualmente se aplica una gran variedad de enmiendas de diferentes fuentes ligadas a la restauración de suelos tras las operaciones mineras. Tras la revisión de los diferentes artículos sobre restauración de canteras comentados en materiales y métodos, se ha visto que la aplicación de residuos orgánicos es beneficiosa para el suelo y que su aplicación, produce un aumento de la materia orgánica del suelo, mejora la fertilidad del suelo, estimula la formación de agregados y el desarrollo de las poblaciones microbianas, además, mejora la infiltración y la retención del agua. Con la aplicación de estos residuos, se cumple con las estrategias europeas de cero residuos y se contribuye con la economía circular, además, se disminuye la acumulación de residuos que suponen un problema para su eliminación.

Para restaurar zonas áridas y semiáridas degradadas y con importantes índices de erosión, como la Región de Murcia, es necesario establecer una cubierta vegetal además de restaurar el suelo. El uso de especies nativas para la restauración, es de especial interés para el equilibrio del ecosistema, además, estas especies se adaptan mejor a las condiciones climáticas del suelo.

Las técnicas que se han encontrado en la recuperación de espacios mineros en zonas áridas y semiáridas junto con los resultados más destacables de las mismas han sido las siguientes:

- Aplicación de mantillo de diferentes tipos de turba: este mantillo limita la pérdida de agua, mejora la filtración y el crecimiento de las raíces, además, establece la vegetación y reduce la erosión. Este mantillo también mejora la estabilidad de los agregados. Sin embargo, se ha encontrado en algunos experimentos con uso de mantillo vegetal que no produce efectos significativos sobre la tasa de supervivencia de las plantas en ambientes áridos dónde hay bajas precipitaciones, ya que poca agua de lluvia puede llegar al suelo. Por otro lado, en otros estudios, la aplicación de mantillo está relacionado con mejoras en el contenido del agua del suelo, y mejora el establecimiento de la planta, particularmente en zonas áridas y semiáridas. Para evitar la pérdida de agua, se aplica en ocasiones junto a este mantillo, plástico, piedras o astillas de madera. Al observar los resultados de algunos estudios, con respecto al uso de grava, no se observan efectos significativos en el crecimiento de las plantas; y con respecto al uso de astillas de madera, se han encontrado efectos contradictorios en el establecimiento de las plantas.

- Compost de residuos sólidos urbanos (RSU): aumenta el contenido de carbono orgánico del suelo, además, aumenta la biomasa microbiana y altera la composición de la comunidad hacia una comunidad dominada por hongos.
- Lodos de depuradora: proporcionan mayor estabilidad de los agregados del suelo. Los suelos tratados con estos lodos, tienen concentraciones más altas de actinobacterias, sin embargo, el contenido y la proporción de biomasa microbiana, tanto en suelos restaurados como de naturales, responde con el tiempo a los cambios estacionales y al desarrollo de la vegetación.
- Combinación de RSU con lodos de depuradora: mejoran las propiedades microbiológicas del suelo y mejoran la respiración del suelo. Además, producen actividades enzimáticas que se correlacionaron positivamente con el contenido de carbono orgánico y nitrógeno, favoreciendo la productividad y fertilidad del suelo. También contribuyen al crecimiento de las plantas a largo plazo en estos climas áridos y semiáridos.
- Combinación de RSU, lodos de depuradora y grava: favorecen la creación de poros y espacios disponibles para la infiltración rápida y el desarrollo radicular.
- Purines de cerdo: mejora de la fertilidad del suelo facilitando una mayor colonización de la vegetación natural. La aplicación sola del purín no siempre aumenta el contenido de carbono del suelo, debido a su bajo contenido de carbono y su rápida mineralización, además, su alto contenido en carbono lábil, nitrógeno y fósforo disponible podría acelerar la descomposición del carbono del suelo nativo. En cambio, en la zona rizosférica, debido a la liberación de exudados de raíz, la aplicación del purín incrementa el carbono orgánico total y el nitrógeno, puede mejorar la estructura del suelo y proporcionar nutrientes para poblaciones microbianas, siendo la base para garantizar la recuperación del ecosistema. Además, el purín de cerdo es un buen fertilizante debido a la gran cantidad de nutrientes proporcionados, necesarios para promover el desarrollo de la vegetación. El purín de cerdo aumenta la capacidad de intercambio catiónico (CIC). El crecimiento de hongos es más estable con el tiempo, estos hongos son capaces de degradar compuestos orgánicos más complejos, lo que puede permitir un crecimiento más estable a largo plazo.
- Residuos de mármol: al aplicarlos junto con enmiendas orgánicas, reducen la degradabilidad de estos compuestos orgánicos, de este modo, se mejora el secuestro del carbono. Además, aumentan el pH del suelo y favorece la acumulación y la estabilidad de materia orgánica.
- Combinación de purines de cerdo con residuos de mármol: se aplican residuos de mármol junto con el purín de cerdo ya que este aporte de carbonatos, estabiliza la materia orgánica fresca y lábil del purín de cerdo, con esto se consigue aumentar el contenido de carbono en el suelo. Esta combinación produce un crecimiento bacteriano acumulado. Aumenta el crecimiento de la vegetación nativa, incrementa la cubierta vegetal y la biodiversidad.
- Estiércol de cerdo: aumenta el pH y mejora las condiciones para el crecimiento de la planta.

- Combinación de estiércol de cerdo con restos de mármol: mejora el establecimiento de la vegetación, aunque reducen el agua disponible.

4.3. Restoration Techniques Applied in Open Mining Area to Improve Agricultural Soil Fertility.

4.3.1. Residuos aplicados en una cantera del noroeste de la Región de Murcia.

Los tratamientos con residuos orgánicos que se aplicaron en las parcelas, se escogieron debido al problema que supone su eliminación en la Región de Murcia y a su elevada disponibilidad. La industria porcina representa un grave problema medioambiental debido a su gran volumen producido, así que se busca como tratar esto de una forma ambiental racional. El compost de RSU también es un problema en la Región de Murcia, debido a su gran cantidad, por lo que se quieren aprovechar y aplicar en los tratamientos. Además, los residuos de poda leñosa, son procedentes del olivo, la vid y el almendro de la comarca. El almendro representa más del 12% de la superficie agrícola de la Región de Murcia, y con su utilización de reduce el problema del abandono y la incineración incontrolada. La vid y el olivo, están en regresión por abandono, especialmente en zonas marginales y bancales, así que su abandono provoca un colapso en terrazas y la aparición de diferentes formas de erosión.

Además de los residuos orgánicos aplicados, se utilizó el NKP 15-15-15 puesto que es un fertilizante agrícola común y de fácil aplicación (ya que es de gránulo sólido), y además, contiene los 3 elementos más demandados por las plantas del suelo, y su lenta disolución permite la liberación relativamente lenta de nutrientes del suelo.

4.3.2. Aplicación de tratamientos con residuos en una cantera situada al noroeste de la Región de Murcia.

Tras los resultados obtenidos una vez realizado el análisis estadístico, se observa que, en todos los tratamientos aplicados, incluso en las parcelas de control, el pH del suelo supera el valor de 8.5, así que, es un suelo alcalino por matriz calcárea, debido a la naturaleza de la zona y con alta presencia de carbonato cálcico. Valores similares se encontraron en otro estudio en el que se combinaban diferentes enmiendas orgánicas (Luna et al., 2016). En otros estudios (Fernandez and Barba, 2010; Kabas et al., 2013), se observó que la presencia de carbonato cálcico procedente del mármol en las zonas mineras, aumentaba el nivel del pH del suelo, manteniéndose estable durante al menos 1 año. Después de 9 meses de tratamiento, las parcelas tratadas con NKP y purín de cerdo disminuyeron ligeramente el pH, incluso con valores inferiores a las parcelas de control. Resultados similares se observaron en un estudio realizado en suelos de canteras calcáreas de clima semiárido (Rodriguez et al., 2020), en el que se aplicaron lodos y compost de RSU, dónde los valores de pH disminuyen con el tiempo. Por el contrario, en las parcelas tratadas con compost de RSU y residuos de poda leñosa, a los 9 meses de la aplicación de los tratamientos, aumentó ligeramente el pH.

La disponibilidad de nutrientes como K, Ca y Mg estaría asociada con la matriz de carbonato cálcico ya que son más móviles a pH superiores a 6 (Zanuzzi et al., 2009).

Además, se demostró que, con la aplicación de las enmiendas orgánicas utilizadas y el fertilizante inorgánico, se incrementaron considerablemente los macronutrientes del suelo (N, K, P, y Na, en mayor medida, y Ca y Mg en menor medida), en relación con las parcelas de control, como era de esperar. Sin embargo, se observó que después de 9 meses, el contenido de estos nutrientes aún era mayor que en las parcelas de control, excepto el Ca y el Mg.

El aumento del contenido de N es muy positivo, ya que este macronutriente es un elemento esencial para el crecimiento de la vegetación y para las comunidades microbianas, que son responsables de muchos procesos necesarios para la nutrición de las plantas. Resultados similares se encontraron en dos estudios realizados en una cantera de piedra cálida con clima semiárido (Luna et al., 2016; Rodríguez et al., 2020), en el que se aplicaron lodos y compost de RSU, en el primer estudio los resultados mostraron mayor contenido de N, P y K, que las parcelas de control, y el segundo estudio, aumentó la disponibilidad de N. Otros estudios realizados en zonas semiáridas, mostraron un aumento del contenido de N, K y P, con la aplicación de residuos de mármol y purines de cerdo, con la aplicación de estiércol de cerdo y con la aplicación de compost elaborado con purines de cerdo (Martínez et al., 2014; Zanuzzi et al., 2009; Zornoza et al., 2017).

Los micronutrientes (Fe y Cu) también aumentaron significativamente con la aplicación de las enmiendas utilizadas. El Zn, aumentó en las parcelas tratadas con purines y compost de RSU a los 9 meses tras la aplicación de los tratamientos. El suelo tratado con NPK, adquiere valores de Zn similares a las parcelas de control, y en los suelos tratados con residuos de poda leñosa, la concentración de Zn disminuyó del muestreo 1 al muestreo 2, e incluso fue menor que en las parcelas de control. En un estudio realizado en un dique de desechos mineros (Martínez et al., 2014; Zornoza et al., 2017), tras dos años de aplicación de purines de cerdo y residuos de mármol, y con la aplicación de compost elaborado de purín de cerdo, se redujo la concentración de Zn en el suelo.

5. Conclusiones

En la minería a cielo abierto se utilizan diferentes metodologías para evaluar, prevenir y mitigar riesgos, por lo que no existe un método único y sencillo que responda rápidamente y que sea fácil de reproducir y confiable hasta la fecha, por tanto, se ha presentado un sistema, a través de diagramas de flujo, de mitigación de impactos que permite evaluar de una forma sencilla y sistemática los impactos en las canteras en zonas áridas y semiáridas (la mayoría de las veces los impactos son los mismos en zonas con condiciones climáticas similares), y que además, incluye propuestas que permiten desarrollar acciones para reducir los impactos negativos durante la fase activa de la explotación y una vez finalizada. Además, usar estos diagramas antes de empezar la explotación, permite prevenir posibles impactos ambientales.

Sin embargo, como se deduce del análisis preliminar realizado en el artículo 2 sobre el marco legislativo, la mitigación de impactos ambientales está sujeta a posibles nuevas modificaciones que deberán ser incorporadas al marco metodológico de los EIA. En este sentido, el establecimiento de diagramas de flujo permite su incorporación y actualización de forma más sencilla, al igual que su posterior aplicación y evaluación durante la explotación y tras finalizar esta.

La producción de residuos es un problema crucial, por ello se buscan formas de reutilizar estos residuos de forma que no contaminen el medio ambiente y puedan reintroducirse en la actividad económica dentro del marco de la economía circular y la estrategia cero residuos.

El aumento de la materia orgánica del suelo, la mejora de la revegetación y el aumento de la capacidad de retención de agua, son los aspectos más destacables en un entorno semiárido como el de la Región de Murcia.

El uso de diferentes tipos de residuos orgánicos es factible en la restauración de espacios mineros a cielo abierto en zonas áridas y semiáridas y con su uso se puede contribuir al aumento de la materia orgánica del suelo y de la capacidad de retención de agua, además, mejora el establecimiento de la vegetación.

La aplicación de las enmiendas utilizadas en una cantera del noroeste de la Región de Murcia, fue muy beneficiosa, ya que aumentó la disponibilidad de nutrientes vegetales en el suelo y, por lo tanto, facilita la mejora de las condiciones del suelo para el desarrollo de los cultivos. Además, en este ámbito, esta estrategia podría favorecer la implantación y la recuperación de una agricultura mediterránea de secano que también contribuya a la recuperación del paisaje.

El aprovechamiento de estos residuos en la restauración de zonas mineras es factible. Recuperar los sistemas suelo-planta es una estrategia necesaria para el paisaje, la agricultura y la silvicultura en áreas restauradas.

6. Referencias bibliográficas.

1. Aitken, R.L.; Moody, P.W. Interrelations between Soil pH Measurement in Various Electrolytes and Soil Solution ph in Acidic Soils. Aust. J. Soil Res. 1991, 29, 483–491. DOI: 10.1071/SR9910483.
2. Almendro-Candel, M.B.; Lucas, I.G.; Navarro-Pedreño, J.; Zorpas, A.A. PHysical Properties of Soils Affected by the Use of Agricultural Waste: Agricultural Waste and Residues; Aladjadjiyan, A., Ed.; IntechOpen: London, UK, 2018; pp. 9–28.
3. Anderson, M.J. Permutation tests for univariate or multivariate analysis of variance and regression. Can. J. Fish. Aquat. Sci. 2021, 58, 626–639. DOI: 10.1139/f01-004.
4. Antonsiewicz, D.M.; Escude-Duran, C.; Wierzbowska, E.; Sklodowska, A. Indigenous plant species with potential for the phytoremediation of arsenic and metal contaminated soil. Water Air Soil Poll. 2008, 19:197-210.
5. Asyakina, L.K.; Dyshlyuk, L.S.; Prosekov, A.Y. Reclamation of Post-Technological Landscapes: International Experience. Food Process. Tech. Technol. 2021, 51, 805–818. DOI: 10.21603/2074-9414-2021-4-805-818.
6. Atuchin, V.V.; Asyakina, L.K.; Serazerdinova, Y.R.; Frolova, A.S.; Velichkovich, N.S.; Prosekov, A.Y. Microorganisms for Bioreme-diation of Soils Contaminated with Heavy Metals. Microorganisms. 2023, 11, 864. DOI: 10.3390/microorganisms11040864.
7. Bakker, J.D., Colasurdo, L.B.; Evans, J.R. Enhancing Garry oak seedling performance in a semiarid environment. Northwest Sci. 2012, 86:300-309.
8. Bastin, J.-F.; Berrahmouni, N.; Grainger, A.; Maniatis, D.; Mollicone, D.; Moore, R. The Extent of forest in Dryland Biomes. Science. 2017, 356, 635–638. DOI: 10.1126/science.aam652.
9. Beretta, A.N.; Silbermann, A.V.; Paladino, L.; Torres, D.; Bassahun, D.; Musselli, R.; García-Lamohte, A. Soil texture analyses using a hydrometer: Modification of the Bouyoucos method. Cienc. Investig. Agrar. 2014, 41, 263–271. DOI: 10.4067/S0718-16202014000200013.
10. Black, C.A. Methods of Soil Analysis: Part I PHysical and Mineralogical Properties; American Society of Agronomy: Madison, WI, USA, 1965. DOI: 10.2134/agronmonogr9.1.
11. Burger, J.; Gochfeld, M.; Kosson, D.S.; Brown, K.G.; Salisbury, J.A.; Jeitner, C. Risk to ecological resources following remediation can be due mainly to increased resource value of successful restoration: A case study from the Department of Energy’s Hanford Site. Environ. Res. 2020, 186, 109536. DOI: 10.1016/j.envres.2020.109536.
12. Carabassa, V.; Domene, X.; Alcañiz, J.M. Soil restoration using compost-like-outputs and digestates from non-source-separated urban waste as organic amendments: Limitations and opportunities. J. Environ. Manag. 2020, 225, 109909. DOI: 10.1016/j.jenvman.2019.109909.

13. Castelo, J.; Reba, R.; Duarte, J.; Bautista, J.S. Evaluación de Riesgos en la Industria Minera a Cielo Abierto. Semental. Sistema. Decide. Control. 2019, 202: 13-21.
14. Chaturvedi, R.K.; Singh, J. Restoration of mine spoil in a dry tropical region: A review. Proc. Indian Natl. Sci. Acad. 2017, 83, 789–844. DOI: 10.16943/ptinsa/2017/49123.
15. Clemente, A.S.; Werner, C.; Máguas, C.; Cabral, M.S.; Martins-Louçao, M.A., Correia, O. Restoration of a limestone quarry: effect of soil amendments on the establishment of native Mediterranean sclerophyllous shrubs. Restor. Ecol. 2004, 12:20-28.
16. Conesa, V., Conesa, L., & Conesa, V. Guía metodológica para la evaluación de impacto ambiental. Madrid, España: Mindi-Prensa, 2010.
17. Daraz, U.; Li, Y.; Ahmad, I.; Iqbal, R.; Ditta, A. Remediation technologies for acid mine drainage: Recent trends and future perspectives. Chemosphere 2022, 311, 137089. DOI: 10.1016/j.chemosphere2022.137089.
18. De Silva, M.S.T.L.; Rohitha, L.P.S.; Dharmaratne, P.G.R. Zero Waste Sustainable Mining and Processing Operation of Quartz. In Proceedings of the International Mineral Symposium, Colombo, Sri Lanka, 15 September 2018.
19. Directiva 2006/21/CE del Parlamento Europeo y del Consejo, de 15 de marzo de 2006, sobre la gestión de los residuos de industrias extractivas y por la que se modifica la Directiva 2004/35/CE.
20. Escribano MM, Mataix C, editors. La minería y el medio Ambiente. El recorrido de los minerales [Internet]. Madrid (ES): Consejería de Economía e Innovación Tecnológica, Dirección General de Industria, Energía y Minas. 2007, 1st ed. p. 201-221. Disponible en: http://conocelosaridos.org/pdfs/UT9_-_La_Mineria_y_el_Medio_Ambiente.pdf.
21. FAO. Standard Operating Procedure for Soil Available Phosphorus—Olsen Method; Food and Agriculture Organization of the United Nations: Rome, Italy, 2021.
22. FAO. Standard Operating Procedure for Analysis of Calcium Carbonate Equivalent in Soil—Volumetric Calcimeter Method; Food and Agriculture Organization of the United Nations: Rome, Italy, 2021.
23. Fernández-Caliani, JC; Barba-Brioso, C. Inmovilización de metales en suelos de minas contaminados peligrosos después de la aplicación de desechos de lechada de mármol. Una evaluación de campo en el distrito minero de Tharsis (España). J. Peligro. 2010, 181, 817–826. DOI: 10.1016/j.jhazmat.2010.05.087.
24. González, D.; Almendros, P.; Álvarez, J.M. Methods of analysis of elements in soils: Availability and fractionation. An. Quim. 2009, 105, 205–212.
25. Hueso-González, P.; Ruiz-Sinoga, J.D.; Martínez-Murillo, J.F.; Lavee, H. Geomorphology Overland flow generation mechanisms affected by topsoil treatment: application to soil conservation. Geomorphology. 2015, 228:796-80458.
26. Kabas, S.; Faz, A.; Acosta, J.A.; Zornoza, R.; Martínez-Martínez, S.; Carmona, D.M.; Bech, J. Effect of marble waste and pig slurry on the growth of native vegetation and heavy metal mobility in a mine tailing pond. J. Geochem. Explor. 2012, 123:69-76.

27. Kabas, S.; Arocena, J.M.; Acosta, J.A.; Faz, A.; Martínez-Martínez, S.; Zornoza, R.; Carmona, D.M. Syrian bean-caper (Zygophyllum fabago L.) improves organic matter and other properties of mine wastes deposits. Int. J. Phytoremediation 2013, 16, 366–378. DOI: 10.1080/15226514.2013.783552.
28. Kabas, S.; Faz, A.;, Acosta, J.A.; Arocena, J.M.;, Zornoza, R.; Martínez-Martínez, S.; Carmona, D.M. Marble wastes and pig slurry improve the environmental and lantrelevant properties of mine tailings. Environ. Geochem. Hlth. 2014, 36(1):41-54.
29. Khabali, H.; Kamal, EK. Quarrying in coastal Kenikra and its area of influence: environmental impact study. Est. andaluces. 2013, 30: 1-26. DOI: http://dx.doi.org/10.12795/rea.2013.i30.01.
30. Jing, Z.R.; Wang, J.M.; Zhu, Y.C.; Feng, Y. Effects of land subsidence resulting from coal mining on soil nutrient distributions in a loess area of China. J. Clean. Prod. 2018, 177, 350–361. DOI: 10.1016/j.jclepro.2017.12.191.
31. Ley 21/2013, de 9 de diciembre, de evaluación ambiental. Boletín Oficial del Estado, Madrid, Spain. 2013, 296: 98151-98227.
32. Ley 9/2018, de 5 de diciembre, por la que se modifica la Ley 21/2013, de 9 de diciembre, de evaluación ambiental, la Ley 21/2015, de 20 de julio, por la que se modifica la Ley 43/2003, de 21 de noviembre, de Montes y la Ley 1/2005, de 9 de marzo, por la que se regula el régimen del comercio de derechos de emisión de gases de efecto invernadero. Boletín Oficial del Estado, Madrid, ES. 2018, 294: 119858-119905.
33. Liu, S.L.; Li, W.P.; Qiao, W.; Wang, Q.Q.; Hu, Y.B.; Wang, Z.K. Effect of natural conditions and mining activities on vegetation variations in arid and semiarid mining regions. Ecol. Indicat. 2019, 103, 331–345. DOI: 10.1016/j.ecolind.2019.04.034.
34. Luo, A.K.; Hou, Y.; Hu, X.Y. Mining influence on underground water resources in arid and semiarid regions. Earth Environ. Sci. 2018, 113, 012131. DOI: 10.1088/1755-1315/113/1/012131.
35. Luna, L.; Pastorelli, R.; Bastida, F.; Hernández, T.; García, C.; Miralles, I.; Solé-Benet, A. The combination of quarry restoration strategies in semiarid climate induces different responses in biochemical and microbiological soil properties. Appl. Soil Ecol. 2016, 107, 33–47. DOI 10.1016/j.apsoil.2016.05.006.
36. Macci, C.; Peruzzi, E.; Doni, S. Monitoring of a long term phytoremediation process of a soil contaminated by heavy metals and hydrocarbons in Tuscany. Environ. Sci. Pollut. Res. 2020, 27, 424–437. DOI: 10.1007/s11356-019-06836-x.
37. Martínez-Fernández, D.; Arco-Lázaro, E.; Bernal, M.P.; Clemente, R. Comparison of compost and humic fertiliser effects on growth and trace elements accumulation of native plant species in a mine soil phytorestoration experiment. Ecol. Eng. 2014, 73, 588–597. DOI: 10.1016/j.ecoleng.2014.09.105.
38. Miralles, I.; Ortega, R.; Almendros, G.; Sánchez-Marañón, M.; Soriano, M. Soil quality and organic carbon ratios in mountain agroecosystems of South-east Spain. Geoderma. 2009, 150(1-2):120-128.
39. Mora-Barrantes, J.; Molina-león, O.; Sibaja-Brenes, J. Application of a method for the environmental impact assessment of university construction projects. Tecnol. Marcha. 2016, 29(3), 132-145. DOI: http://dx.doi.org/tm.v29i3.2893.

40. Murray, A.; Skene, K.; Haynes, K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. J. Bus. Ethics 2017, 140, 369–380. DOI: 10.1007/s10551-015-2693-2.
41. Olsen, R.S. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate; United States Department of Agriculture: Washington, DC, USA, 1954.
42. Opekunova, M.; Opekunov, A.; Somov, V.; Kukushkin, S.; Papyan, E. Transformation of metals migration and biogeochemical cycling under the influence of copper mining production (the Southern Urals). CATENA. 2020, 189, 104512. DOI: 10.1016/j.catena.2020.104512.
43. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 2007, 11, 1633–1644. DOI: 10.5194/hess-11-1633-2007.
44. Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Methods of soil recovery in quarries of arid and semiarid areas using different waste types. Span. J. Soil Sci. 2020, 2, 101–122. DOI: 10.3232/SJSS.2020.V10.N2.01.
45. Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas. Glob. J. Environ. Sci. Manag. 2021, 7, 565–586. DOI:10.22034/gjesm.2021.04.06.
46. Real Decreto 975/2009, de 12 de junio, sobre gestión de los residuos de las industrias extractivas y de protección y rehabilitación del espacio afectado por actividades mineras. Boletín Oficial del Estado, Madrid, ES. 2009, 143: 49948-49993.
47. Ritzén, S.; Sandström, G.Ö. Barriers to the Circular Economy—Integration of Perspectives and Domains. Procedia CIRP. 2017, 64, 7–12.DOI: 10.1016/j.procir.2017.03.005.
48. Rodríguez-Berbel, N.; Ortega, R.; Lucas-Borja, M.; Solé-Benet, A.; Miralles, I. Long-term effects of two organic amendments on bacterial communities of calcareous Mediterranean soils degraded by mining. J. Environ. Manag. 2020, 271, 110920. DOI: 10.1016/j.jenvman.2020.110920.
49. Senesi, N.; Plaza, C.; Brunetti, G.; Polo, A. A comparative survey of recent results on humic-like fractions in organic amendments and effects on native soil humic substances. Soil Biol. Biochem. 2007, 39(6):1244-1262.
50. Sheoran, V.; Sheoran, A.S; Poonia, P. Role of hyperaccumulators in phytoextraction of metals from contaminated mining sites: A Review. Crit. Rev. Env. Sci. Technol. 2010, 41(2): 168-214. DOI:10.1080/10643380902718418.
51. Sonter, L.J.; Ali, S.H.; Watson, J.E.M. Mining and biodiversity: Key issues and research needs in conservation science. Proc. R. Soc. B. 2018, 285, 20181926. DOI: 10.1098/rspb.2018.1926.
52. Soria, R.; Rodríguez-Berbel, N.; Ortega, R.; Lucas-Borja, M.E.; Miralles, I. Soil amendments from recycled waste differently affect CO2 soil emissions in restored mining soils under semiarid conditions. J. Environ. Manag. 2021, 294, 112894. DOI: 10.1016/j.jenvman.2021.112894.

53. Sort, X.; Alcañiz, J.M. Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. Land Degrad. Dev. 1996, 7(1): 69-76. DOI:10.1002/(SICI)1099-145X(199603)7:1<69::AID-LDR217>3.0.CO;2-2.
54. Wang, Z.Y.; Lechner, A.M.; Yang, Y.J.; Baumgartl, T.; Wu, J.S. Mapping the cumulative impacts of long-term mining disturbance and progressive rehabilitation on ecosystem services. Sci. Total Environ. 2020, 717, 137214. DOI: 10.1016/j.scitotenv.2020.137214.
55. Xiang, H.; Wang, Z.; Mao, D.; Zhang, J.; Zhao, D.; Zeng, Y.; Wu, B. Surface mining caused multiple ecosystem service losses in China. J. Environ. Manag. 2021, 290, 112618. DOI: 10.1016/j.jenvman.2021.112618.
56. Yildiz, T. The impacts of EIA procedure on the mining sector in the permit process of mining operating activities & Turkey analysis. Resour. Pol. 2020, 67, 1-17. DOI: 10.1016/j.resourpol.2020.101681.
57. Zanuzzi, A.; Arocena, J.M.; van Mourik, J.M.; Faz, A. Amendments with organic and industrial wastes stimulate soil formation inmine tailings as revealed by micromorphology. Geoderma. 2009, 154, 69–75.
58. DOI:10.1016/j.geoderma.2009.09.014.
59. Zhou, W.; Yin, W.; Peng, X.; Liu, F.; Yang, F. Comprehensive evaluation of land reclamation and utilisation schemes based on a modified VIKOR method for surface mines. Int. J. Min. Reclam. Environ. 2018, 32: 93-108. DOI: 10.1080/17480930.2016.1228031.
60. Zhu, X.H.; Chen, Y.; Feng, C. Green total factor productivity of China's mining and quarrying industry: A global data envelopment analysis. Res. Policy. 2018, 57, 1–9. DOI: 10.1016/j.resourpol.2017.12.009.
61. Zornoza, R.; Faz, Á.; Martínez, S.; Acosta, J.A.; Gómez, M.D.; Muñoz, M.A.; Sánchez, R.; Murcia, F.J.; Fernández, F.; López, E.; et al. Rehabilitación de una presa de residuos mineros mediante la aplicación de lodo de mármol y purín de cerdo para el desarrollo de una fitoestabilización asistida. Bol. Geol. Min. 2017, 128, 421–435. DOI: 10.21701/bolgeomin.128.2.010.

7. Anexo (publicaciones)

SJSS
SPANISH JOURNAL OF SOIL SCIENCE

Methods of soil recovery in quarries of arid and semiarid areas using different waste types

Métodos de recuperación del medio edáfico en canteras de zonas áridas y semiáridas mediante el uso de residuos
Métodos de recuperação do solo em pedreiras de zonas áridas e semi-áridas usando diferentes tipos de resíduos

AUTHORS

Peñaranda Barba M. A.[1,@]
marianpeba@gmail.com

Alarcón Martínez V.[2]

Gómez Lucas I.[1]

Navarro Pedreño J.[1]

@ Corresponding Author

[1]Departamento de Agroquímica y Medio Ambiente. Universidad Miguel Hernández de Elche. Edif. Alcudia. Avda. de la Universidad, s/n. 03202 Elche, Alicante, Spain.

[2]Departamento de Organización Industrial y Electrónica. Escuela de Ingeniería. Universidad Internacional de la Rioja. C/Almansa, 101. 28040, Madrid, Spain.

Received: 17.01.2020 | **Revised:** 21.05.2020 | **Accepted:** 22.05.2020

ABSTRACT

In the Region of Murcia, there are many abandoned quarries in which restoration processes have not been carried out, and there are others that have a restoration plan but soil rehabilitation has not been achieved. Open pit mining generates a great environmental impact in the area where the activity takes place since it alters the morphology of the earth's crust, pollutes the air, the surface and underground waters, eliminates the flora of the area and destroys the biotope, causing changes in the landscape and strong changes in ecosystems. There is an international concern to promote sustainable development and waste reuse. In the European Union and Spain there is a requirement to carry out a restoration plan for mining operations. Waste production is a big problem; ways of reusing waste without polluting the environment and reintroducing it into economic activity are sought. In this article, several techniques are compiled that have given satisfactory results in the restoration of mining spaces, mainly in the Region of Murcia (SE Spain), by using waste such as pig manure, marble debris, sewage sludge or compost of urban household waste. These wastes pose a problem due to their disposal if they are not reused, and their use to restore mining spaces is a good option against dumping, abandonment or incineration.

RESUMEN

En la Región de Murcia se encuentran abundantes explotaciones mineras abandonadas en las que no se ha llevado a cabo un proceso de restauración, y existen otras que disponen de un plan de restauración que no ha conseguido la adecuada rehabilitación del suelo. La minería a cielo abierto genera un gran impacto ambiental en la zona en que se desarrolla la actividad ya que altera la morfología de la corteza terrestre, contamina el aire y las aguas superficiales y subterráneas, elimina la flora de la zona y destruye el biotopo, causando modificaciones en el paisaje y fuertes cambios en los ecosistemas. Existe una preocupación internacional para promover el desarrollo sostenible, la reutilización de residuos y la exigencia en la Unión Europea y España para que se lleve a cabo un plan de restauración de las explotaciones mineras. La producción de residuos constituye un gran problema, se buscan maneras de reutilizarlos en las que no contaminen al medio ambiente y reintroducirlos en la actividad económica. En este artículo se recopila información sobre técnicas que han dado resultados satisfactorios en la restauración de espacios mineros, principalmente de la Región de Murcia (SE España), utilizando residuos como el purín de cerdo, restos de mármol, lodos de depuradoras o compost de residuos domésticos urbanos. Estos residuos suponen un problema por su eliminación si no se reutilizan y su uso para restaurar espacios mineros es una buena opción frente a los vertederos, abandonos o incineración de los mismos.

DOI: 10.3232/SJSS.2020.V10.N2.01

SJSS
SPANISH JOURNAL OF SOIL SCIENCE

RESUMO

Na Região de Múrcia, existem muitas explorações mineiras e pedreiras abandonadas, nas quais não foi realizado qualquer processo de restauração, e outras em que, embora possuindo um plano de restauração, a reabilitação do solo não foi alcançada. A exploração mineira a céu aberto gera um grande impacto ambiental na área onde se desenvolve a atividade, pois altera a morfologia da crosta terrestre, polui o ar e as águas superficiais e subterrâneas, elimina a flora da área e destrói o biótipo, causando alterações na paisagem e fortes mudanças nos ecossistemas. Existe uma preocupação internacional em promover o desenvolvimento sustentável e a reutilização de resíduos. Na União Europeia, incluindo em Espanha, há uma exigência para que se realizem planos de restauração das áreas onde ocorrem operações mineiras. A produção de resíduos é um grande problema; atualmente, procuram-se formas de reutilizar os resíduos sem poluir o ambiente e reintroduzi-los na atividade económica. Neste artigo, são compiladas técnicas que obtiveram resultados satisfatórios na restauração de espaços mineiros, principalmente na região de Múrcia (SE Espanha), utilizando resíduos como chorume de suínos, resíduos de mármore, lamas de ETAR ou composto de resíduos de sólidos urbanos. Estes resíduos representam um problema ambiental se não forem reutilizados. O seu uso para restaurar espaços de áreas mineiras é uma boa opção quando comparado com a sua inclusão em aterros, abandono ou incineração.

KEY WORDS
Circular economy, marble, mining, restoration, slurry.

PALABRAS CLAVE
Economía circular, mármol, minería, purines, restauración.

PALAVRAS-CHAVE
Atividade mineira, chorume, economia circular, mármore, restauração.

1. Introduction

Open-pit mining generates a great environmental impact because it alters the morphology of the earth's crust, pollutes the air, surface and underground water, eliminates the existing flora in the area and destroys the biotope. This activity can also affect the health conditions of the surrounding inhabitants. By causing these modifications, negative visual impacts and strong ecological changes in the affected ecosystems are generated in the landscape (Gunn and Bailey 1993; Sheoran et al. 2010; Sort and Alcañiz 1996).

This article presents the important mining heritage that the Region of Murcia (SE Spain) has. The importance that this activity has had, especially in the Northwest of Murcia in the nineteenth and twentieth centuries, has left some mining spaces that should be the subject of an environmental policy.

The regional government is clearly committed to the mining industry, an economic activity that it plans to protect and promote through regulations that would have a validity of at least 25 years and that favors the exploitation of quarries over any other use of the territory. The analysis of the cartography included in the mining guidelines reveals that 59 population centers and 241 housing groups would be less than two kilometers from quarries. The Autonomous Community hardly poses restrictions on mining activity for environmental reasons: only in the case that industrial activity affects a protected natural area. Important steps have been taken but there is still not enough action to protect and enhance the vestiges left by this activity.

At present, the mining regulations require a restoration plan to be carried out before starting exploitation in order to prevent or reduce possible adverse effects on the environment and health caused by mining activity, and to establish the necessary preventive measures so that these impacts either do not occur, or affect the environment to a lesser extent. In addition, the land must be rehabilitated once the operation has been completed. Directive 2006/21/EC, on the management of waste from extractive industries requires the rehabilitation of areas where mining waste facilities have been located, as does the pre-existing Spanish mining legislation. This Directive is carried out, on a basic basis, by Spanish Royal Decree

975/2009 of June 12 on the management of waste from extractive industries and the protection and rehabilitation of space affected by mining activities. Restoration and rehabilitation are among the most important measures, as it allows the exploited land to be integrated into its ecological and landscape environment, and to develop an alternative use to mining once its exploitation has ended (Escribano and Mataix 2007). With restoration, the aim is to return the original condition of the land, whereas with rehabilitation or recovery, a different use is achieved from that which the land had before being exploited.

In this article, the terms restoration and rehabilitation will be dealt with indistinctly, since the aim is to show that the soil must acquire such conditions that it is capable of serving as a biotope, allowing the development of living organisms, especially vegetation, regardless of the subsequent use to which the recovered space is destined.

Currently, there are abundant mining operations in which a restoration process has not been carried out and they have been abandoned, as in the case of the Region of Murcia. In addition, in other cases restoration plans have not achieved the correct rehabilitation of the soil. Thus, the objective of this review is to compile the most relevant information on the techniques used for the recovery of soils in open-pit mining spaces, which serve as a basis for future rehabilitation.
Restoration in arid or semi-arid areas, as is the case in the Region of Murcia, is much slower than in rainy areas due to the scarcity and torrential nature of the rainfall at certain times and the intense solar radiation in these areas contribute to desertification, which subjects the plants to severe water stress, contributing as a whole to increased soil erosion (Miralles et al. 2009).

2. State of the art 2000-2019

As a preliminary approximation, a bibliometric analysis was carried out based on the Scopus database, which allowed us to determine the interest of the scientific community in the restoration of open-pit mining spaces. In this sense, 446 documents were located for the period 2000-2019 using the “quarry restoration” search. Of these documents, only 338 corresponded to scientific articles.

Focusing our attention on these articles, the country with the highest number of publications on the subject was Spain (**Figure 1**). In the Spanish contributions, 35 of them were related to Murcia. In addition, in this group of countries with the greatest number of publications, the European countries stand out, indicative of the interest in solving an environmental problem such as restoration after mining activity.

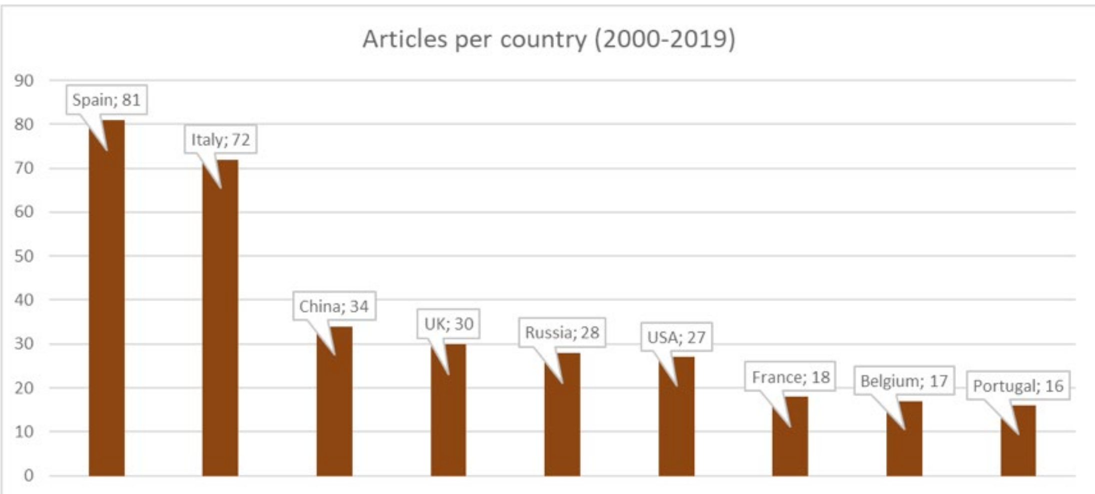

Figure 1. Number of published articles on quarry restoration published by country in the period 2000-2019 (own source).

In terms of the subdisciplines in which Scopus distributes the published articles, the one corresponding to "Environmental Science" stands out above all others, followed by the publications in "Earth and Planetary Sciences", as shown in **Figure 2**.

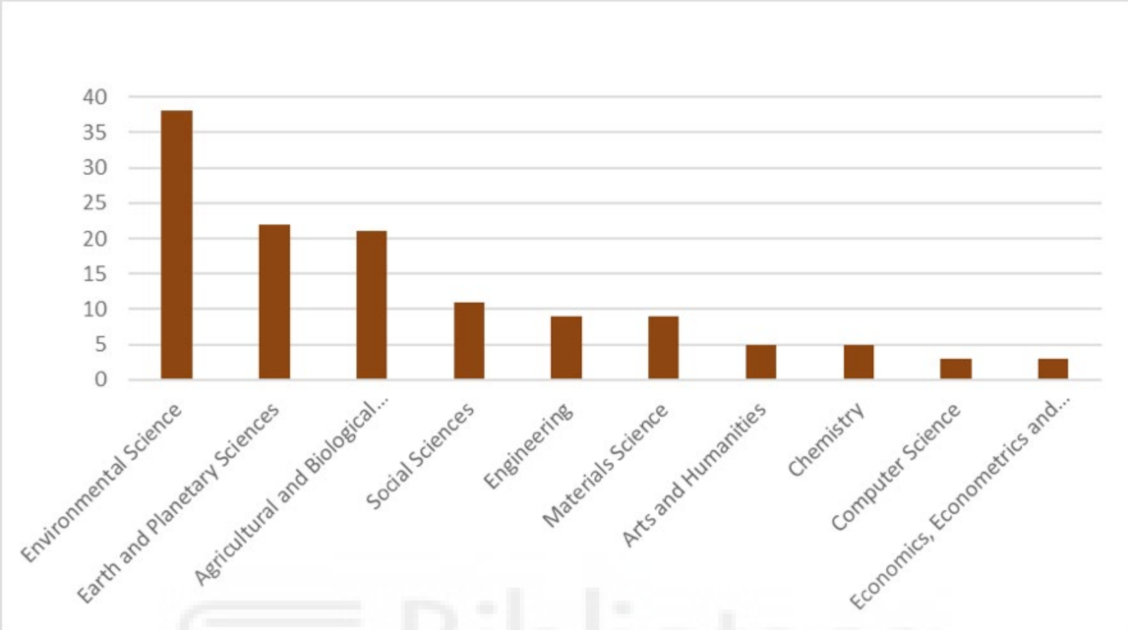

Figure 2. Subdisciplines where the articles published on quarry restoration in the Scopus database in the 2000-2019 period are grouped (own source).

In the studies with Spanish authors on waste used in mine restoration, those where sludge is used stand out, especially those that use sludge from wastewater treatment (**Figure 3**).

To conclude this preliminary analysis, the most frequently cited articles by Spanish authors in which the term "waste" is used are the following: (a) based on "pig slurry, municipal solid waste, marble waste", the publication of Castro-Gomes et al. (2012); (b) if we consider "sewage sludge, quarry solid waste", the most cited article is that of Luna et al. (2016a).

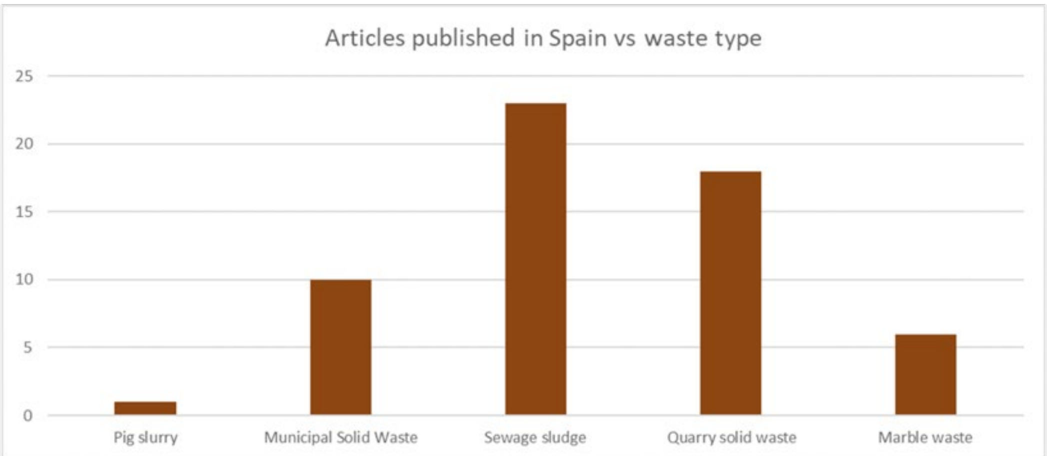

Figure 3. Scopus publications by Spanish authors in the period 2000-2019 according to the type of waste used in quarry restorations (own source).

3. Situation in the Region of Murcia

Nowadays, in the Region of Murcia, there are a large number of abandoned quarries in which no restoration plan has been carried out, as in the rest of Spain. In the case of Murcia, most of them are located in the northwest of the Region. According to the latest data prepared by the Regional Directorate General of Industry, Energy and Mines, in 2006 there were 88 aggregate quarries in the Region of Murcia, of which 54 were active, and 144 ornamental rock quarries of which 83 were still active, giving a total 273 existing exploitations in the Region of Murcia of which 157 were active. The Region of Murcia is one of the areas with the greatest geological potential on a national scale, as it represents about 12.6% of the extraction of marble and limestone. Many areas are affected by metalliferous mining activities. These areas are located in Cartagena and La Unión, so for more than 2,500 years until 1991, Phoenicians, Romans, Arabs, Carthaginians and Spaniards have been extracting zinc, lead, copper, silver, manganese, iron and tin (Conesa and Faz 2009). Thus, all these mining activities have caused a large accumulation of heavy metals and generated acid drainage in the mines (Faz et al. 2008).

A high percentage of the mountains of the Region of Murcia are formed by limestones; predominant in the mountain ranges of Moratalla, Villafuertes, Gavilán, Cerezo, Los Alamos, Mojantes, Quípar, Oro, Ricote, Manzanete, Pila, Corque Place, Quibas, Espuña, Carrascoy, among others. The public administration today is faced with a large number of abandoned areas, with consequent landscape degradation (some of which are used as uncontrolled landfills), and with active exploitations, which should be restored in the future.

The limestones are the rocks that are currently most exploited in the region, their main use being gravels and concretes, or masonry stone and ornamental rocks, which are marketed both inside and outside the region. Some of the best-known varieties of ornamental rocks from quarries located in the region are: Caravaca red, Cehegín red, Cehegín gray, Cehegín medium and Quipar red, which are Jurassic red nodular limestones; and the ivory cream of the Sierra de la Puerta, which is a Paleogene limestone. They are known as marbles, although from the geological point of view, they are sedimentary carbonate rocks.

The Region of Murcia has a Mediterranean climate with hot and dry summers and mild winters, although with frequent inland frosts, and rains in spring and autumn. The general characteristic of this climate is its scarcity of precipitation, concentrated over a few days of the year with a maximum in autumn. These rains, generally torrential, are produced when a mass of warm and humid air from the Mediterranean Sea rises over the coastal mountains, meets another mass of cold air and precipitates. These rains should be considered because of the high erosive power they can trigger when it comes to recovering mining spaces.

According to the Köppen climate classification, several climates are distinguished in the Region: semi-arid warm (BSh), semi-arid cold (BSk), and Mediterranean (Csa).

In the BSh climate the average annual temperature is above 18 °C and rainfall is scarce. Solar evaporation exceeds rainfall; it is a hot and dry climate. In the BSk climate, the average annual temperature is below 18 ºC. Rainfall is also scarce and evaporation like in the BSh also exceeds rainfall; this climate is cold and dry. The CSa has an average temperature of the coldest month less than 18 °C and higher than -3 °C, and that of the warmest month is greater than 10 °C and the temperature of the warmest month exceeds 22 °C. Precipitation exceeds evaporation and there are seasonal rains. Summer is dry, so the minimum rainfall coincides with the period of higher temperatures. The rainiest season is not winter.

4. Keys for the recovery of the environment

The soil is the fundamental pillar for recovery of the open mining areas, and next to it, the vegetation that is a key factor for landscape regeneration. If we add the need to reuse waste based on circular economy to these keys, we can conclude that the three basements in rehabilitation are soils, vegetation and the reuse of waste as the main source of organic matter. **Figure 4** shows the general restoration process of a quarry.

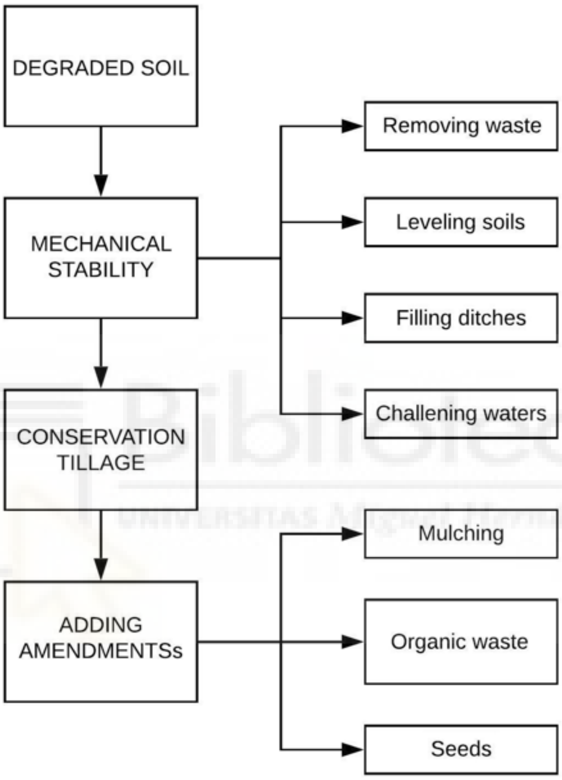

Figure 4. General restoration process of a quarry (own source).

The environmental properties affected by open-pit extractive activities are very diverse, altering both the morphology and the processes that affect the territory, changing them completely. If we focus on the example of the Region of Murcia, extrapolated to other arid and semi-arid Mediterranean areas, open pit limestone mining is particularly harmful due to the type of extraction (Luna et al. 2016b). In addition, these areas are susceptible to desertification and very sensitive to erosion due to the absence or scarcity of vegetation cover. Therefore, in order to restore an area without soils or with highly degraded and often unstructured soils, a surface layer with adequate physical, chemical and biological properties should be prepared. The usual strategy in the restoration is therefore to re-establish the edaphic cover, but in many cases, to build a new edaphic environment - a Technosol (IUSS Working Group WRB 2015).

After mechanical stabilization of the environment, efforts should be directed towards improving the soil by adding organic materials (e.g. through waste) and then revegetation, in such a way that allows the landscape lost after mining to be returned to its previous state.

Before creating this layer of "new soil" or artificial soil created *ad hoc* (Technosol), it is necessary to clean the surface, removing materials or debris (artifacts) from the soil that are not useful for its recovery and leveling it to prevent erosion. It is crucial to adapt the hydrography for proper rehabilitation and so the gullies and trails must be covered and the waters must be channeled to prevent the material supplied from flowing and dragging (Zornoza et al. 2017).

Once mechanical stability is achieved, the soil is prepared using tillage techniques to reduce compaction and bulk density and increase the porosity of the arable layer, which in turn facilitates seed germination and seedling development (Kabas et al. 2012). It is also necessary to recover the fertility of the soil, incorporating or covering the surface with organic waste that in turn remedies the soil, fertilizes and protects it.

The strategy based on the increase of organic matter in the soil is essential to guarantee a real rehabilitation of the soils, since soil organic matter is a property closely related to soil structure (Tisdall and Oades 1982), aeration, water retention and circulation, reduction of erosion rates, stimulation of biological activity and the increase of fertility by nutrient release (Smith et al. 1993; Shafi et al. 2007). Soil organic matter is universally recognized as one of the most important factors responsible for soil fertility and protection against pollution, degradation, erosion and desertification, especially in semi-arid areas (Senesi et al. 2007). This new substrate must be transformed into a fertile soil in the short and medium term, which improves biological activity, activates biogeochemical cycles, and accelerates the regeneration of plant communities (Caravaca et al. 2002; Heneghan et al. 2008; Domene et al. 2010; Soliveres et al. 2012).

To achieve this, the incorporation of organic matter must allow the structure to be neither too loose nor too compact (Jorba et al. 2002), and it must achieve good water infiltration, be resistant to erosion and contain nutrients and microorganisms that allow vegetation to grow (Banning et al. 2011; Muñoz-Rojas et al. 2016).

5. Organic matter and soil properties

The improvement of soil properties by application of organic matter is a strategy linked to the roots of the history of agriculture. It was traditionally based on the application of organic residues and waste from animal origin. However, a wide variety of amendments from many different sources are currently applied. These are also used in the restoration of soils in mining operations.

Waste from activities such as slaughterhouses, forest management, livestock, agriculture, households, wastewater treatment (biosolids) or food industries can be considered as organic products or waste (Navarro-Pedreño et al. 1995). Organic waste must have a biological origin and composition and contain the so-called bioelements, to a greater extent carbon, hydrogen and oxygen (C, H and O) and to a lesser extent nitrogen, phosphorus and sulfur (N, P and S).

5.1. Increase in soil organic matter

The application of organic waste to the soil is a useful tool to maintain and increase the amounts of organic matter (Mondini et al. 2008; Jorba and Vallejo 2008; Kabas et al. 2014). Organic waste can be used as a source of nutrients, improving soil fertility and stimulating the formation of aggregates and the development of microbial populations (Ortiz et al. 2012; Ye et al. 2002; Zanuzzi et al. 2009). Effective recycling of organic waste in soil requires optimization of waste management to minimize CO_2 emissions and optimize the efficiency of soil C retention. Since the main objective after the application of organic amendments is the increase of organic matter, it is crucial to carry out an exhaustive study on the stability and mineralization of organic C (Zornoza et al. 2012). Therefore, amendments can be implemented with nutrients that are not mineralized so quickly that the organic matter disappears before the vegetation cover is properly developed. In addition, the implementation of these amendments could be beneficial to the environment, as it prevents their incineration or uncontrolled dumping, thereby helping to promote the circular economy.

These amendments improve soil C sequestration by replacing labile organic carbon from aggregates with more stable compounds (Ojeda et al. 2015), contributing to plant growth (Hemmat et al. 2010). With the application of organic amendments, in addition to total organic carbon (TOC) the total nitrogen (TN) also increases. These increases are associated with increases in basal respiration and dehydrogenase activity, which are accepted as indicators of total soil microbial activity (García et al. 1997; Bastida et al. 2006). The effect of organic amendments on soil TOC depends on the chemical composition of amendments (Tejada et al. 2009), which determines the rate of their mineralization by soil microorganisms (Hahn and Quideau 2013).

5.2. Biological activation

Soil biological activity is related to soil health and will act as an indicator of the effectiveness of recovery procedures (Epelde et al. 2009). In this sense, biochemical properties are considered potentially sensitive, early and effective indicators of soil health in contaminated soils (Clemente et al. 2007). There is a direct relationship between the addition of organic matter with the stimulation of growth and the activity of the microbial community of soils degraded by mining, resulting in the mineralization of nutrients for plants (Alvarenga et al. 2014) and the increase of fertility and soil quality (Diacono and Montemurro 2010).

Soil organic matter is a source of energy and carbon for soil microorganisms, which promote the formation of micro and macro-aggregates (Lehmann and Rillig 2015). There is clear evidence that microorganisms are involved in the aggregation process because microbial activity controls the production of exudates that act as binding agents in aggregates (De Gryze et al. 2005). In any soil where clay is present, interactions between polysaccharide exudates, organic colloids and other decomposition products promote stability (Dontsova and Bigham 2005).

A group of these microorganisms, arbuscular mycorrhizal fungi (AMF), produce a proteinaceous material called glomalin present in roots, soil and hyphae, and this protein has the function of favouring the sequestration of C (Rillig 2004).

5.3. Structure and formation of aggregates

The application of organic waste, as indicated above, favors the formation of aggregates and thus the structure of the soil, so that it could lead to improved infiltration and water retention, making the soil more suitable for plant growth (Hueso-González et al. 2014). The stability of soil aggregates and the architecture of porous space affect water movement and storage, aeration, erosion, biological activity and plant growth (Bosch-Serra et al. 2017). At the same time, by achieving stable aggregates, the organic material is protected from microbial decomposition (Bronick and Lal 2005), erosion is reduced, root development is promoted (Tisdall and Oades 1982), soil structure degradation is prevented and water storage is favoured (Franzluebbers 2002). In short, organic matter amendments increase the stability of aggregates, contribute to the formation of new aggregates, increase porosity and water retention capacity, facilitate the development and establishment of vegetation and the formation of microbial communities and reduce erosion (Six et al. 2004).

In semi-arid environments, the presence of carbonates interferes with the relationship between clay minerals and soil aggregation, resulting in improved macro-aggregated stabilization in soils rich in carbonates, but with less porosity within macro-aggregates (Fernández-Ugalde et al. 2013). Moreover, the contribution of calcium carbonate in certain mining areas stabilizes the organic carbon added by organic amendments, minimizing losses of soil organic matter by mineralization (Zornoza et al. 2013).

5.4. Microbiota and enzyme activity

Soil microbiota helps the formation of soil structure, plant establishment and transformation of soil organic matter (Zink and Allen 1998). Many studies have demonstrated the importance of soil microbial communities for successful plant establishment and growth

(Kulmatiski et al. 2008; Epelde et al. 2010). However, extreme conditions caused by mining activities generally have a negative influence on soil biological activity (Asensio et al. 2013; Zornoza et al. 2013).

Not all organic waste produces the same effects on the soil microbiota. The microbial community responds faster to environmental changes than plants and is very sensitive (Harris 2009). However, many factors such as soil organic matter characteristics, soil moisture and soil temperature can affect biomass (Zhou et al. 2014) and soil microbial community structure (Hortal et al. 2015). The structure and activity of the soil microbial community may change in response to the quality of organic amendments. Therefore, soil processes mediated by microorganisms may also change depending on these changes in the microbial community (Lucas et al. 2014). In addition, since bacteria and fungi have different pH preferences (Rousk et al. 2009), the addition of alkaline amendments increases the pH of the soil, alters the balance between fungal/bacterial growth and the microbial structure of the community. This in turn can change the nature and magnitude of soil processes related to specific microbial groups (Zornoza et al. 2016). Changes in soil microbiota due to environmental factors should be reflected in the level of enzymatic activity of the soil (Kandeler et al. 1996). After the application of residues, there are changes in soil function that may indicate the evolution of microbial activity (Li et al. 2015). In general, organic amendments increase the enzymatic activities (b-glucosidase, alkaline phosphatase and urease) related to biogeochemical cycles of the elements in the soil (Pascual et al. 1997; Ros et al. 2003; Bastida et al. 2007; Tejada et al. 2009; Santos et al. 2014).

In semi-arid Mediterranean areas, indigenous microbial communities are well adapted to severe climatic conditions such as high temperatures and scarce rainfall, while new soil microbial communities from organic waste are more sensitive to water stress than native soil microbiota (Hueso et al. 2011). Organic amendments can also cause changes in the microbial populations of the native soil due to the diverse available substrates they provide (Luna et al. 2016b). Organic amendments have a strong effect on phospholipid contents, stimulating bacterial and fungal proliferation, as demonstrated by several authors (Marschner et al. 2003; Bastida et al. 2008; García-Orenes et al. 2013; Lazcano et al. 2013; Luna et al. 2016b). The profiles obtained from the phospholipid analysis were positively correlated with the total carbon content (TOC), the total N content and the total P content.

6. Revegetation

In order to restore degraded arid and semi-arid areas with significant rates of erosion such as the Region of Murcia, it is necessary to establish a vegetation cover in addition to restoring the soil (Zornoza et al. 2017).

In arid and semi-arid regions, due to low rainfall, severe water stress is produced in plants. Normally the species used are seedlings or greenhouse plants, which experience post-transplant shock after sowing, associated with moisture or nutritional stress (Jacobs et al. 2005; Bateman et al. 2018). Therefore, it is necessary to use plant species adapted to water stress, the nutrients existing in the restored area and the climatology of the site, since these have developed morphological and physiological adaptations that allow them to survive and grow in difficult conditions (Clemente et al. 2004).

The use of native species for restoration is of special interest to maintain the equilibrium of the ecosystem. In addition, native plants adapt to climatic and soil conditions and provide the basis for natural ecological succession (Méndez et al. 2007). Native plants have greater possibilities of survival, growth and reproduction under conditions of environmental stress than plants introduced from other environments (Adriano 2001; Antonsiewicz et al. 2008). It is a very important and basic strategy in all mining operations to have a seed bank of the existing species prior to exploitation, or failing that, prepare one with the plants of the closest environment with the same conditions as those that were initially in the quarry. In this way, it will be possible to use species characteristic of the area that can guarantee a better success in revegetation.

The beneficial effects of revegetation are very relevant from a soil and landscape point of view. Plants reduce water erosion by intercepting rain (Roundy et al. 2017; Tromble 1987), favor the increase of water infiltration (Huang et al. 2015; King et al. 2012; Piñol et al. 1991) and promote soil regeneration.

The application of organic matter inputs as a restoration technique increases the growth of plants due to the increase of available nutrients, mainly from organic amendments (Maisto et al. 2010; Moreno-Peñaranda et al. 2004). Thus, the appropriate combination of organic amendments and revegetation promotes the growth of plants (Caravaca et al. 2002) and, ultimately, the landscape recovery of the restored area.

7. Waste types applied as amendments

The European Commission (EC), during 2014 and 2015, made proposals focused on the circular economy and published an action plan that aims to “treat waste as a resource and convert Europe towards a circular economy”. The action plan suggests as an objective for 2030, among others, to prepare 65% of municipal waste for reuse and recycling.

In addition to environmental degradation, one of the main environmental problems in the world is the production and accumulation of waste, so the objectives established by the European Union (EU) must be taken into account. Waste generation together with the depletion of many resources, lead the EU towards a zero-waste strategy through the circular economy, in which the value of products, materials and resources is maintained in the economy for as long as possible and waste generation is reduced (Almendro-Candel et al. 2018). An essential part of the circular economy is the use of urban solid waste (MSW) in soils as a source of nutrients, mainly through prior composting (Almendro-Candel et al. 2019).

Given the need to integrate European zero-waste strategies and the adoption of the circular economy, the recovery of mining operations is an opportunity for the convenient use of organic waste that allows the recovery of soil and landscape of areas affected by extractive activities. Therefore, this section focuses on contrasting the use of different amendments that have been used in the rehabilitation of mining spaces and their results, based on those applied in the Region of Murcia. The accumulation of waste is a problem and for this reason it is important to look for ways to reuse them without polluting the environment. In the studies and examples analyzed, mulching with peat and other materials, sewage sludge, compost, pruning waste, pig slurry and inorganic marble waste are considered, as well as combinations between them.

These amendments have been studied because of their excess in the Region of Murcia, as they pose a problem for their elimination. It is very common for farmers to abandon pruning remains in wadis and wastelands or carry out uncontrolled incineration. Municipal solid waste is a problem due to its abandonment in uncontrolled dumps and sewage sludge would soon overtake us if we did not do anything with it. In the Region of Murcia, the pig sector is one of the most important in Spain, with a census of 2,145,408 heads producing more than 6.9% of the country’s output (MAPA 2019). This generates a large amount of waste, about 6.5 hm^3 per year, and generates management problems for producers. In addition, in the Region, the marble natural stone extraction industry processes 147,000 m^3 of product per year, generating 128,120 t of inert waste, of which only 10% is recovered (Zornoza et al. 2017).

7.1. Mulching

One of the techniques used for the restoration of degraded mining soils is the application of mulch by using different types of peat. This acts by limiting water loss through evaporation, improving filtration and root growth, as well as establishing vegetation and reducing soil erosion (Shao et al. 2014; Hueso-González et al. 2015). In addition, the plant remains and the mulch increases the stability of soil aggregates (Wright and Upadhyaya 1998).

Along with mulching, there are other strategies associated with it such as the use of plastic, stones or wood chips, which are effective measures to prevent water loss (Bakker et al. 2012; Devine et al. 2007). At the same time as plant mulch reduces the evaporation of soil water (Laliberté et al. 2008), soil protection is favoured and mulching is efficient for improving the establishment of vegetation (Valdecantos et al. 2009).

However, it has been observed in some experiments that the use of a vegetable mulch does not produce significant effects on the survival rate of plants in arid environments where annual precipitation is very low and only little rain can reach the soil due to interception by the mulch cover (Grantz et al. 1998; Luna et al. 2016b). In addition, plant mulches can have a negative effect on the activity of certain enzymes such as glucosidase, suggesting that mulch can prevent the entry of plant debris and native organic matter caused by the barrier created by mulch itself (Qiu et al. 2014).

By applying pruning residues as a mulch, we prevent uncontrolled incineration of them as they form a focus of disease. Moreover, the process of optimal dehydration expels large amounts of CO_2 into the air. In addition, the abandonment of pruning residues in ramblas and wastelands constitutes a serious risk during torrential rains and contributes to the spread of pests and diseases. Mulching may not always provide the expected beneficial effects on soil microbial activity as in some cases the effects on alkaline phosphatase and urease activities are positive and in other negative (Luna et al. 2016b). Several authors have found a significant negative effect on enzymatic activities related to C and P (b-glucosidase and alkaline phosphatase, respectively), while microbial biomass was not significantly affected by the type of coverage. Therefore, since these enzymes are frequently immobilized in clay and humic fractions (Nannipieri 2006; Bastida et al. 2012), it can be suggested that mulch has a stronger impact on the extracellular environment than on microbial growth (Luna et al. 2016b).

The positive effect of mulch on vegetation is related to improvements in soil water content, which would provide benefits for plant establishment, particularly in arid and semi-arid areas with severe water scarcity (Bautista et al. 2009).

Regarding the use of other surface materials, Luna et al. (2016b) did not observe clear positive effects with the use of gravel on the growth of plants and found a general negative effect using wood chips as mulch. Consistently, several authors found that wood chips could inhibit plant growth due to allelochemical compounds (Duryea et al. 1999; Rathinasabapathi et al. 2005). In addition, differences between plant species were found (Escós et al. 2000; Armas and Pugnaire 2005). Previous studies also reported negative effects (Kruse et al. 2004), no effects (Fernández et al. 2011; Santana et al. 2014) and positive effects (Badía and Marti 2000; Bautista et al. 2009). Contradictory effects have therefore been found in the case of mulch by using wood chips.

7.2. Compost from municipal solid waste

Composted material from municipal solid waste (MSW) mainly induces an increase in TOC and glomalin content in soil (Luna et al. 2016a). The increase in TOC content by compost is caused by the stable nature of the amendment (García et al. 1992; Ros et al. 2003; Dearden et al. 2006).

According to Luna et al. (2016b), composting increases electrical conductivity (EC) ($P < 0.05$) the first few days of being applied, but soil salinity decreases over time. This initial increase in EC may result from the incorporation of low molecular weight organic compounds or the release of salts during the decomposition of organic substances (González-Ubierna et al. 2012; Mingorance et al. 2014; Pérez Gimeno et al. 2016). The decrease over time of the EC may be due to the leaching of ions by rain, which contributes to reduce soil salinity (González-Ubierna et al. 2012).

Regarding soil carbon metabolism, five years after the application of MSW compost in the work carried out by Luna et al. (2016b), basal soil respiration is only sensitive to the application of further amendment and is similar to that of the natural soil of reference.

Compost increases microbial biomass and alters the composition of the community towards a community dominated by fungi. Fungi are capable of degrading more recalcitrant organic material (Boer et al. 2005); therefore, an increase in fungal biomass in soils modified with compost could be attributed to the presence of stabilized substrates that give a competitive advantage to fungi. Moreover, the development of vegetation cover on soils treated with compost could contribute to the entry of cellulose and lignin into the soil. Fungi are able to degrade these C polymers through their enzymatic systems (Boer et al. 2005; Baldrian et al. 2010). According to the study of Luna et al. (2016b), bacterial PLFA and Gram+/Gram- ratios increase in treated plots, reaching values similar to those observed in undisturbed reference soils. Gram+ bacteria communities are more resistant to drying and re-wetting than Gram- bacteria because of their physiological characteristics, i.e. the presence of a strong, thick and interconnected peptidoglycan cell wall (Schimel et al. 2007). In fact, the Gram+/Gram- ratio has been suggested as an indicator of resistance to disturbances in microbial communities (De Vries and Shade 2013). A shift to a more dominant Gram+ microbial community (high Gram+/Gram- values) can be seen as a mechanism to adapt to a semi-arid climate.

7.3. Sewage sludge

Sludge, in general, has stood out in its results for the creation of greater stability of soil aggregates (García-Orenes et al. 2005). Some results, however, indicate that it is not much larger than the reference soil and reaches a lower TOC than unaltered natural soils (Luna et al. 2016b). The organic carbon fraction of the sludge from wastewater treatment is more biodegradable than that of this composted material and can be rapidly hydrolyzed by enzymatic activity (Cook and Allan 1992), which would explain the difference in the results in the use of this waste. In general, composted sewage sludge (biosolids, as several types of treated sewage sludge that can be used as soil conditioner are termed) is a preferential organic waste used in agriculture and environmental rehabilitation.

Soils treated with sludge also have higher concentrations of actinobacteria, which can probably be attributed to the high content of these commonly found in wastewater treatment plants (Bitton 2005; Wang et al. 2014). However, the content and proportion of microbial biomass, both in restored and natural soils, responds over time to seasonal changes and vegetation development (Bastida et al. 2007; Baldrian et al. 2010).

7.4. Combination of MSW compost and sewage sludge

The combination of both residues apparently produces a sum of its positive properties in the soil. These affect enzyme activity, improve soil microbiological properties and improve soil respiration (Luna et al. 2016b).

The amendments of sewage and compost produce a positive correlation between enzymatic activities and the TOC and TN contents, favouring soil productivity and fertility (Luna et al. 2016b). This could be related to the higher organic matter content in plots modified with compost, as well as the stimulation of plant development that provides organic matter inputs to the soil (Bastida et al. 2008).

Compost and sludge contribute to increased plant growth, for example in the species *M. tenacissima, A. cytisoides and A. terniflora* (Valdecantos et al. 2011). However, opposite impacts on plant survival and growth have been observed. On the one hand, plant survival rates decrease slightly in the first months of planting, probably due to a high organic matter content, which increases soil salinity and the possible lack of nutrients associated with the increment of soil microbial activity. On the other hand, organic amendments are beneficial for plant growth in the following months, as they improve nutritional conditions (Luna et al. 2016a). In a semi-arid region under Mediterranean climate, the mean survival value of *M. tenacissima* of 92% was found four years after sowing. Values above 40-60% were noted by Valdecantos et al. (2011) and Oliet et al. (2012) for different species of plants in Mediterranean conditions. This was considerably above the value of 10% reported by Rokich (1999) in a Mediterranean mining restoration 2 years after sowing. The species that developed mechanisms to resist water stress during the summer period are of great interest. *M. tenacissima* is best suited for successful recovery under the semi-arid Mediterranean climate in the short term (Luna et al. 2018).

7.5. Sewage sludge, MSW compost and gravel

In addition to the properties commented on by the previous combination, the addition of inorganic, gravel-sized materials to these amendments introduces a noticeable physical change, favouring the creation of pores and spaces available for rapid infiltration and root development. This combination could be of great interest and application in certain environments where it is necessary to increase macroporosity and facilitate water infiltration and gas exchange.

From the point of view of the biological activity of soils, it should be pointed out that when this mixture of materials has been used, the detected dehydrogenase activity is much greater than if only organic amendments to MSW compost or sludge were applied. This may be correlated with an observed increase in vegetation cover with gravel (Masciandaro et al. 2004; Mukhopadhyay et al. 2016; Luna et al. 2016b), favored by changing physical conditions in the environment.

7.6. Pig slurry

The use of slurry as an amendment can solve two problems: recovery of a by-product and rehabilitation of degraded mining areas.

Slurry has a high organic matter content and can affect soil structure in several ways. The slurry provides sodium, magnesium and calcium (Na, Mg and Ca, respectively) in addition to the three main nutrients, nitrogen, phosphorus and potassium (N, P and K). Interchangeable cations (K^+, Na^+, Mg^{2+} and Ca^{2+}) affect soil aggregation. Sodium mainly causes dispersion of clay particles and destabilization of aggregates (Crescimanno et al. 1995). The dispersion of the aggregates generally leads to the formation of soil crusts, causing slow infiltration and high particle mobility by surface runoff. In calcareous soils, both Ca^{2+} and Mg^{2+} reduce clay dispersion (Amezketa and Araguees 1995). In addition, adsorbed K^+ limits clay dispersion due to its hydration energy, which is equivalent to 72% of that of adsorbed Na^+ (Levy and Torrento 1995). Carbonates probably prevent the decomposition of organic matter, which can be deduced from the evolution of the respiration rate during a growing season and from differences in the stability of aggregates when mineral and organic fertilizers are compared.

The introduction of pig slurry in fertilization strategies benefits porosity, mainly in the range area of 25-200 µm, but this is a transitory effect. These pores are associated with capillary water movement, soil aeration, rapid water drainage and root growth (Bosch-Serra et al. 2017). The dose for pig slurry should be established through the thresholds imposed by legislation on the addition of total nitrogen to soil to avoid contamination by salinity and highly soluble and water-movable nitrates (Directiva del Consejo 91/676/EEC). The dose of pig slurry applied increases the initial salinity values significantly and if unsuitable doses are used, they can be limiting initially in the establishment of the plants (Bosch-Serra et al. 2000). Furthermore, according to Salazar et al. (2009), high doses of slurry have significantly more nitrates than low doses and the highest values of nitrates occur at the surface. The application of pig slurry contributes to the improvement of soil fertility by facilitating greater colonization of natural vegetation (Kabas et al. 2012).

Contrary to what is often observed for solid animal manure, the application of liquid pig manure does not always increase the C content in the soil (Plaza et al. 2005; Carter and Campbell 2006; Angers et al. 2010), partly because of its low C content and rapid mineralization (Rochette et al. 2000; Chantigny et al. 2001; Pardo et al. 2011). The organic matter fraction of pig manure is composed largely of fast-decomposing organic C that may not contribute significantly to stabilizing organic matter. In addition, its high labile C and available N and P contents could accelerate the decomposition of native soil C (Peu et al. 2007; Rochette et al. 2000). Therefore, the application of carbonates seems to be useful to stabilize fresh and very labile organic matter, as is the case with pig slurry.

On the other hand, due to the release of root exudates in the rhizosphere, the application of pig slurry increases TOC and TN, improves soil structure and provides nutrients for microbial populations, which are the basis for ensuring ecosystem recovery. In addition, pig slurry is a good fertilizer due to the large amount of nutrients provided, which are necessary to promote the development of vegetation. Therefore, the use of this waste to recover degraded soils is of great interest, although some procedures, such as liming, must be carried out to minimize the rapid mineralization of organic matter from this type of waste (Zornoza et al. 2012). An increase in soil organic matter content also favours an increase in soil cation exchange capacity (CEC) (Kabas et al. 2012). Zornoza et al. (2017) demonstrated that there was a significant increase in CEC after the application of pig slurry.

Nitrogen is an essential element for vegetation and microbial communities. The increase in N improves the nutritional conditions of the soil and helps the growth and development of the introduced plants. With the application of pig slurry, shortly after a year, production and the different extractions and losses of nitrogen tend to balance out their concentration (Salazar et al. 2002). However, this TN decreases with time, which could be due to plant absorption, and immobilization by microbial biomass. To prevent the lack of TN that could limit the development of vegetation, it would be interesting to include legumes among the species introduced in the revegetation, in order to increase the availability of this nutrient through biological fixation of atmospheric N (Zornoza et al. 2017).

The microbial population increases after the application of pig slurry due to the increase of soluble C. Availability of C should allow the possibility of growth of microorganisms (Pérez de Mora et al. 2005). In addition, pig slurry also contains microbial biomass that can be incorporated into the soil. However, with the depletion of the labile fraction of organic matter, microorganisms do not maintain their growth and return to initial values in about 25 days (Plaza et al. 2007; Pardo et al. 2011; Zornoza et al. 2013). The same trend was observed for b-galactosidase and b-glucosidase activities associated with soluble C dynamics (Zornoza et al. 2012). However, fungal growth is more stable over time, indicating a progressive and continuous growth that depends not only on the most labile organic compounds but also on the total organic carbon content of the soil. Fungi are able to degrade more complex organic compounds (Griffith and Bardgett 2008), which may allow for more stable growth over time.

The addition of marble waste in combination with pig slurry produces an accumulated bacterial growth (Zornoza et al. 2016). Bacterial and fungal growth rates are dependent on the pH and soluble and labile fractions of organic matter. From pH 4 to pH 8, the growth of fungi to bacteria changes about 30 times. The fungi are favored by a lower pH. This trend towards the different effect of pH on bacteria and fungi has previously been observed (Rousk et al. 2009, 2010; Fernández-Calviño et al. 2011). Pig slurry promotes faster microbial growth probably due to the higher content of soluble labile organic compounds (Zornoza et al. 2016).

The use of pig slurry has positive effects on the rehabilitation of mining soils, improving soil properties and increasing germination (Pardo et al. 2011; Zornoza et al. 2017).

7.7. Pig manure

Pig manure is an environmentally attractive amendment to prevent the formation of acid drainage from metal mines due to its high pH and presence of lime. It can be incorporated as part of long-term remediation process in abandoned mines and areas affected by mining activity.

The basic characteristics of pig manure are 13.5% humidity, 57% of $CaCO_3$ and 28.1 g/kg of TN. The study consulted shows that pig manure increases pH and improves conditions for plant growth (Faz et al. 2008).

With the application of pig manure, studies have shown a preliminary increase in pH, TN, organic carbon and equivalent calcium carbonate content, and a reduction in Zn, Bp and Cd, as well as a decrease in EC. It has also been observed that the pH does not have the capacity to neutralise acid in the leachate in the short term when this waste is applied (Faz et al. 2008). Aggregate stability increases significantly with the application of pig manure and in addition, it produces a large fungal growth in soils and increases the concentrations of the saturated PLFAs (Zornoza et al. 2016). Several studies show the ability of pig manure to efficiently adsorb metal, reducing their availability in soil (Beesley et al. 2011; Park et al. 2011; Kelly et al. 2014; Zornoza et al. 2016).

7.8. Marble waste

Waste from these calcareous quarries usually has a high apparent density and a massive structure, which gives them low filtration rates, triggers soil erosion processes and increases runoff (Moreno de las Heras et al. 2008). Its combined use with organic materials can be positive since carbonates and clays stabilize organic carbon and make it more inaccessible for microbial attack (Bernal et al. 1991). Therefore, the application of marble reduces the degradability of organic compounds. This is of particular interest for improving the accumulation of C in regenerated soils from the point of view of C sequestration (Shrestha and Lal 2006). Studies have shown that the application of marble sludge leads to an increase in soil pH and favours the accumulation of soil organic matter (Zornoza et al. 2017). The presence of calcium from marble sludge can favour the bonds between clay minerals, and promote intermolecular interactions between organic and inorganic compounds, forming aggregates (Baldock and Skjemstad 2000; Clough and Skjemstad 2000).

According to Kabas et al. (2012), marble waste inhibits plant development, probably due to the presence of higher contents of salts and clays, whereas according to Risser and Baker (1990), these residues can be used to neutralize the acidity of many types of mining waste. This favours the establishment of vegetation and increases the availability of nutrients such as K, C, Mg, Mo or P, which are more mobile at pH about 6. The application of marble waste stabilizes organic matter, microorganisms and enzymes involved in the degradation of more complex molecules to degrade organic matter, such as arylsterase, which could be used as an indicator of organic matter stability. If only marble waste is used, the biochemical properties of the soil do not increase, indicating that changes in these properties are mainly due to the organic matter provided, verified with the use of pig slurry (Zornoza et al. 2013). The application of marble sludge together with pig slurry increases the growth of native vegetation, increases vegetation cover and biodiversity (Kabas et al. 2012).

7.9. Pig manure with marble waste

This waste combination, as mentioned previously, offers aspects that should be considered. It was observed that this combination can reduce the available water but also improves the establishment of vegetation. It appears that the application of lime or alkaline materials together with the use of double doses of pig manure is a reasonable alternative for remediation of soils in acidic mining areas. However, it has been indicated that salinity should be considered with medium- and long-term monitoring (Faz et al. 2008).

8. Conclusions

In the XXI century, the mining industry stands out as one of the most important sectors when providing essential materials for economic development. However, great effort needs to be made to improve the economic, social and environmental aspects of this industry. This includes the need to rehabilitate the affected areas taking into account all the social agents involved in its development (administration, neighborhoods, town halls, etc.).

This review works on the importance of organic matter in the restoration of soils in areas affected by mining, in particular by open-pit extractive activities. It aims to highlight the great possibilities presented through the research and work generated in the last 20 years. The use of organic waste of many different kinds is feasible; however, not only the positive aspects have to be considered, but also the negative ones such as possible pollutants that are emitted as a result of the quarrying activity. It should be noted that most of these are expected to be gases (CO2) from the combustion of the engines of the machines and the trucks used to transport the quarry materials and the waste. As a preventive measure in this regard, it would be advisable to have the ISO 14,000 standard and to have an environmental management system that establishes periodic maintenance of vehicles and/or equipment in general. This maintenance contributes to improving combustion and making it as efficient as possible, generating the least amount of carbon dioxide. In short, pollution is a limiting factor for the use of waste.

The major conclusions are that the increase of soil organic matter, the improvement in revegetation and the increase in water retention capacity are the most noteworthy aspects in a semi-arid environment such as the Murcia region.

As mentioned above, waste production is a crucial problem. Therefore, different ways of reusing waste that do not pollute the environment and can be reintroduced into economic activity in the frame of circular economy are sought.

9. Future actions

Future lines of research, complementing soil and vegetation aspects, are proposed. The first could be the improvement of habitat conditions for wildlife and the use of wildlife as an indicator, although the wildlife colonization of a restored quarry does not occur immediately because there is no habitat to support it. The main improvement for the fauna, in the beginning, is the restoration of vegetation and recovery the original habitat. Except for some species of birds and mammals quite elusive to human presence, wildlife may be present in the early stages of the exploitation if restoration is initiated from the early stages (favouring the landscape evolution and habitat). The diversification of the flora species used in plant restoration results in a significant improvement in the landscape. Even more importantly, it supports a greater number of wildlife species and increases the stability of the system. For this reason, a non-homogenous restoration is important. Other actions that can specifically help wildlife are sowings on debris or other altered spaces in which cereals and other cultivated plants are planted as a first-rate food source for many birds and mammals, as evidenced by numerous small plots used in hunting.

In line with the above, a high biodiversity footprint remains a key area of work. This includes both efforts to minimize the potential negative impact on biodiversity and to seek opportunities to increase it. Achieving a net positive impact (NPI) is a challenge for the future.

To achieve the target, it is proposed to work with major building materials companies to help actively reverse the trend of declining global biodiversity. As a proposal for future lines of work, it could be agreed to work within the following objectives:

- Reduce the ecological footprint on climate change through improved energy efficiency of installations, the use of renewable energy and special low carbon footprint cements.
- Improving knowledge and control of persistent organic pollutants, through systematic measurements, development and implementation of best practices, reporting on progress made.
- Reduce water consumption in operations and aim to improve knowledge of water flows by developing practices for their control.
- Analyze the potential of biodiversity in our quarries to study and develop biodiversity management programs; and aim to reduce the impact of quarries on biodiversity.

In conclusion, the general objective, is to achieve a positive net balance in nature after mining activities.

The second future line is the creation of artificial lagoons in the quarry and gravel exploitation sites that collect rainwater, thus creating lake spaces of great ecological value. These would serve as a refuge for many aquatic species and allow the development of some amphibians and invertebrates. Instead of generating a large single lagoon, it is preferable to build several small lagoons with different ecological slope conditions, etc., because the possibilities for different types of fauna are greatly increased. Once space and spatial distribution are known, it will be necessary to generate the gaps in the lagoon in which rainwater will be deposited. In this type of design, there should be at least two depths, one more shallow to allow amphibian spawning and larval growth, and a deeper one for temporary maintenance of adults and other wildlife species that need more time in its development like some dragonflies, beetles, etc.

REFERENCES

• Adriano DC. 2001. Trace elements in terrestrial environments: Biogeochemistry, bioavailability and risks of metals. New York: Springer-Verlag.

• Almendro-Candel MB, Gómez I, Navarro-Pedreño, Zorpas AA. 2018. Physical properties of soils affected by the use of agricultural waste: Agricultural waste and residues. In: Aladjadjiyan A, editor. Agricultural Waste and Residues, Chapter 2. London (UK): Ed Intech. p. 9-28.

• Almendro-Candel MB, Gómez I, Navarro-Pedreño, Zorpas AA, Voukkali I, Loizia P. 2019. The use of composted municipal solid waste under the concept of circular economy and as a source of plant nutrients and pollutants. In: Saleh HEM, editor. Municipal Solid Waste Management, Chapter 3. London (UK): Ed Intech. p. 33-50.

• Alvarenga P, de Varennes A, Cunha-Queda AC. 2014. The effect of compost treatments and a plant cover with Agrostis tenuis on the immobilization/mobilization of trace elements in a mine-contaminated soil. Int J Phytoremediation 16(2):138-154.

• Amezketa E, Aragües R. 1995. Flocculation-dispersion behavior of arid-zone soil clays as affected by electrolyte concentration and composition. Investigación Agraria: Serie Producción y Protección Vegetales 10:101-112.

• Angers DA, Chantigny MH, MacDonald JD, Rochette P, Cote D. 2010. Differential retention of carbon, nitrogen and phosphorus in grassland soil profiles with longterm manure application. Nutr Cycl Agroecosys. 86:225-229.

• Antonsiewicz DM, Escude-Duran C, Wierzbowska E, Sklodowska A. 2008. Indigenous plant species with potential for the phytoremediation of arsenic and metal contaminated soil. Water Air Soil Poll. 19:197-210.

• Armas C, Pugnaire FI. 2005. Plant interactions govern population dynamics in a semi-arid plant community. J Ecol. 93:978-989.

• Asensio V, Covelo EF, Kandeler E. 2013. Soil management of copper mine tailing soils - Sludge amendment and tree vegetation could improve biological soil quality. Sci Total Environ. 456-457:82-90.

• Badía D, Marti C. 2000. Seeding and mulching treatments as conservation measures of two burned soils in the central Ebro valley, NE Spain. Arid Soil Res Rehab. 13:219-232.

• Bakker JD, Colasurdo LB, Evans JR. 2012. Enhancing Garry oak seedling performance in a semiarid environment. Northwest Sci. 86:300-309.

• Baldock JA, Skjemstad JO. 2000. Role of the soil matrix and minerals in protecting natural organic materials against biological attack. Org Geochem. 31:697-710.

• Baldrian P, Merhautova V, Petrankova M, Cajthaml T, Snajdr J. 2010. Distribution of microbial biomass and activity of extracellular enzymes in a hardwood forest soil reflect soil moisture content. Appl Soil Ecol. 46:177-182.

• Banning NC, Phillips IR, Jones DL, Murphy DV. 2011. Development of Microbial Diversity and Functional Potential in Bauxite Residue Sand under Rehabilitation. Restor Ecol. 19(101):78-87.

• Bastida F, Jindo K, Moreno JL, Hernández T, García C. 2012. Effects of organic amendments on soil carbon fractions: enzyme activity and humus–enzyme complexes under semi-arid conditions. Eur J Soil Biol. 53:94-102.

• Bastida F, Kandeler E, Moreno JL, Ros M, García C, Hernández T. 2008. Application of fresh and composted organic wastes modifies structure: size and activity of soil microbial community under semiarid climate. Appl Soil Ecol. 40:318-329.

• Bastida F, Moreno JL, García C, Hernández T. 2006. Microbiological degradation index of soils in a semiarid climate. Soil Biol Biochem. 38:3463-3473.

• Bastida F, Moreno JL, García C, Hernández T. 2007. Addition of urban waste to semiarid degraded soil: long-term effect. Pedosphere 17:557-567.

• Bateman A, Lewandrowski W, Stevens J, Muñoz-Rojas M. 2018. Ecophysiological indicators to assess drought responses of arid zone native seedlings in reconstructed soils. Land Degrad Dev. 29(4):984-993.

• Bautista S, Robichaud PR, Bladé C. 2009. Post-fire mulching. In: Cerdá A, Robichaud PR, editors. Fire effects on soils and restoration strategies. Enfield (NH): Science Publishers. p. 353-372.

• Beesley L, Moreno-Jimenez E, Gomez-Eyles JL, Harris E, Robinson B, Sizmur T. 2011. A review of biochars' potential role in the remediation, revegetation, and restoration of contaminated soils. Environ Pollut. 159:3269-3282.

• Bernal MP, Roig A, Cegarra J. 1991. Effect of pig slurry additions on the organic carbon of calcareous soils. Bioresource Technol. 37:867-876.

• Bitton G. 2005. Wastewater Microbiology, 3rd ed. New York: Wiley-Liss Hoboken.

• Boer W, de Folman LB, Summerbell RC, Boddy L. 2005. Living in a fungal world: impact of fungi on soil bacterial niche development. Fems Microbiol Rev. 29:795-811.

• Bosch-Serra AD, Poch RM, Salazar MA. 2000. Evaluación de la utilización de estériles de una explotación minera carbonífera, junto con purín porcino, para la revegetación de la propia escombrera. Edafología 7(3):137-142.

• Bosch-Serra AD, Yagüe MR, Poch RM, Molner M, Junyent B, Boixadera J. 2017. Aggregate strength in calcareous soil fertilized with pig slurries. Eur J Soil Sci. 68(4):449-461.

• Bronick CJ, Lal R. 2005. Estructura del suelo y gestión: una revisión. Geoderma 124:3-22.

• Caravaca F, García C, Hernández MT, Roldán A. 2002. Aggregate stability changes after organic amendment and mycorrhizal inoculation in the afforestation of a semiarid site with Pinus halepensis. Appl Soil Ecol. 19(3):199-208.

• Carter MR, Campbell AJ. 2006. Influence of tillage and liquid swine manure on productivity of a soybean-barley rotation and some properties of a fine sandy loam in Prince Edward Island. Can J Soil Sci. 86:741-748.

• Castro-Gomes JP, Silva AP, Cano RP, Durán Suárez J, Albuquerque A. 2012. Potential for reuse of tungsten mining waste-rock in technical-artistic value added products. J Cleaner Prod. 25:34-41.

• Chantigny MH, Rochette P, Angers DA. 2001. Short-term C and N dynamics in a soil amended with pig slurry and barley straw: a field experiment. Can J Soil Sci. 81:131-137.

• Clemente AS, Werner C, Máguas C, Cabral MS, Martins-Louçao MA, Correia O. 2004. Restoration of a limestone quarry: effect of soil amendments on the establishment of native Mediterranean sclerophyllous shrubs. Restor Ecol. 12:20-28.

• Clemente R, de la Fuente C, Moral R, Bernal MP. 2007. Changes in microbial biomass parameters of a heavy metal-contaminated calcareous soil during a field remediation experiment. J Environ Qual. 36(4):1137-1144.

• Clough A, Skjemstad JO. 2000. Physical and chemical protection of soil organic carbon in three agricultural soils with different contents of calcium carbonate. Aust J Soil Res. 38:1005-1016.

• Conesa HM, Faz A. 2009. Metal uptake by naturally occurring vegetation in a metal polluted salt marsh in southeast Spain. In: Faz A, Mermut AR, Arocena JM, Ortiz R, editors. Land Degradation and Rehabilitation. Reiskirchen (DE): Ed. Catena Verlag p. 287-294.

• Cook BD, Allan DL. 1992. Dissolved organic carbon in old field soils: total amounts as a measure of available resources for soil mineralization. Soil Biol Biochem. 24:585-594.

• Crescimanno G, Iovino M, Provenzano G. 1995. Influence of salinity and sodicity on soil structural and hydraulic characteristics. Soil Sci Soc Am. J 59:1701-1708.

• De Gryze S, Six J, Brits C, Merckx R. 2005. A quantification of short-term macroaggregate dynamics: influences of wheat residue input and texture. Soil Biol Biochem. 37(1):55-66.

• De Vries FT, Shade A. 2013. Control son soil microbial community stability under climate change. Front Microbiol. 4:1-16.

• Dearden FM, Dehlin H, Wardle DA, Nilsson MC. 2006. Changes in the ratio of twig to foliage in litterfall with species composition, and consequences for decomposition across a long term chronosequence. Oikos 115:453-462.

• Devine WD, Harrington CA, Leonard LP. 2007. Post-planting treatments increase growth of Oregon white oak (*Quercus garryana* Dougl. ex Hook.) seedlings. Restor Ecol. 15:212-222.

• Diacono M, Montemurro F. 2010. Long-term effects of organic amendments on soil fertility. A review. Agron Sustain Dev. 30:401-422.

• Directiva del Consejo 91/676/CEE , de 12 de diciembre de 1991, relativa a la protección de las aguas contra la contaminación producida por nitratos utilizados en la agricultura. Boletín Oficial del Estado. Madrid, 31 de diciembre de 1991, núm. 375. https://www.boe.es/buscar/doc.php?id=DOUE-L-1991-82066.

• Domene X, Mattana S, Ramírez W, Colón J, Jiménez P, Balanyà T, Bonmatí M. 2010. Bioassays prove the suitability of mining debris mixed with sewage sludge for land reclamation purposes. J Soils Sediments 10(1):30-44.

• Dontsova KM, Bigham JM. 2005. Anionic polysaccharide sorption by clay minerals. Soil Sci Soc Am J. 69(4):1026-1035.

• Duryea ML, English RJ, Hermansen LA. 1999. A comparison of landscape mulches: Chemical, allelopathic, and ecomposition properties. J Arboric 25:88-97.

• Epelde L, Becerril JM, Barrutia O, González-Oreja JA, Garbisu C. 2010. Interactions between plant and rhizosphere microbial communities in a metalliferous soil. Environ Pollut. 158(5):1576-1583.

• Epelde L, Mijangos I, Becerril JM, Garbisu C. 2009. Soil microbial community as bioindicator of the recovery of soil functioning derived from metal phytoextraction with sorghum. Soil Biol Biochem. 41(9):1788-1794.

• Escós J, Alados CL, Pugnaire FI, Puigdefábregas J, Emlen J. 2000. Stress resistance strategy in an arid land shrub: Interactions between developmental instability and fractal dimension. J Arid Environ. 4:25-336.

• Escribano MM, Mataix C, editors. 2007. La minería y el medio Ambiente. El recorrido de los minerales [Internet]. Madrid (ES): Consejería de Economía e Innovación Tecnológica, Dirección General de Industria, Energía y Minas; 1st ed. p. 201-221. Available from: http://conocelosaridos.org/pdfs/UT9_-_La_Mineria_y_el_Medio_Ambiente.pdf

• Faz A, Carmona DM, Zanuzzi A, Mermut AR. 2008. Pig manure application for remediation of mine soils in Murcia province, SE Spain. Sci World J. 8:819-827.

• Fernández C, Vega JA, Jiménez E, Fonturbel MT. 2011. Effectiveness of three post-fire treatments at reducing soil erosion in Galicia (NW Spain). Int J Wildland Fire 20:104-114.

• Fernández-Calviño D, Rousk J, Brookes PC, Bååth E. 2011. Bacterial pH-optima for growth track soil pH, but are higher than expected at low pH. Soil Biol Biochem. 43:1569-1575.

• Fernández-Ugalde O, Barré P, Hubert F, Virto I, Girardin C, Ferrage E, Chenu C. 2013. Clay mineralogy differs qualitatively in aggregate-size classes: clay-mineral-based evidence for aggregate hierarchy in temperate soils. Eur J Soil Sci. 64(4):410-422.

• Franzluebbers AJ. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Till Res. 66:197-205.

• García C, Hernández T, Costa F. 1997. Potential use of dehydrogenase activity as an index of microbial activity in degraded soils. Commun. Soil Sci Plant Anal. 28:123-134.

• García C, Hernández T, Costa F, Ceccanti B, Calcinai M. 1992. A chemicalstructural study of organic wastes and their humic acids during composting by means of pyrolysis-gas chromatography. Sci Total Environ. 119:157-168.

• García-Orenes F, Guerrero C, Mataix-Solera J, Navarro-Pedreño J, Gómez I, Mataix J. 2005. Factors controlling the aggregate stability and bulk density in two different degraded soils amended with biosolids. Soil Till Res. 82:65-76.

• García-Orenes F, Morugán-Coronado A, Zornoza R, Scow K. 2013. Changes in soil microbial community structure influenced by agricultural management practices in a Mediterranean agro-ecosystem. Plos One 8(11):e80522.

• González-Ubierna S, Jorge-Mardomingo I, Carrero-González B, de la Cruz MT, Casermeiro MA. 2012. Soil organic matter evolution after the application of high doses of organic amendments in a Mediterranean calcareous soil. J Soils Sediments 12:1257-1268.

• Grantz DA, Vaughn DL, Farber RJ, Kim B, Ashbaugh L, VanCuren T, Zink T. 1998. Transplanting native plants to revegetate abandoned farmland in the western Mojave Desert. J Environ Qual. 27:960-967.

• Griffith GS, Bardgett RD. 2008. Influence of resource unit distribution and quality on the activity of soil fungi in a particulate medium. New Phytol. 148:143-151.

• Gunn J, Bailey D. 1993. Limestone quarrying and quarry reclamation in Britain. Environ Geol. 21(3):167-172.

• Hahn AS, Quideau SA. 2013. Long-term effects of organic amendments on the recovery of plant and soil microbial communities following disturbance in the Canadian boreal forest. Plant Soil 363(1-2):331-344.

• Harris J. 2009. Soil microbial communities and restoration ecology: facilitators or followers? Science 325:573-574.

• Hemmat A, Aghilinategh N, Sadeghi M. 2010. Shear strength of repacked remoulded samples of a calcareous soil as affected by long-term incorporation of three organic manures in central Iran. Biosyst Eng. 107(3):251-261.

• Heneghan L, Miller SP, Baer S, Callaham MA, Montgomery J, Pavao-Zuckerman M, Richardson S. 2008. Integrating soil ecological knowledge into restoration management. Restor Ecol. 16(4):608-617.

• Hortal S, Bastida F, Moreno JL, Armas C, García C, Pugnaire FI. 2015. Benefactor and allelopathic shrub species have different effects on the soil microbial community along an environmental severity gradient. Soil Biol Biochem. 88:48-57.

• Huang L, Zhang P, Hu Y, Zhao Y. 2015. Vegetation succession and soil infiltration characteristics under different aged refuse dumps at the Heidaigou opencast coal mine. Global Ecology and Conservation 4:255-263.

• Hueso S, Hernández T, García C. 2011. Resistance and resilience of the soil microbial biomass to severe drought in semiarid soils: the importance of organic amendments. Appl Soil Ecol. 50:27-36.

• Hueso-González P, Martínez-Murillo JF, Ruiz-Sinoga JD. 2014. The impact of organic amendments on forest soil properties under Mediterranean climatic conditions. Land Degrad Dev. 25:604-612.

• Hueso-González P, Ruiz-Sinoga JD, Martínez-Murillo JF, Lavee H. 2015. Geomorphology Overland flow generation mechanisms affected by topsoil treatment: application to soil conservation. Geomorphology 228:796-804.

• IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Rome: FAO.

• Jacobs DF, Haase DL, Rose R. 2005. Growth and foliar nutrition of Douglas-fir seedlings provided with supplemental polymer-coated fertilizer. West J Appl For. 20:58-63.

• Jorba M, Romanyà J, Rovira P, Hereter A, Josa R, Vallejo R. 2002. La restauración ecológica aplicada a la minería a cielo abierto en Cataluña. Ingeopres 106:56-63.

• Jorba M, Vallejo R. 2008. La restauración ecológica de canteras: un caso con aplicación de enmiendas orgánicas y riegos. Ecosistemas 17(3):119-132.

• Kabas S, Faz A, Acosta JA, Arocena JM, Zornoza R, Martínez-Martínez S, Carmona DM. 2014. Marble wastes and pig slurry improve the environmental and plant-relevant properties of mine tailings. Environ Geochem Hlth. 36(1):41-54.

• Kabas S, Faz A, Acosta JA, Zornoza R, Martínez-Martínez S, Carmona DM, Bech J. 2012. Effect of marble waste and pig slurry on the growth of native vegetation and heavy metal mobility in a mine tailing pond. J Geochem Explor. 123:69-76.

• Kandeler F, Kampichler C, Horak O, Kandeler E, Kampichler C, Horak O. 1996. Influence of heavy metals on the functional diversity of soil microbial communities. Biol Fertil Soils 23:299-306.

• Kelly CN, Peltz CD, Stanton M, Rutherford DW, Rostad CE. 2014. Biochar application to hardrock mine tailings: soil quality, microbial activity, and toxic element sorption. Appl Geochem. 43:35-48.

• King EG, Franz TE, Caylor KK. 2012. Ecohydrological interactions in a degraded two-phase mosaic dryland: Implications for regime shifts, resilience, and restoration. Ecohydrology 5:733-745.

• Kruse R, Bend E, Bierzychudek P. 2004. Native plant regeneration and introduction of non-natives following post-fire rehabilitation with straw mulch and barley seeding. Forest Ecol Manag. 196:299-310.

• Kulmatiski A, Beard KH, Stevens JR, Cobbold SM. 2008. Plant-soil feedbacks: a meta-analytical review. Ecol Lett. 11(9):980-992.

• Laliberté E, Bouchard A, Cogliastro A. 2008. Optimizing hardwood reforestation in old fields: The effects of treeshelters and environmental factors on tree seedling growth and physiology. Restor Ecol. 16:270-280.

• Lazcano C, Gómez-Brandón M, Revilla P, Domínguez J. 2013. Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function: a field study with sweet corn. Biol Fertil Soils 49:723-733.

• Lehmann A, Rillig MC. 2015. Understanding mechanisms of soil biota involvement in soil aggregation: A way forward with saprobic fungi? Soil Biol Biochem. 88:298-302.

• Levy GJ. Torrento JR. 1995. Clay dispersion and macroaggregate stability as affected by exchangeable potassium and sodium. Soil Sci. 160:352-358.

• Li J, Cooper JM, Lin ZA, Li YT, Yang XD, Zhao BQ. 2015. Soil microbial community structure and function are significantly affected by long-term organic and mineral fertilization regimes in the North China Plain. Appl Soil Ecol. 96:75-87.

• Lucas ST, D'Angelo EM, Williams MA. 2014. Improving soil structure by promoting fungal abundance with organic soil amendments. Appl Soil Ecol. 75:13-23.

• Luna L, Miralles I, Andrenelli, MC, Gispert M, Pellegrini S, Vignozzi N, Solé-Benet A. 2016a. Restoration techniques affect soil organic carbon, glomalin and aggregate stability in degraded soils of a semiarid Mediterranean region. Catena 143:256-264.

• Luna L, Miralles I, Lázaro R, Contreras S, Solé-Benet A. 2018. Effect of soil properties and hydrologic characteristics on plants in a restored calcareous quarry under a transitional arid to semiarid climate. Ecohydrology 11(6):e1896.

• Luna L, Pastorelli R, Bastida F, Hernández T, García C, Miralles I, Solé-Benet A. 2016b. The combination of quarry restoration strategies in semiarid climate induces different responses in biochemical and microbiological soil properties. Appl Soil Ecol. 107:33-47.

• Maisto G, De Marco A, De Nicola F, Arena C, Vitale L, Virzo De Santo A. 2010. Suitability of two types of organic wastes for the growth of sclerophyllous shrubs on limestone debris: a mesocosm trial. Sci Total Environ. 408:1508-1514.

• MAPA (Ministerio de Agricultura, Pesca y Alimentación) [Internet]. 2019. Madrid (ES): Sistema integral de trazabilidad animal. Informe SITRAN (enero 2019); c2019 [cited 2019 Oct 16]. Available from: https://www.mapa.gob.es/es/ganaderia/temas/trazabilidad-animal/registro/default.aspx.

• Marschner P, Kandeler E, Marschner B. 2003. Structure and function of the soil microbial community in a long-term fertilizer experiment. Soil Biol Biochem. 35:453-461.

• Masciandaro G, Ceccanti B, Benedicto S, Lee HC, Cook HF. 2004. Enzyme activity and C and N pools in soil following application of mulches. Can J Soil Sci. 84:19-30.

• Méndez MO, Glenn EP, Maier R. 2007. Phytostabilization potential of quailbush for mine tailings: growth metal accumulation, and microbial community changes. J Environ Qual. 36:245-253.

• Mingorance MD, Rossini Oliva S, Valdés B, Pina Gata FJ, Leidi EO, Guzmán I, Peña A. 2014. Stabilized municipal sewage sludge addition to improve properties of an acid mine soil for plant growth. J Soils Sediments 14:703-712.

• Miralles I, Ortega R, Almendros G, Sánchez-Marañón M, Soriano M. 2009. Soil quality and organic carbon ratios in mountain agroecosystems of South-east Spain. Geoderma 150(1-2):120-128.

• Mondini C, Cayuela ML, Sinicco T, Sánchez-Monedero MA, Bertolone E, Bardi L. 2008. Soil application of meat and bone meal. Short-term effects on mineralization dynamics and soil biochemical and microbiological properties. Soil Biol Biochem. 40(2):462-474.

• Moreno de las Heras M, Nicolau JM, Espigares T. 2008. Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment. Ecol Eng. 34:168-178.

• Moreno-Peñaranda R, Lloret F, Alcañiz JM. 2004. Effects of sewage sludge on plant community composition in restored limestone quarries. Restor Ecol. 12:290-296.

• Mukhopadhyay S, Masto RE, Yadav A, George J, Ram LC, Shukla SP. 2016. Soil quality index for evaluation of reclaimed coal mine spoil. Sci Total Environ. 542:540-550.

• Muñoz-Rojas M, Erickson TE, Martini D, Dixon KW, Merritt DJ. 2016. Soil physicochemical and microbiological indicators of short, medium and long term post-fire recovery in semi-arid ecosystems. Ecol Indic. 63:14-22.

• Nannipieri P. 2006. Role of stabilised enzymes in microbial ecology and enzyme extraction from soil with potential applications in soil proteomics. Soil Biol. 8:75-94.

• Navarro-Pedreño J, Moral R, Gómez I, Mataix J. 1995. Residuos orgánicos y agricultura. Alicante (ES): S.P. Universidad de Alicante.

• Ojeda G, Ortiz O, Medina CR, Perera I, Alcañiz JM. 2015. Carbon sequestration in a limestone quarry mine soil amended with sewage sludge. Soil Use Manage. 31(2):270-278.

• Oliet JA, Artero F, Cuadros S, Puértolas J, Luna L, Grau JM. 2012. Deep planting with shelters improves performance of different stocktype sizes under arid Mediterranean conditions. New Forest 43:925-939.

• Ortiz O, Ojeda G, Espelta JM, Alcañiz JM. 2012. Improving substrate fertility to enhance growth and reproductive ability of a Pinus halepensis Mill. afforestation in a restored limestone quarry. New Forest 43(3):365-381.

• Pardo T, Clemente R, Bernal MP. 2011. Effects of compost, pig slurry and lime on trace element solubility and toxicity in two soils differently affected by mining activities. Chemosphere 84(5):642-650.

• Park JH, Choppala GK, Bolan NS, Chung JW, Chusavathi T. 2011. Biochar reduces the bioavailability and phytotoxicity of heavy metals. Plant Soil 348:439-451.

• Pascual JA, García C, Hernández T, Ayuso M. 1997. Changes in the microbial activity of an arid soil amended with urban organic wastes. Biol Fertil Soils 24:429-434.

• Pérez de Mora A, Ortega-Calvo JJ, Cabrera F, Madejón E. 2005. Changes in enzyme activities and microbial biomass after "in situ" remediation of a heavy metal-contaminated soil. Appl Soil Ecol. 28:125-137.

• Pérez-Gimeno A, Navarro-Pedreño J, Almendro-Candel MB, Gómez I, Jordán MM. 2016. Environmental consequences of the use of sewage sludge compost and limestone outcrop residue for soil restoration: salinity and trace elements pollution. J Soils Sediments 16:1012-1021.

• Peu P, Birgand F, Martinez J. 2007. Long term fate of slurry derived nitrogen in soil: a case study with a macro-lysimeter experiment having received high loads of pig slurry (Solepur). Bioresource Technol. 98:3228-3234.

• Piñol J, Lledó MJ, Escarré A. 1991. Hydrological balance of two Mediterranean forested catchments (Prades, northeast Spain). Hydrolog Sci J. 36:95-107.

• Plaza C, García-Gil JC, Polo A. 2005. Effects of pig slurry application on soil chemical properties under semiarid conditions. Agrochimica 49:87-92.

• Plaza C, García-Gil JC, Polo A. 2007. Microbial activity in pig slurry amended soils under aerobic incubation. Biodegradation 18:159-165.

• Qiu Y, Wang Y, Xie Z. 2014. Long-term gravel–sand mulch affects soil physicochemical properties, microbial biomass and enzyme activities in the semi-arid Loess Plateau of North-western China. Acta Agric. Scand. Sect. B. Soil Plant Sci. 64:294-303.

• Rathinasabapathi B, Ferguson J, Gal M. 2005. Evaluation of Allelopathic potential of wood chips for weed suppression in horticultural production systems. Hort Sci. 40:711-713.

• Rillig MC. 2004. Arbuscular mycorrhizae, glomalin, and soil aggregation. Can J Soil Sci. 84(4):355-363.

• Risser JA, Baker DE. 1990. Testing Soils for Toxic Metals. In: Westerman RL, editor. Soil Testing and plant analysis, 3rd ed. Madison: Soil Science Society of America, Inc. p. 275-298.

• Rochette P, Angers DA, Cote D. 2000. Soil carbon and nitrogen dynamics following application of pig slurry for the 19th consecutive year: I. Carbon dioxide fluxes and microbial biomass carbon. Soil Sci Soc Am J. 64:1389-1395.

• Rokich D. 1999. Banksia woodland restoration. Nedlands (AU): The University of Western Australia.

• Ros M, Hernández MT, García C. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biol Biochem. 35:463-469.

• Roundy BA, Farmer M, Olson J, Petersen S, Nelson DR, Davis J, Vernon J. 2017. Runoff and sediment response to tree control and seeding on a high soil erosion potential site in Utah: Evidence for reversal of an abiotic threshold. Ecohydrology 10:e1775.

• Rousk J, Brookes PC, Bååth E. 2009. Contrasting soil pH effects on fungal and bacterial growth suggests functional redundancy in carbon mineralisation. Appl Environ Microbiol. 75:1589-1596.

• Rousk J, Brookes PC, Bååth E. 2010. The microbial PLFA composition as affected by pH in an arable soil. Soil Biol Biochem. 42:516-520.

• Salazar M, Bosch AD, Estudillos G, Poch RM. 2009. Rehabilitation of semiarid coal spoil bank soils with mine spoils and farm by-products. Arid Land Res Manag. 23(4):327-341.

• Salazar M, Poch RM, Bosch AD. 2002. Reclamation of steeply sloping coal spoil banks under Mediterranean semi-arid climate. Aust J Soil Res. 40:827-845.

• Santana VM, Alday JG, Baeza MJ. 2014. Mulch application as post-fire rehabilitation treatment does not affect vegetation recovery in ecosystems dominated by obligate seeders. Ecol Eng. 71:80-86.

• Santos ES, Abreu MM, Macías F, de Varennes A. 2014. Improvement of chemical and biological properties of gossan mine wastes following application of amendments and growth of Cistus ladanifer. L J Geochem Explor. 147:173-181.

• Schimel J, Balser TC, Wallenstein M. 2007. Microbial stress-response physiology and its implications for ecosystem function. Ecology 88:1386-1394.

• Senesi N, Plaza C, Brunetti G, Polo A. 2007. A comparative survey of recent results on humic-like fractions in organic amendments and effects on native soil humic substances. Soil Biol Biochem. 39(6):1244-1262.

• Shafi M, Bakht J, Jan MT, Shah Z. 2007. Soil C and N dynamics and maize (*Zea may* L.) yield as affected by cropping systems and residue management in North-western Pakistan. Soil Till Res. 94(2):520-529.

• Shao P, Gu W, Dai QY, Makoto S, Liu Y. 2014. Efectividad de las coberturas de geotextil para restauración pendiente en las áreas semiáridas del norte de China. Catena 116:1-9.

• Sheoran V, Sheoran AS, Poonia P. 2010. Role of hyperaccumulators in phytoextraction of metals from contaminated mining sites: A Review. Crit Rev Env Sci Tec. 41(2):168-214.

• Shrestha RK, Lal R. 2006. Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. Environ Int. 32:781-796.

• Six J, Bossuyt H, Degryze S, Denef K. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil Till Res. 79(1):7-31.

• Smith JM, Smith NH, O´Rourke M, Spratt BG. 1993. How clonal are bacteria? Proc Natl Acad Sci. 90(10):4384-4388.

• Soliveres S, Monerris J, Cortina J. 2012. Irrigation, organic fertilization and species successional stage modulate the response of woody seedlings to herbaceous competition in a semi-arid quarry restoration. Appl Veg Sci. 15(2):175-186.

• Sort X, Alcañiz JM. 1996. Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. Land Degrad Dev. 7(1):69-76.

• Tejada M, Hernandez MT, Garcia C. 2009. Soil restoration using composted plant residues: Effects on soil properties. Soil Till Res. 102(1):109-117.

• Tisdall JM, Oades JM. 1982. Organic matter and water-stable aggregates in soils. J Soil Sci 33(2):141-163.

• Tromble JM. 1987. Water interception by two arid land shrubs. J Arid Environ. 15:65-70.

• Valdecantos A, Baeza MJ, Vallejo VR. 2009. Vegetation management for promoting ecosystem resilience in fire-prone Mediterranean shrublands. Restor Ecol. 17:414-421.

• Valdecantos A, Cortina J, Vallejo VR. 2011. Differential field response of two Mediterranean tree species to inputs of sewage sludge at the seedling stage. Ecol Eng. 37:1350-1359.

• Wang J, Li Q, Qi R, Tandoi V, Yang M. 2014. Sludge bulking impact on relevant bacterial populations in a full-scale municipal wastewater treatment plant. Process Biochem. 49:2258-2265.

• Wright SF, Upadhyaya A. 1998. A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. Plant Soil 198:97-107.

• Ye ZH, Shu WS, Zhang ZQ, Lan CY, Wong MH. 2002. Evaluation of major constraints to revegetation of lead/zinc mine tailings using bioassay techniques. Chemosphere 47(10):1103-1111.

• Zanuzzi A, Arocena JM, van Mourik JM, Faz A. 2009. Amendments with organic and industrial wastes stimulate soil formation in mine tailings as revealed by micromorphology. Geoderma 154(1-2):69-75.

• Zhou W, Hui D, Shen W. 2014. Effects of soil moisture on the temperature sensitivity of soil heterotrophic respiration: a laboratory incubation study. Plos One 9(3):e92531.

• Zink TA, Allen MF. 1998. The effects of organic amendments on the restoration of a disturbed coastal sage scrub habitat. Restor Ecol. 6:52-58.

• Zornoza R, Acosta JA, Faz A, Bååth E. 2016. Microbial growth and community structure in acid mine soils after addition of different amendments for soil reclamation. Geoderma 272:64-72.

• Zornoza R, Faz Á, Carmona DM, Acosta JA, Martínez S, De Vreng A. 2013. Carbon mineralization, microbial activity and metal dynamics in tailing ponds amended with pig slurry and marble waste. Chemosphere 90(10):2606-2613.

• Zornoza R, Faz A, Carmona DM, Martínez S, Acosta JA. 2012. Plant cover and soil biochemical properties in a mine tailing pond five years after application of marble wastes and organic amendments. Pedosphere 22(1):22-32.

• Zornoza R, Faz Á, Martínez S, Acosta JA, Gómez MD, Muñoz MA, Sánchez R, Murcia FJ, Fernández FJ, López E, Espín A. 2017. Rehabilitación de una presa de residuos mineros mediante la aplicación de lodo de mármol y purín de cerdo para el desarrollo de una fitoestabilización asistida. Bol Geo Min. 128(2):421-435.

Global J. Environ. Sci. Manage. 7(4): 1-22, Autumn 2021

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas

M.A. Peñaranda Barba[1,*], V. Alarcón Martínez[2], I. Gómez Lucas[1], J. Navarro Pedreño[1]

[1]*Departamento de Agroquímica y Medio Ambiente. Universidad Miguel Hernández de Elche Edif. Alcudia. Avda. de la Universidad, Alicante, Spain*

[2]*Departamento de Organización Industrial y Electrónica. Escuela Superior de Ingeniería y Tecnología, Universidad Internacional de la Rioja, Madrid, Spain*

ARTICLE INFO

Article History:
Received 02 February 2021
Revised 21 April 2021
Accepted Published: 27 May 2021

Keywords:
Environmental impact assessment
Flow charts
Mitigation methodology
Open-pit mining
Preventive measures
Reducing impacts

ABSTRACT

BACKGROUND AND OBJECTIVES: Open-pit mining is an important activity to obtain mineral resources that supply society with raw materials to improve people's quality of life. However, this extractive activity causes negative environmental impacts and, it is therefore necessary to identify and evaluate these impacts in order to design preventive and control measures to reduce them and thus safeguard the environment and natural resources. In the Region of Murcia, in Spain, as well as other Mediterranean areas with similar climatic conditions, there is a great deal of mining activity linked to the building sector, in which mainly ornamental rock (marble and marble limestone) and limestone aggregates are used. All of this has given rise to numerous active and abandoned mines, where no restoration process has been carried out, generating strong impacts on the environment.

METHODS: In this study, 8 environmental impact assessments studies of ornamental rock and aggregate quarries in the Region of Murcia were analysed to identify the negative impacts on the abiotic and biotic environment, landscape, socio-economic and socio-cultural environment, and infrastructures and analysing preventive and control measures.

FINDINGS: According to the environmental impact assessment studies analysed, the importance of the most significant environmental impacts has been calculated, indicating whether the impacts are critical, severe, moderate or compatible, and based on it, preventive and corrective measures are proposed together in an impact mitigation management system based in flow charts that will serve to more easily apply and control these measures, in order to prevent them from causing significant or irreversible damage to the environment. Analysing these measures, it has been observed that 90% of the measures applied to control the different negative environmental factors in this type of quarry are the same.

CONCLUSION: Open-pit mining extraction systems have a series of similar characteristics that allow a systematic approach to be established when analysing the impacts. With the use of flowcharts, it becomes easier to apply measures to reduce environmental impacts and in addition, these diagrams, allow at the same time the easy incorporation of updates due to changing regulations.

DOI: 10.22034/gjesm.2021.04.0*

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
60	9	6

*Corresponding Author:
Email: *marianpeba@gmail.com*
Phone: +34 6366 81773
Fax: +34 8689 12319

Note: Discussion period for this manuscript open until January 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Open-pit mining have been considered as an activity that represents a social and economic benefit for the regions and improve the quality of life of the inhabitants, thus constituting an important element for development. However, quarrying, like other mining-related works, causes negative impacts on the environment and strong ecological changes in the affected ecosystems (Sheoran *et al.,* 2010; Sort and Alcañiz, 1996). The level of destruction caused by open pit mining is ten times greater than that caused by other types of mining (Zhou *et al.,* 2018). It is important the identification and assessment these risk in order to design strategies that avoid, mitigate and compensate for these impacts (Luna, 2015). The increase in human capacity to transform the natural environment has led to an imbalance between the damage caused and the capacity of the environment to recover from it. It is clear that this type of exploitation cannot be dispensed with, as it supplies society with the raw materials necessary to improve its quality of life (Parrota and Knowles, 2001). The abandonment of open-pit quarries, without any kind of rehabilitation or recovery of their initial state, is the main source of impacts (Darwish *et al.*, 2010; Khabali and Kamal, 2013). Open-pit mining negatively affects the environment in a variety of ways, from exploration and blasting, transport and disposal of waste rocks (Lad and Samant, 2014). In addition, the exploitation of open-pit quarries causes other environmental impacts: affectation and disappearance of vegetation, fauna, soil and landscape degradation; disruption of animal habitats; changes in air quality, dust pollution; increase of particulate matter in the air; loss of water resources due to degradation of aquifers, diversion of underground streams, changes in the water table and water pollution; contamination of rivers; diversion and blockage of natural drainage systems; production of large volumes of highly polluting waste; noise and vibration; landscape alteration, visual pollution of waste dumps and degradation of large areas that take thousands of years to restore; land use conflict (Maponga and Munyanduri, 1998; Stehouwer *et al.,* 2006; Fierro, 2012). Moreover, it can also affect the health conditions of the surrounding population. Today, awareness of the limitation of natural resources, as well as that of the various elements which constitute ecosystems, makes it necessary to solve the problems for the demand of raw materials in accordance with the conservation of nature, in such a way as to safeguard the environment and natural resources in order to be able to pass them on to future generations (Montes de Oca and Ulloa, 2013). To achieve greener mining with fewer impacts, it is necessary to improve the pollution produced by activities in the air and water and those produced by noise, as well as the need to recover the land and its uses after the activities on the exploitations (Zhou *et al.,* 2020). For all these reasons, Spain created the Law 21, (2013), on environmental assessment, amended by Law 9, (2018), which states that an environmental impact assessment is essential for the protection of the environment. This is an adaptation of the national legislation to the existing legislation in the European Union. It facilitates the incorporation of sustainability criteria in strategic decision-making and guarantees adequate prevention of the specific environmental impacts that may be generated, while at the same time establishing effective mechanisms for correction or compensation of the damage. In Spain, the mining activity achieve account 3,280 million euros (M€) in 2017 (MET, 2018). In the Region of Murcia, the exploitation of geological resources has always been linked to the extraction of minerals and rocks. Specifically, it is represented by the extraction of marble, marble limestone and limestone aggregates, which are used by building companies in multiple applications, ranging from the production of concrete, mortar and asphalt agglomerates, to the construction of bases and sub-bases for roads, ballast and sub-ballast for railway tracks, or breakwaters for the defence and construction of ports. The consequence of obtaining them is linked to the damage caused to rural areas and the natural environment during the different phases of exploitation, concerning for the correct development, conservation of the environment and, obligations under legislation have evolved over the years (Casas, 2018). Quarries are found in all the territories of the Region of Murcia, but the Norwest area and the Mula basin stand out due to their great variety of ornamental rock, and the Fortuna-Abanilla area due to its large production of limestone aggregates. The aim of this study is to create an impact mitigation management system based in flow charts with corrective and preventive measures that can be easily applied in ornamental rock and aggregate quarries in arid and semi-arid areas. To this end, several environmental impact assessment (EIA) studies of quarries in the Region of Murcia have been analysed, the importance of the impacts they produce has been calculated and the measures used to mitigate these impacts have been taken into account. The conventional methods used to mitigate impacts are characterized by being a cumbersome, slow and expensive process. So, in this study, a decision support system is proposed that minimizes these problems. This study has been carried out in the Region of Murcia, Spain during 2020-2021.

European and national legal framework

The evolution of the regulations up to the current situation implies the need to study and define a systematic methodology for impact assessment and mitigation. The environmental assessment is a well-established instrument that accompanies mining development, ensuring that it is sustainable and inclusive. At the international level, environmental assessment regulation is under the Espoo Convention, (1991), and it's Protocol on Strategic Environmental Assessment, (UN, 2003). In the European Unión, it is regulated by Directive 42, (2001), by Directive 92, (2011), and by Directive 52, (2014). At the national level, in Spain, it is regulated by Law 21, (2013), on environmental assessment, modified by Law 9, (2018). This regulation includes the obligation to carry out an EIA of the projects. The EIA, aims to incorporate environmental aspects in decision making and seeks sustainable development and environmental protection (Enriquez-de-Salamanca, 2021). In addition, it is considered as an instrument to support decision making (Retief *et al.*, 2020). According to Pchalek (2019), the objective of the EIA is to point out suitable alternatives, minimizing and compensating impacts. According to Glasson and Therivel, (2019), the EIA is a process in which the possible environmental impacts of a project are evaluated in a phase prior to decision-making to promote healthy environmental management. Therefore, the minimization of environmental impacts is a standard procedure in mining operations (Falck, 2016). Environmental management is the key to sustainability in mining (Yildiz, 2020), it is necessary to carry out a sustainable management of natural resources to create the minimum negative results on the environment (Elvan, 2013). Mining has an important role in the sustainable development of natural resources, given by the important environmental and social impacts that it can generate (Ghorbani and Kuan, 2017). Directive 52, (2014). This indicates that EIA has to identify, describe and assess the significant effects of a project on the following factors: population and human health; biodiversity, paying particular attention to species and habitats protected under Council Directive, (1992) and Directive 147, (2009); land, soil, water, air and climate; material assets, cultural heritage and landscape; and the interaction between the factors referred previously. In addition, Law 9, (2018) makes compulsory to carry out an environmental impact study in the ordinary EIA. The EIA study is intended to prevent possible natural damage, establishing corrective measures and ensuring the possibility of compatibility of the extractive activity with the conservation of the environment and developing methods of recovery and monitoring of impacts on soil and water (Casas, 2018). The objective of EIA in mining is to identify, predict and prevent environmental alterations caused by extractive activities, from research and mining exploitation to the processing of the minerals to be processed (Astorga *et al.*, 2003). The main objective is to ensure that environmental considerations are explicitly expressed and included in the decision-making process and to anticipate and avoid, minimise and compensate for negative effects on the environment (Mora-Barrantes, 2016). Among the main objectives are: to ensure that environmental considerations are explicitly expressed and included in the decision-making process; to anticipate and avoid, minimise and compensate for significant negative biophysical, social and other relevant effects of the development proposal; to protect the productivity and capacity of natural systems and their ecological processes; to promote sustainable development by optimising the use of resources and management opportunities (Johnson and Bell, 1975). In addition to the EIA, a complementary environmental assessment must be carried out in accordance with the "Methodological Guide for Environmental Impact Assessment in Natura 2000 Network" (MET,2019), for Sites of Community Interest (SCI) and Special Areas of Conservation (SAC), which are protected areas integrated in the Natura 2000 Network (RN2000) designated for hosting an area of one or more types of natural Habitats of Community Interest (HIC) and/or habitats of the species listed in Law 42, (2007), modified by Law 33, (2015), which transposes the Habitat Directive of the European union.

MATERIALS AND METHODS

In order to know the environmental impacts and the measures to mitigate them, a methodological procedure is used to identify mining actions, such as environmental impacting components and environmental factors susceptible to receive impacts. The environmental impacts were identified, characterised, assessed and evaluated. In this way, premises are established to ensure that quarries carry out environmentally friendly mining operations. In order to identify impacts, it is necessary to analyse the different environmental factors that undergo variations. In most studies for the identification and assessment of impacts, the impact assessment method of Conesa *et al.* (2010) is used, this is an *ad hoc* method described in their book "Methodological guide for environmental impact assessment". However, this methodology predates the latest legislative amendments. Nevertheless, it provides a solid basis on which to develop EIA studies. Castelo *et al.* (2019), after having analysed various methodologies to assess risks in open pit mining, has verified that evaluating these risks depends on a number of data that are difficult to obtain or on general quantitative methods or the data are of uncertain reproducibility, in addition, they depend on multiple occasions of the evaluator and their experience and if more reliability is required, experienced teams or expensive processes are needed, so there is no method to respond quickly and that is reproducible and reliable to date. So, following the method described above, the project actions that may cause impacts are identified, and then the impacts are assessed in a qualitative manner, characterised by a series of attributes such as synergy, effect, accumulation, periodicity and recoverability. This technique is based on the cause-effect matrix method, which according to Garmendia *et al.* (2005) is the most widely used tool for determining impacts, derived from the Leopold matrix (Leopold, 1971) with qualitative results. This matrix is based on relating project actions with the environmental factors of the project, identifying the magnitude and importance of the potential effects on a certain environmental factor and the one generated for a certain project action. Once the impacts have been identified in the impact identification matrix and their causes, each of the impacts identified are evaluated according to a series of parameters to determine their importance in an impact assessment matrix. The importance will take values between 13 and 100 depending on the scores given to each parameter. The definition of these impacts together with their importance is shown in Table 1 and it will be concluded in the EIA study whether the development of the project is acceptable or not.

The methodology followed in this article is based on the analysis of EIA studies by several authors (Handjaba, 2012; Khabali and Kamal, 2013; Luna, 2015; Gómez, 2016; Villalba, 2017; Miñarro, 2018; Casas, 2018; Moreno, 2021), in order to apply techniques to mitigate and reduce the negative effects caused by the extraction of ornamental rock (marble and marble limestone) and limestone aggregates in open-pit quarries and their abandonment without any type of restoration. In this study the EIA studies of 8 quarries found in the Region of Murcia, which is an arid and semi-arid region, have been analysed. To identify

Table 1: Classification of impacts and its importance

Classification of impacts		Importance
Compatible	It is the one whose recovery is immediate after the cessation of the activity and does not require preventive or corrective measures.	13-25
Moderate	It is one whose recovery does not require intensive preventive or corrective measures and in which the achievement of the initial environmental conditions requires a certain amount of time.	25-50
Severe	It is one in which the recovery of the environmental conditions requires the adoption of preventive or corrective measures, and in which, even with these measures, recovery requires a long period of time.	50-75
Critic	It is one whose magnitude is higher than the acceptable threshold. It results in a permanent loss of the quality of environmental conditions, with no possibility of recovery, even with the adoption of preventive and corrective measures.	75-100

the most significant impacts on these quarries, the importance of each activity in the different phases of a quarry with respect to the different environmental factors has been calculated. For this, the lowest and highest data have been collected on the importance that each mining activity can take in each of the different phases of exploitation in relation to each environmental factor in each of the 8 analysed quarries. The components usually considered in this inventory are the abiotic and biotic environment, the perceptual environment, the socio-economic environment and the socio-cultural environment and infrastructures. The different phases in a quarry are: phase I, of preparation, in which the roads and accesses are adapted and the clearing of the vegetation and the drainage and sewers are carried out; phase II, of operation, in which the start-up is carried out by loading and blasting, the transport of materials, the creation of fissures, the auxiliary and processing operations and the maintenance of machines, an occupation and change of use is carried out of the land, the fencing and enclosure of the quarry and spills and dumps are generated; and phase III, of restoration, in which in which remodelling and revealing is carried out and there is vehicle traffic. Once the most important impacts that occur in quarry operations have been obtained, preventive and control measures are proposed to reduce or eliminate these impacts based on the different components of the environment (these measures have also been obtained from impact studies analysed) and flow diagrams are created to facilitate the application of corrective and preventive measures with respect to the pollutants existing in the quarries (dust, noise, oils and lubricants, reject materials and other quarry waste). In addition, a diagram will be created to control the topsoil, another to improve the environment and human health and one to improve the health and safety of workers and another to improve the surfaces altered by the quarrying activity and reduce the impact on the landscape, fauna and flora. This detailed study establishes a methodology that can be applied generally in other regions and open-pit mining operations, facilitating systematic monitoring and the proposal of impact mitigation measures.

Study area

The Region of Murcia is located in the Southeast of the Iberian Peninsula, and forms part of the eastern part of the Betic Mountain Range. The area, according to the National Geographic Institute (IGN, 2020), is structurally divided into two zones: External Zones, subdivided into the Prebetic and Subbetic domains, and the Internal Zone, which is divided into three domains that rode on top of each other but were later transformed into extensional detachment faults. These domains are, from bottom to top, Nevado, Filábride, Alpujárride and Maláguide. All these domains are represented in the Region of Murcia. In addition to the materials of the Betic Mountain Range linked to the main tectonics, there are other post-orogenic materials that are well developed in the inner depressions and alluvial valleys: the tertiary basins of Campo de Cartagena, Mula, Fortuna, Calasparra syncline, Moratalla, Lorca and Rambla de Tarragoya stand out, and among the latter, the Plio-Quaternary valley of the Guadalentín-Segura. Mining in Murcia is mainly represented by the ornamental rock and aggregate sector. According to the Mining Service of the Autonomous Community of the Region of Murcia (CREM, 2019), the number of existing mines in the Region of Murcia is 227, all of them carried out by open-pit mining methods. Of these, 98 are still active. Fig. 1 shows the municipalities in which there are ornamental rock quarries and the most representative ones in which there are aggregate quarries.

There were 122 ornamental rock quarries in the Region, of which 42 are active (CREM, 2019). Specifically, these ornamental rocks are different varieties of marble and marble limestones. Their location is shown in Table 2, which shows the type of ornamental rock that exists in each municipality. The ornamental rock, in the Northeast and the Altiplano, is associated with the Jurassic layers of the Subbetic and Prebetic Eocene, large thicknesses of limestones and dolomites, with a wide variety of colours: creams, browns and reds. Marbles, strictly speaking, appear in the Betic alignments of the Alpujarride of the Cabezo Gordo in Torre Pacheco. Aggregate quarries are distributed throughout all the districts of the Region, there are 74 quarries and 32 of them are active. The most representative limestone aggregate quarries are located in the Fortuna-Abanilla district and in the district of the metropolitan area of Murcia, in Santomera, with 44 percent (%) of production, and in the district of Campo de Cartagena, in Fuente Álamo,

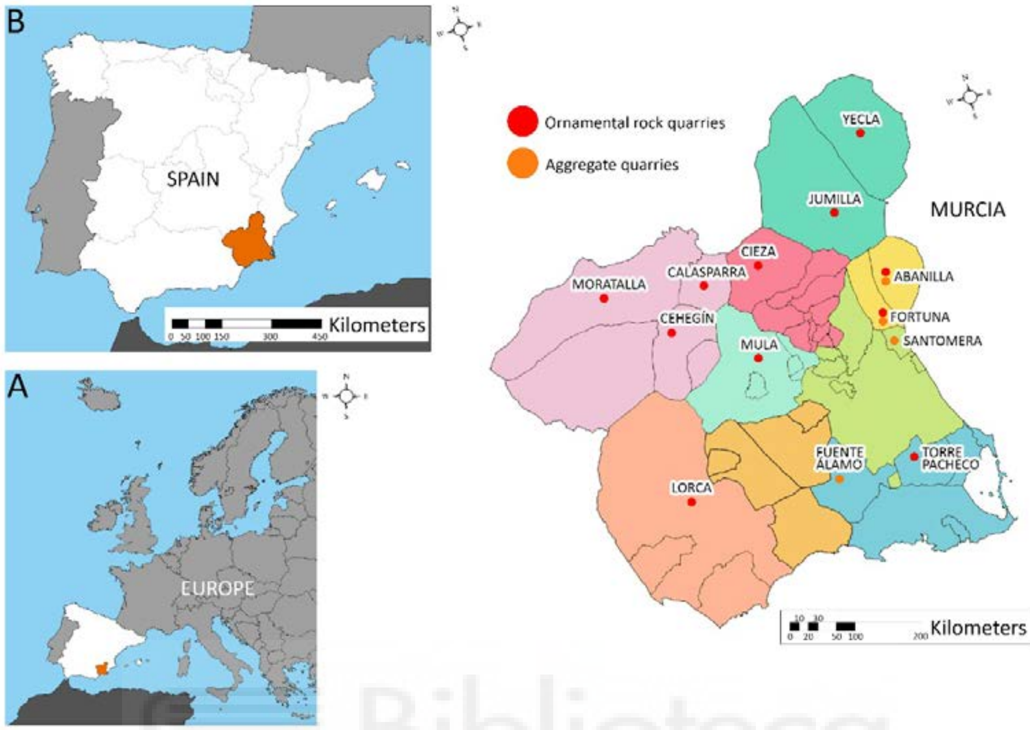

Fig. 1: Geographic location of the study area in the most representative municipalities in the Murcia region of Spain with ornamental rock and aggregate quarries

with 14% of production. Of the total production in quarries in the Region, approximately 74.8% corresponds to the aggregate extraction subsector.

The Region of Murcia has a Mediterranean climate with arid features: hot, dry summers, mild winters, although with frequent frosts in the interior, and rainfall in spring and autumn. The general characteristic of this climate is its scarcity of rainfall, concentrated in a few days of the year, with maximum rainfall in autumn. These rains, usually torrential, are produced when a mass of warm, humid air from the Mediterranean Sea enters the area and, on colliding with the coastal mountain ranges and rising, comes into contact with another mass of cold air and precipitates. These rains must be considered precisely because of the high erosive power they can unleash when it comes to recovering mining areas. According to Köppen's climate classification, (Köppen, 1936), the following climate types can be distinguished in the region: warm semi-arid (BSh), cold semi-arid (BSk) and Mediterranean (Csa). In the BSh climate, the mean annual temperature is above 18 degrees Celsius (°C) and precipitation is low, solar evaporation exceeds precipitation, it is a hot and dry climate; in the BSk climate, the mean annual temperature is below 18°C, precipitation is also low and evaporation, like BSh, also exceeds precipitation, this climate is cold and dry; in CSa, the average temperature of the coldest month is below 18°C and above -3°C and that of the warmest month is above 10°C, the temperature of the warmest month is above 22°C and average temperatures above 10°C occur in less than four months of the year. Precipitation exceeds evaporation and there is seasonal rainfall. The summer is dry, so the minimum rainfall is quite marked and coincides with the period of highest temperatures. The rainiest season is not necessarily winter. Table 3 shows the average annual temperatures, in ºC, and rainfall, in litres per square meter (l/m²), for 2019 in the study sites, the table is based on data obtained from the Murcia regional statistics portal (CREM, 2020). With regard to the winds, the west/northwest-south/east orientation (WNW-SE) of the great Betic relief lines channels the winds from the Atlantic, while the winds

Table 2: Types of ornamental rock currently exploited in the Region of Murcia and their geographical distribution. Source: own elaboration according to data obtained from the Ministry of Business, Industry and Spokesperson of the Region of Murcia

District	Municipality	Ornamental rock
Region of Lorca	Lorca	Oolitic limestones Crinoid limestones
Campo de Cartagena-Mar Menor	Torre Pacheco	Greyish-white or greyish-white limestones, with white and ochre veining
Mula basin	Mula	Light and grey massive dolomites White to pinkish coloured limestones Reddish nodular limestones Limestones with Nummulites Limestone with algae Limestones with large Nummulites
Northwest	Calasparra	Dark brown dolomites Greyish and brown dolomites
	Caravaca and Moratalla	Greyish limestones White and cream massive limestones Massive sandy limestones Calcarenites Cream-coloured massive limestone
	Cehegín	Brecciated and massive limestones varying from red to dark grey
Vega del Segura	Cieza	Brown dolomites White limestone
Abanilla-Fortuna basin	Fortuna and Abanilla	Reddish massive limestone Tertiary limestone
Altiplano	Jumilla and Yecla	Dark-coloured massive dolomite Honey-coloured dolomite White limestone

from the north/northwest orientation (N-NW), which predominate during the winter, are dry and cold due to their long route. The Mediterranean squalls associated with convection phenomena give rise to a regime of easterly winds, with humid characteristics on the eastern flank of the region, which gradually dry out towards the interior. This situation predominates in spring and summer, extending into autumn. Wind speed is generally moderate, except on the coast, where it is higher due to its exposure to easterly winds. Relative humidity varies according to proximity to the sea. Inland it varies between 52 and 63% and on the coast between 71 and 76%. These climatic characteristics create a high rate of evapotranspiration which results in a permanent water deficit. This situation is generalised throughout the Region of Murcia.

The Region of Murcia is the most arid area of the Iberian Peninsula and is part of the Segura Hydrographic Basin. The drainage network of the Region is structured around the Segura river and its tributaries, the Guadalentín, the Argos and the Quipar. Groundwater comes from the fraction of precipitation that infiltrates due to the action of gravity. The Segura basin has been one of the first in the exploitation of groundwater, which has allowed unirrigated areas to be transformed into irrigated areas. There are currently ten different aquifer systems in the Region: Jumilla-Yecla, Calasparra, Cieza-Abanilla, Mula-Aledo, Caravaca-Moratalla, Bullas-Coy, Puentes-Valdeinfierno, Segura-Guadalentín, Cartagena and Mazarrón-Águilas (SITMURCIA, 2019). In general terms, in the Region of Murcia, there are more than two thousand plant species, which represents approximately 33% of the total number of species on the Iberian Peninsula, giving rise to a wide regional spectrum and making it one of the richest in Spain. The area occupied by crops exceeds 50% of the total and the rest is dominated by scrubland and tree species. With regard to scrubland, there is noble scrubland, with species such as Pistacia, Quercus, Rhamnus, Chamaerops, Arbutus, etc., and the characteristic scrubland of regressive stages such as rosemary (*Salvia imantopus*), esparto grassland

Table 3: Average annual temperature and annual rainfall by region with quarries

District	Municipality	Approximate annual average temperature 2019 (ºC)	Approximate annual rainfall in 2019 (l/m²)
Region of Lorca	Lorca	17,5	318
Campo de Cartagena-Mar Menor	Torre Pacheco and Fuente Álamo	18,6	419,5
Metropolitan area of Murcia	Santomera	18,5	523,9
Mula basin	Mula	18	455
Northwest	Calasparra, Caravaca, Moratalla, Cehegín	15,4	493,2
Vega del Segura	Cieza	17,3	475
Fortuna-Abanilla	Fortuna and Abanilla	18,8	575
Altiplano	Jumilla and Yecla	16	430

(*Stipa tenacissima*), thyme (*Thymus*), etc. From the coast to the inland mountain ranges, in a south-east-north-west direction, the wooded area increases and, therefore, the diversity of forest systems. The tree formations consist of frugal species, such as pines, junipers and xerophytic oaks. The wooded hills are made up of conifers and the broadleaved forests are mainly composed of kermes oaks, although they also appear in mixtures with other broadleaved and resinous species. The mid-mountain and foothill areas in the centre, north-west and north-east of the Region, include quercines (*quercus*), although these areas are highly altered. The intensive use of vegetation cover has led to significant deforestation, accentuated by climatic conditions. The fauna presents a very heterogeneous territory with a great variety of habitats, which contributes to maintaining a significant biodiversity of species such as Phartet (*Aphanius iberus*), Great Bustards (*Otis tarda*), Otters (*Lutrinae*), Shelducks (*Tadorna*), Vultures, Birds of Prey, Salamanders (*Caudata*), etc. Linked to the forest ecosystems, there are unique species such as the mountain goat (*Capra pyrenaica*), the Trompet Bullfinch (*Bucanetes githagineus*) and Dupont's Lark (*Chersophilus duponti*), as well as other species included in the annexes of the Habitats Directive and the Birds Directive, especially bats. There are also 51 species of mammals, both terrestrial and marine, many of them threatened or under some kind of conservation status. On the other hand, there are not many reptile and amphibian species, there are only 20 reptile species and 11 amphibian species and they are decreasing due to several negative factors that are influencing the region such as the aridity of the area, the use of water resources, the intensive agriculture, the introduction of invasive species, etc. Regarding to birdlife, there are almost 300 species, only one third of which are sedentary. According to the Council Directive, (1992), 42% of the regional area is classified as HIC (SITMURCIA, 2019).

RESULTS AND DISCUSSION

Main impacts from ornamental rock and limestone aggregate quarries in the Region of Murcia

In EIA studies, the description of the Environmental Inventory must take into consideration the components of the environment that intervene or may potentially be affected by the activities of the project to be environmentally assessed (Garmendia, 2005). The following tables show the most significant impacts that are usually produced by ornamental rock and limestone aggregate quarries in the Region of Murcia, in arid and semi-arid areas, according to the EIA studies analysed (Table 4, 5 and 6). These tables indicate the values that the impacts usually take, these values are previously defined in table 2 according to the classification of the impact. The impacts represented in Tables 4, 5 and 6 are those that generate a negative impact.

Analysing this phase, it is obtained that the environmental factors that can cause a severe impact on quarries in arid and semi-arid areas are noise and vibrations in the phase of adaptation of roads and accesses, the loss of soil quality in the clearing of the land, the loss of water quality when creating drains and aquifers, the alteration of flora and vegetation in the adaptation of roads and accesses and the clearing of vegetation and a visual impact on the creation of roads and accesses. In the elimination of the existing vegetation to carry out work in the

Table 4: Importance of the most significant environmental impacts in ornamental rock and aggregate quarries in the Region of Murcia in Phase I of preparation

Environmental factors			Phase I preparation		
			Adequacy of roads and accesses	Drains and sewers	Vegetation clearing
Physical environment	Atmosphere	Noise and vibration	35-55		
		Air quality	35-40		15-30
	Terrestrial environment	Soil quality	25-30	25-40	35-55
		Geomorphology	20-35		
	Water	Water quality		45-60	30-40
		Hydrogeology		35-45	
Biotic environment	Flora and vegetation		45-60		25-60
	Fauna	Biotypes	25-50		
		Species of interest	25-50		25-30
Perceptual environment	Landscape	Intrinsic quality	40-50		25-40
		Visual impact	45-60		25-40
Socio-economic and socio-cultural environment	Productive use	Agricultural forestry and livestock	40-45		

quarry; the surrounding vegetation is affected by the dust particles generated on the exploitation, these particles are deposited on the stomata, interfering with the chlorophyll function and intervening in growth. High concentrations or long exposures of nitrogen oxides (NOx) from vehicles and machinery cause leaf pigmentation, necrosis and reduced growth. The high concentration of sulfur dioxide (SO_2), released from the fuels used, prevents an assimilable transformation for the metabolism of the vegetation and initiates a cellular rupture (Villalba, 2017). With the elimination of the vegetation the habitat of some species is destroyed, which leads to the emigration of the fauna, and the edaphic fauna is also eliminated. The rest of the impacts are moderate (with values of the importance between 25 and 50) or compatible (with the importance between 13 and 25) and in the gaps in which there is no importance it is because they are insignificant.

In this phase, there may be a critical impact on the activity of occupation and change of land use, since it creates a modification of the landscape and a qualitative visual impact. There may also be severe impacts (with values of importance between 50 and 75) such as noise and vibrations to the atmosphere produced by the use of heavy machinery and in drilling, blasting and mechanical preparation of the raw material. Loss of air quality caused by emissions of polluting substances due to the use of heavy machinery, the use of explosive substances for blasting, and the use of fuels and lubricants for machinery. Among the polluting substances that are released are nitrogen oxides (NOx), which contribute to the generation of photochemical smog and acid rain and, in addition, in areas where there is surface water, can cause eutrophication. Another polluting substance is carbon dioxide (CO_2), which increases the greenhouse effect, in addition, it also contributes to the loss of air quality, the generation of dust in extraction operations, drilling, blasting, accumulation, charging, transport, crushing and classification of the resource and that produced in the creation of accesses to the quarry (Villalba, 2017; Jiskani, 2021). Another severe impact would be the alteration of the geology and the loss of the quality of the soil when carrying out the work in the quarry. There is also the risk of groundwater contamination due to accidental discharge of polluting substances such as oils or other substances from vehicles and machinery used. The voids generated in the quarries, in addition, can create irreversible contamination in the water table due to the creation of tailings, especially if these voids occur in karst areas with a high degree of cracking and in which the waters flow rapidly, without being by filtration processes, reaching more or less deep aquifers (depending on the topography) with their respective discharge and catchment areas (Khabali and Kamal, 2013). With regard to surface waters, there may be contamination of rivers due to erosion by rainwater currents and

Table 5: Importance of the most significant environmental impacts in ornamental rock and aggregate quarries in the Region of Murcia in Phase II of exploitation

Environmental factors			Phase II of operation						
			Blast start and charge	Transport of materials	Auxiliary and processing operations	Creation of fissures	Occupation and change of land use	Landfill of tailings, waste rock dumps	Fencing and enclosures
Medium physical	Atmosphere	Noise and vibration	35-65	40-55	45-60			45-50	
		Air quality	20-25	50-55	40-50	40-45		40-50	
	Terrestrial environment	Soil quality		25-30		40-60	40-45		
		Geology	25-35			25-60			
		Soil science	25-35			25-30	25-30		
		Geomorphology	30-35			30-40			
	Water	Water quality	30-35	30-40		35-45		30-55	
Biotic environment	Flora	Plant formations		40-50			25-30		
		Species of interest					25-35		
	Fauna	Biotypes		35-40			25-30		40-45
		Species of interest	25-35	30-40	30-35		45-50		35-45
Medium perceptual	Landscape Visual impact		50-55				55-90		40-45
Socio-economic and socio-cultural environment	Recreational use: Tourism, hunting and sporting activities						35-50		25-30
	Productive use: Forestry, agriculture and livestock						40-50		
	Human health and safety			50-65					
	Communication routes: mobility			40-50					
	Land use					40-45	45-50		

Table 6: Importance of the most significant environmental impacts in ornamental rock and aggregate quarries in the Region of Murcia in Phase III of restoration

Environmental factors			Phase III restoration		
			Vehicle traffic	Remodelling	Revegetation
Medium physical	Atmosphere	Noise and vibration	45-55	25-30	
		Air quality	35-45	25-35	
	Terrestrial environment	Soil quality	45-50	40-50	40-45
		Geomorphology		30-35	
	Water	Water quality	45-50		
Medium biotic	Flora	Plant formations	30-40	25-35	25-30
		Species of interest	45-50	30-40	25-35
	Fauna	Biotypes		30-35	40-45
		Species of interest	45-50	30-35	30-40
Medium perceptual	Landscape	Intrinsic quality	45-50		25-30
		Visual impact	35-45	30-40	30-35
Socio-economic and socio-cultural environment	Productive use: Forestry, agriculture and livestock				25-30
	Human health and safety		40-50	30-40	
	Communication routes: mobility		45-50		
	Land use		40-45		

the wind, since they can carry substances from the vehicles and machinery used and can lead to the loss of ecosystems. Due to the noise, vibrations and dust produced in the quarries, fauna is displaced and redistributed and habitats can be altered due to the possible contamination of groundwater and rivers. In the generation of holes and slag heaps, the visual quality of the landscape is lost and, in addition, visual intrusion occurs due to the use of machinery. The emission of noise, vibration, dust and water pollution can cause harmful effects on workers, those generated cause eye irritation, congestion and lung diseases and SO_2 and dust particles in suspension, produce allergies and infections in the respiratory system. The rest of the impacts are moderate (with values of the importance between 25 and 50) or compatible (with the importance between 13 and 25) and in the gaps in which there is no importance it is because they are insignificant.

In this phase, all the impacts obtained would be moderate, except for the noise and vibrations produced by vehicle traffic, which could become severe. The rest of the impacts not indicated would be compatible or insignificant. In this phase, the contribution of land is of interest, which can generate occasional air pollution due to suspended particles generated by the unloading of trucks. Dust has a negative impact on air pollution in the atmosphere, but also on water and land resources, as it interrupts the natural processes of flora and fauna and causes irreversible effects on human health (Timofeeva and Murzin, 2020). Reducing the noise and vibrations produced in many operations such as removal of the surface soil, drilling, blasting, excavation, crushing, handling and transport and other operations with machinery is important to the health of people and their well-being and that of the ecosystem, as high levels negatively influence species by increasing stress levels, modifying their habitat and masking other sounds they need for their survival (Jain *et al.,* 2016). Another factor that negatively influences the environment is mining waste, because if they are not treated properly they contaminate the water, the atmosphere, the soil and the occupied land. (Chen *et al.,* 2020).

Preventive measures to control and mitigate environmental impacts

Once the impacts that usually occur in ornamental rock and aggregate quarries in the region of Murcia have been obtained and analysed, the measures that are usually applied to control and reduce these impacts have been analysed on the basis of the environmental impact studies studied and it has been found that 90% of the measures that are applied to control the different negative environmental factors are always the same. These measures are described below, and in relation to them, flow diagrams will be proposed to simplify their control and application in the quarries. In order to control the visual impact

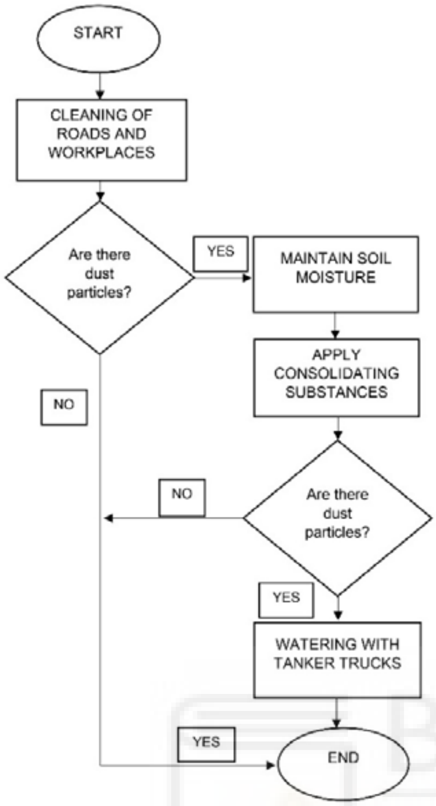

Fig. 2: Flowchart to reduce dust on roads and workplaces

and the modification of the landscape, the original forms of the accesses that are not essential for access to the restoration of the land must be restored by means of disabling and environmental recovery. In addition, as work on the slopes is completed, a slope ageing product should be applied that simulates the chromatic characteristics of the environment. Efforts should also be made to work in areas of low visibility from main roads and urban centres. The measures that are usually applied to reduce dust are: clearing land and opening roads, as far as possible, on days when the force of the wind does not imply a high risk of suspension of materials; carrying out effective maintenance of access roads to avoid the formation of dust and the accumulation of mud on the roads due to the transit of lorries; maintaining tracks and squares with a sufficient degree of humidity to avoid the dust deposited on them becoming suspended, using, if necessary, substances that consolidate and maintain the humidity of the soil. Another option is to irrigate with water tankers, as water is not normally available in mining areas and rainfall in the Region of Murcia is scarce; workplaces should be kept clean to prevent the accumulation of dust that can later be put into suspension. When there are accumulations of dust in different parts of the quarry, these shall be removed as soon as possible; in addition, the provisions of Order ITC 2585, (2007) on protection of workers against dust, in relation to silicosis, in the extractive industries. The suspension of dust in vehicle and machinery transit operations must also be controlled by irrigation, paying special attention to the quarry site, access tracks and unpaved areas, in order to affect human beings and the surrounding flora and fauna as little as possible. In order to make it easier to control dust, a flow chart has been drawn up with some proposed measures (Fig. 2).

To control noise and vibrations in quarries, the engines of machines that are going to be on standby for long periods of time should be switched off, the noisiest operations should be planned so that they do not coincide in time to avoid a large amount of noise and vibrations, and noise should be made on working days and intermittently. Except in emergency situations, work should not be carried out at night. The machinery used must comply with the permitted noise emissions, in this case regulated by Royal Decree 212, (2002). Blasting must be carried out in the middle of the day. In addition, to reduce the effect of air waves and vibrations from blasting, bottom-loading cartridges should be primed with non-electric detonators, detonating cord should not be used in the open air and the connection and sequencing between blast holes on the surface should be done with non-electric connectors so that the sequencing time is different from one another. In addition, if mechanical preparation plants are present, noise protection screens should be provided. The correct operation and commissioning of the vehicles on the operation must be checked, carrying out the corresponding gas emission controls and equipment checks established by the manufacturers. This will reduce noise and the emission of polluting gases, as well as reducing the risk of breakdowns and potential accidental spillage of polluting liquids. Periodic inspections of machinery must comply with Law 34, (2007), with respect to air quality and protection of the atmosphere and with Decree 1439, (1972) with respect to noise. In order to control oil and lubricant spills, the use of vehicles should be optimised to allow for the maximum

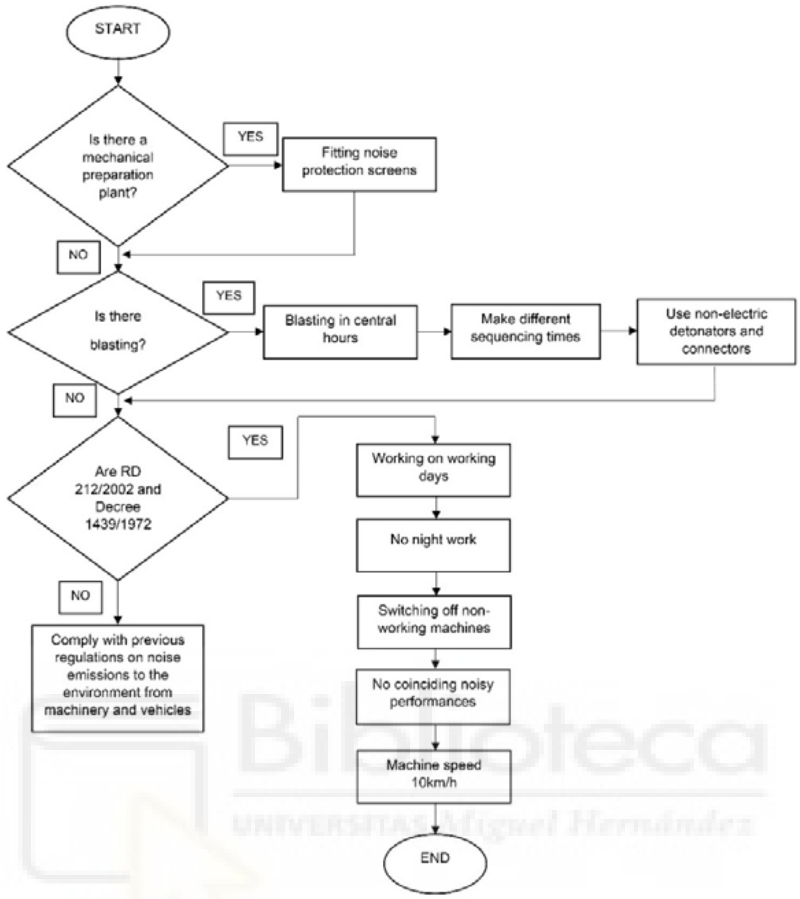

Fig. 3: Flow chart to reduce noise and vibrations in mining

operationally possible fuel savings. Equipment and vehicles must be more efficient and less polluting, more efficient vehicles and heavy equipment produce less pollution and reduce greenhouse gas emissions since their engines are cleaner, so older equipment must be replaced (Jiskani *el al.,* 2021). Repairs or oil changes of machines should be carried out in specialised workshops. In the event of accidental spillage of these materials, they must be cleaned and collected, deposited in containers for subsequent removal by an authorised waste manager, so that they do not affect runoff water or water that may infiltrate. Used oils and any other waste qualified as such from the exploitation must be compulsorily removed by an authorised hazardous waste manager. To reduce SO_2, CO_2 and NOx emissions as far as possible, the speed of machinery will be reduced to 10km/h in the area, in addition to choosing machinery that is equipped with catalytic converters that reduce emissions as much as possible, and the days on which the atmospheric phenomenon of thermal inversion occurs will also be taken into account so that accumulations of emissions do not form in the area due to a lack of ventilation (Villalba, 2017). To make it easy to implement these measures, a flow chart for noise and vibration reduction (Fig. 3) and a flow chart for fuels and lubricants (Fig. 4) have been developed.

A simple flow chart (Fig. 5) is proposed to control topsoil. The measures to be applied for this would be as follows: the topsoil should be removed, stockpiled and adequately maintained for later use in restoration. This removal must be carried out with care to avoid its deterioration by compaction and thus to preserve the soil structure, the existence of microorganisms, etc. For this reason, the passage of machinery over this soil should be avoided. During storage, it must

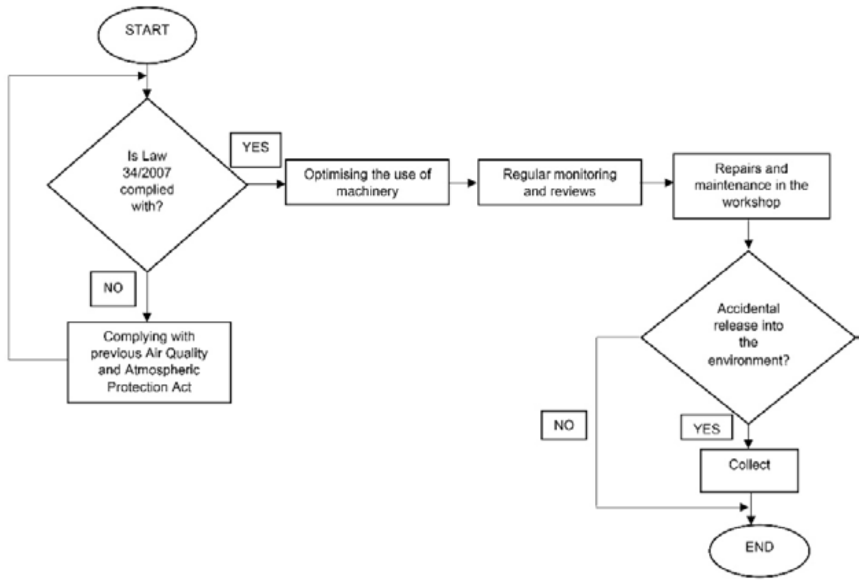

Fig. 4: Flow chart for reducing fuels and lubricants in mining

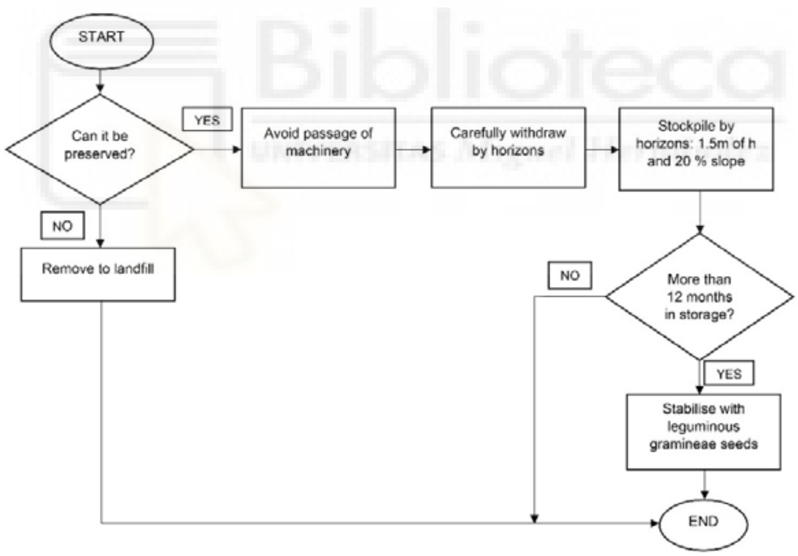

Fig. 5: Flow chart to control topsoil in mining

be protected from wind, water erosion and pollutants that alter the vegetative capacity. Stockpiles should not exceed 1.5m in height and slope gradients should not exceed 20º to avoid erosion (Casas, 2018; Moreno, 2020). The removal and stockpiling should be done differentiating the different soil horizons in order to be able to restore them in the restoration with the same original arrangement. Where feasible, the original soil flora will be preserved, in order to try to maintain a fertile layer on the surface to facilitate vegetation growth and control runoff erosion in the short term in sloping areas. If topsoil is to be stockpiled for more than 12 months, it should be stabilised with a mixture of leguminous and grass seeds to protect it from erosion and preserve its soil characteristics.

In order to control waste material in quarries, an inner spoil heap must be created to deposit the tailings generated in the exploitation, which will progress as the exploitation pit progresses. The pit must be filled to the level of the surrounding ground surface with the tailings from the limestone rejects. The topsoil, previously removed and reserved, shall be spread over the tailings from the rejects located inside the shaft, in order to subsequently proceed with the revegetation of the land. If there is no topsoil from the mining activity, a topsoil with similar characteristics to the existing one must be placed. When work is finished in the mining areas or work is stopped for more than one year, all types of material, machinery, waste and remains that may be left in the area must be collected and taken to a landfill site, leaving the area in a perfectly clean condition. Revegetation should be attempted with native and fast-growing species. Exotic species should be avoided, as they are susceptible to becoming invasive. Planting will include, when the soils require it due to insufficient stockpiles or inadequate quality, topsoil, fertilisers and amendments, and of course, the necessary tillage. When the revegetation work is completed, care of the topsoil has to be carried out, including replacing dead plants during the following years, installing protective structures to prevent trampling and additional foot watering. A simple flow chart has been proposed to control the reject material (Fig. 6).

In quarries there are reject materials that must be removed from the work areas so that they do not contaminate the environment; these can produce, among other things, water, soil and atmospheric pollution. For this purpose, the most common measures that are usually applied are shown together with a flow chart (Fig. 7) to make it easier to control them. Solid waste should be disposed of in controlled landfills. Leftover materials and non-hazardous waste should be deposited in authorised landfills. If there is a layer of debris prior to the removal of usable soil, this should also be taken to authorised landfill sites or put to an appropriate use. Perimeter channels can be planned to prevent water from the outside from entering exploitation. Small mammals and other vertebrates that may fall into ditches or holes created

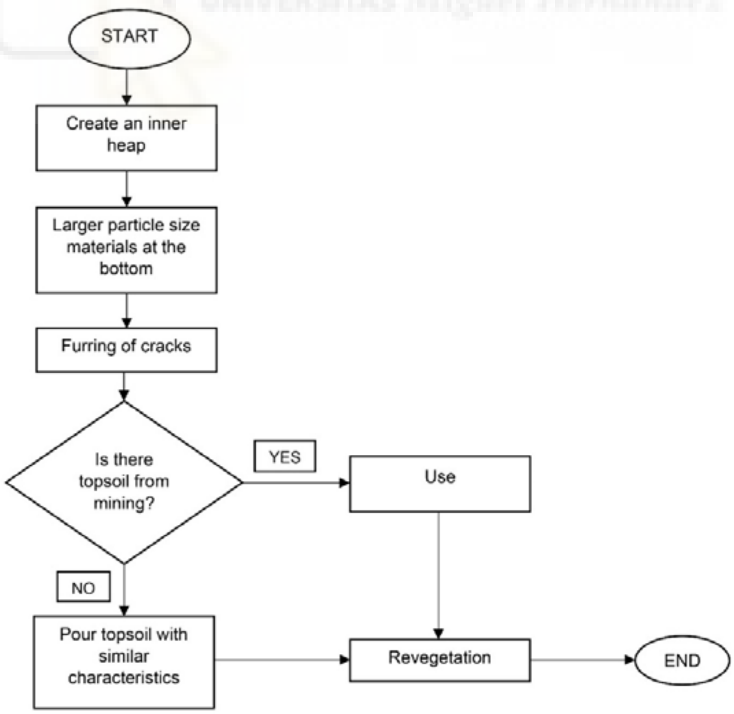

Fig. 6: Flow chart for controlling reject material from mining

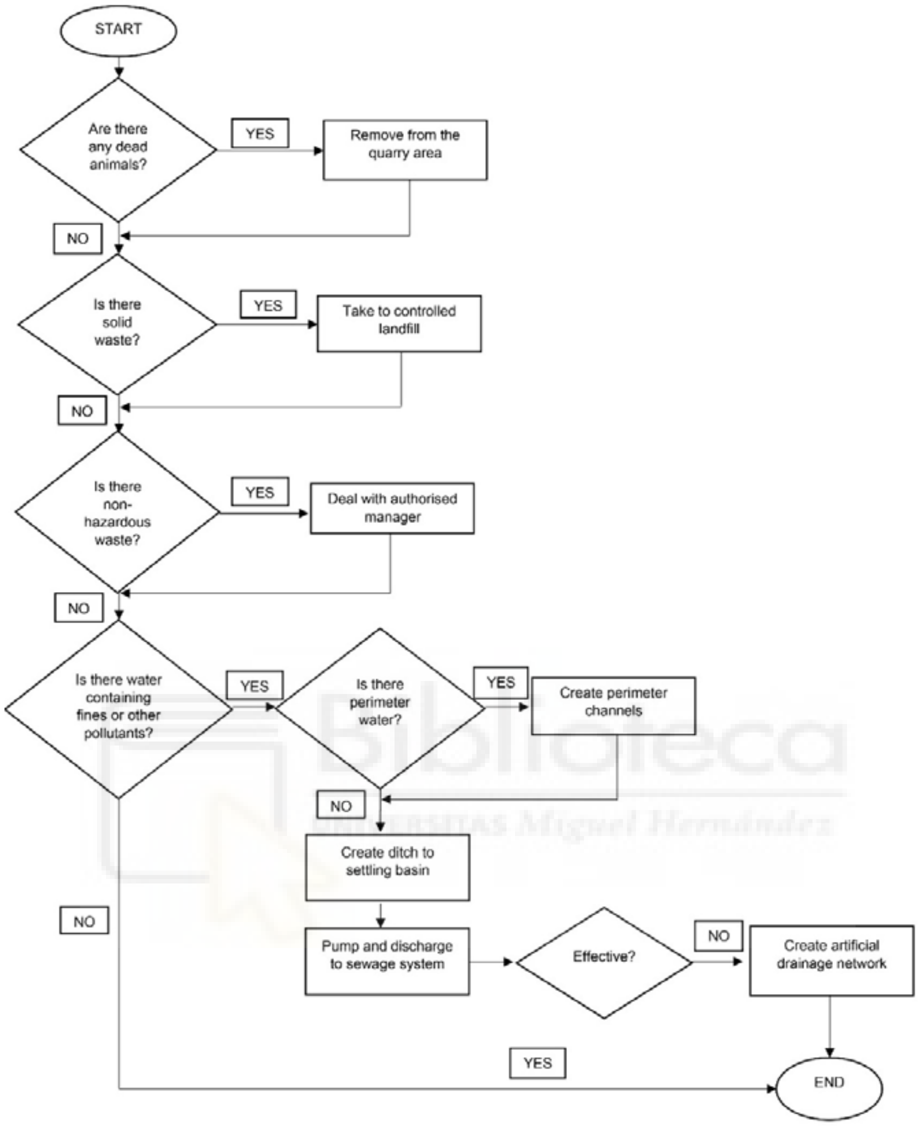

Fig. 7: Flow chart to control and reduce other quarry waste in quarries

on the exploitation must be released after daily checks prior to the start of exploitation work. For the collection of water from the interior, a ditch can be built to collect the water in a settling basin, so that the water laden with fines does not reach the natural drainage network. The clean water from the settling basin will be pumped and discharged directly into the drainage network. If the water table is below the excavation level and with the above measures, the mining activity will not affect the drainage network or any aquifer. If necessary, an artificial drainage network must be created to ensure trafficability and to channel the resulting runoff. The processing and use of waste, in addition to not polluting the environment, serves to compensate for the scarcity of resources, which means that I have great social, environmental and economic benefits. In addition, there is a strategic commitment to the circular economy that supports waste minimization (Jiskani *et al.,* 2021).

It is crucial to consider the environmental and human health, one to improve the health and safety of workers for which the measures given below are usually used and based on them a flow chart has been created for easy application (Fig. 8) and another to improve the surfaces altered by the quarrying activity and reduce the impact on the landscape, fauna and flora for which other measures also described below have been established and have been collected in Fig. 9. Beacons and barriers must be placed indicating danger zones on the site, access points, speed limits, etc. Workers must wear the appropriate work clothes and personal protective equipment necessary for the performance of their tasks. The collaboration of forestry agents must be ensured so that the works are carried out with the least possible risk of fire. The evolution of the slopes must be monitored as the work progresses. The bottom layer of the backfill must be made up of the materials with the highest granulometry, in order to favour the stability and drainage of the whole deposit. No people or material should be in the vicinity of the working slope during the removal of the material. Fire must not be used in

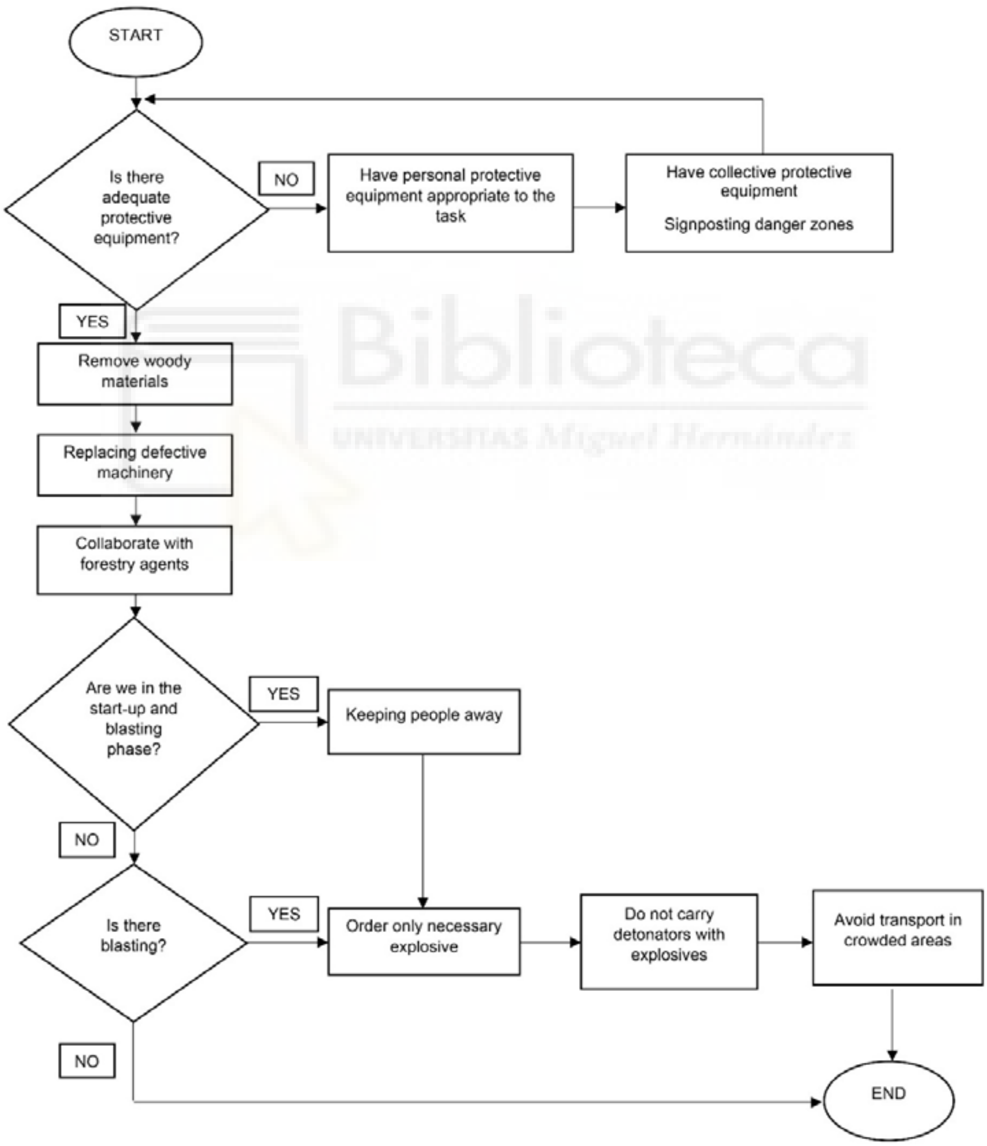

Fig. 8: Flow chart for improving the health and safety of workers in quarrying

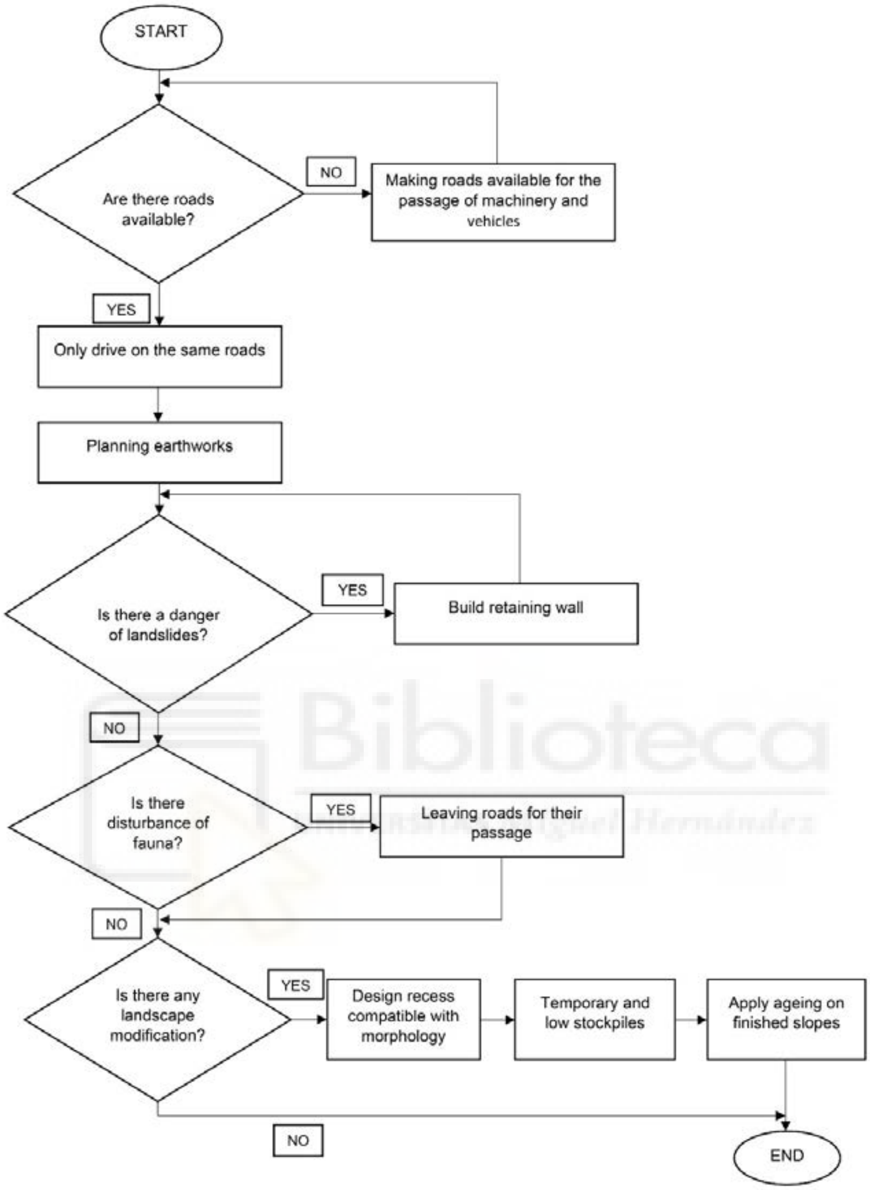

Fig. 9: Flow chart to improve disturbed areas in mining and reduce the impact on landscape, fauna and flora

the area during the mining phase. Woody materials from the opening of roads and tracks must be removed so that they do not pose a fire risk once dry. In addition, to avoid sparks, malfunctioning machinery must be replaced. The necessary extinguishing media must be provided to prevent the spread of fire. Non-flammable species should also be selected from among the species suitable for revegetation in this area.

For the preservation of the fauna, the roads must be used by both vehicles and people and not use areas not designed for traffic. In order for the fauna species to gradually adapt to the changes in their habitat, the removal of soil and vegetation must be done progressively and slowly. Every day before work begins, it must be checked that there are no animals in the ditches or holes. If an area is to be enclosed, small mammals must be allowed to pass through at points where areas with natural vegetation are interconnected. Design of a hollow compatible with the morphology of the environment both during the exploitation phase and in the final phase of restoration. In order to foster natural regeneration over time, conservative as well as preservative actions must be carried to protect biodiversity through the greening of areas (Jiskani *et al.,* 2021). Existing roads and tracks should be used, opening new roads only if strictly necessary. It is important to plan earthworks to reduce disturbed areas. If necessary, retaining walls should be built to prevent soil slides and possible landslides.

The use of this flow charts, which can be widely applied in open-pit mining activities, allow to reduce the impacts of this activity. Moreover, they serve as tools before starting the exploitation and aid to prevent possible effects.

CONCLUSION

Open-pit mining extraction systems have a series of similar characteristics that allow a systematic approach to be established when analysing the impacts. Many authors use different methodologies to assess, prevent and mitigate risks, so there is no single and simple method to respond quickly and that is easy to reproduce and reliable to date, so an impact mitigation system has been presented that allows evaluating the impacts of quarries in arid and semi-arid areas (most of the time the impacts are the same in areas with similar climatic conditions), but at the same time it includes proposals established through the use of flow charts that allow the development of actions to mitigate the negative effects of the exploitation during the active phase and once it finishes. In addition, the use of these charts before starting mining allows to prevent some possible environmental impacts. In this study, were found that 90% of the preventive and corrective measures applied in environmental impact studies in quarries in arid and semi-arid zones are the same. Several environmental impact studies have been first analysed to create these charts, taking into account the importance of the most significant environmental impacts in this type of quarries in the different exploitation phases (preparation, operation and restoration) in order to identify the impacts, the negative effects that they produce. The flow charts propose in a simple way measures to reduce dust on roads and workplaces, noise, fuels and lubricants in mining activities, measures to control topsoil and reject materials in open-pit mines and measures to control other wastes. In addition, some measures have been created to improve the safety and health of workers in quarrying and to improve disturbed areas affected by mining, reducing the impact on landscape, fauna and flora. In this study, a number of preventive and corrective measures have been taken in order to avoid or, when appropriate, moderate the impacts indicated above, considering the components of the environment that intervene o could potentially be affected by mining: physical and biotic environment, perceptual environment, socio-economic and socio-cultural environment. However, as it can be deduced from the preliminary analysis of the legislative framework, the mitigation of environmental impacts is subject to possible new modifications that will have to be incorporated into the methodological framework of the EIAs. In this sense, the establishment of flow charts allows their easy incorporation and updating in a simpler way, as well as their subsequent application and evaluation during and after exploitation. Moreover, future actions will achieve the development of a software, modelling the environmental impact studies based on the framework established by these flow charts. Another future action is to establish the Environmental Surveillance Plan (ESP), since in it, it is about establishing a system that guarantees compliance with the indications, preventive and corrective measures, it tries to define the fundamental elements that must be controlled to meet its objectives. In this specific case, the function of the ESP is to establish a control system, that is, to monitor during the preparation, exploitation and restoration phases of the project.

AUTHOR CONTRIBUTIONS

M.A. Peñaranda Barba performed the literature review, experimental design, analysed and interpreted the data, prepared the manuscript text, compiled the data and manuscript preparation and manuscript edition. V. Alarcón Martínez compiled the data and manuscript preparation, helped in the literature review and manuscript preparation and helped in the manuscript text. J. Navarro Pedreño performed the literature review, manuscript edition, helped in the literature review and manuscript preparation and helped to prepared the manuscript text. I. Gómez Lucas helped in literature review and helped to prepared the manuscript text.

ACKNOWLEDGMENTS

The authors thank management and professors of Department of Agro-chemistry and Environment, University Miguel Hernandez of Elche for their constant support in helping to write this manuscript.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

BSh	Warm semi-arid
BSk	Cold semi-arid
CREM	Statical portal of the Region of Murcia
CO_2	Carbon dioxide
Csa	Mediterranean
EIA	Environmental impact assessment
ESP	Environmental Surveillance Plan
HIC	Habitats of community interest
IGN	National Geographic Institute
l/m^2	Liters per square meter
MET	Ministry for Ecological Transition
M€	Million euros
N-NW	north/northwest orientation
NOx	Nitrogen oxides
RN2000	Natura 2000 network
SAC	Special areas of conservation
SCI	Sites of community interest
SITMURCIA	Territorial information system of the Region of Murcia
SO_2	Sulfur dioxide
WNW-SE	west/northwest-south/east orientation
ºC	Degrees Celsius
%	Percent

REFERENCES

Astorga, A.; Aguilar, G.; and Hernández, G., (2003). Manual técnico de EIA: lineamientos generales para Centroamérica. IUCN, San José, CR.

Casas, L., (2018). Estudio de impacto ambiental de la cantera "La Esperanza". Master´s Thesis, Polytechnic University of Cartagena, ES.

Castelo, J.; Rebbah, R.; Duarte, J.; Baptista, J.S, (2019). Risk Assessment in the Open Pit Mining Industry. Stud. Syst. Decis. Control. 202: 13-21 **(9 pages)**.

Chen, J.; Jiskani, I.M.; Jinliang, C.; Yan, H, (2020). Evaluation and future framework of green mine construction in China based on the DPSIR model. Sustain. Environ. Res. 30: 1-10 **(10 pages)**.

Conesa, V.; Conesa, L.; and Conesa, V., (2010). Methodological guide for environmental impact assessment. Mindi-Prensa, Madrid, ES.

Council Directive, (1992). on the conservation natural habitats and wild fauna and flora, Off. J. Eur. Communities. 206: 7-50 **(43 pages).**

CREM., (2019). Evolution of the main features of the mining sector. Department of business, Industry and Spokesperson of the Region of Murcia. Murcia, ES.

CREM, (2020). Climatology. Department of business, Industry and Spokesperson of the Region of Murcia. Murcia, ES.

Darwish, T.; Khater, C.; Jomaa, I.; Stehouwer, R.; Shaban, A.; Hamze, M., (2010). Environmental Impact of Quarries on Natural Resources in Lebanon. Land. Degrad. Develop. 22: 345-358 **(14 pages)**.

Decree 1439, (1972)., on the approval of motor vehicles with regard to the noise produced by them. Boletín Oficial del Estado, Madrid, ES. 138: 10215-10216 **(2 pages)**.

Directive 42, (2001)., of the European Parliament and of the Council, of 27 June 2001, on the assessment of the effects of certain plans and programmes on the environment. Off. J. Eur. Communities. 197: 30-37 **(8 pages)**.

Directive 147, (2009)., of the European Parliament and of the Council, of 10 November 2009, on the conservation of wild birds. Off. J. Eur. Union. 20: 7-25 **(19 pages)**.

Directive 92, (2011)., of the European Parliament and of the Council, of 13 December 2011, on the assessment of the effects of certain public and private projects on the environment. Off. J. Eur. Union. 26: 1-21 **(21 pages)**.

Directive 52, (2014)., of the European Parliament and of the Council, of 16 April 2014, amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, Off. J. Eur. Union. 124: 1-18 **(18 pages)**.

Enríquez de Salamanca, A., (2021). Project justification and EIA: Anything goes? Environ. Impact. Assess. Rev. 87: 1-4 **(4 pages)**.

Elvan, O.D., (2013). The legal environmental risk analysis (LERA) sample of mining and the environment in Turkish legislation. Resour. Pol. 38(3): 252–257 **(6 pages).**

Espoo Convention, (1991). Convention on Environmental Impact Assessment in a Transboundary Context. Espoo, FI.

Falck, W.E., (2016). Social was licensing in mining—between ethical dilemmas and economic risk management. Min. Econ., 29: 97–104 **(8 pages)**.

Fierro, J., (2012). Políticas mineras en Colombia. ILSA, CO.

Garmendia, A.; Salvador, A.; Crespo, C.; Garmendia, L., (2005).

Environmental Impact Assessment. Pearson Educación, S.A., Madrid, ES.

Ghorbani, Y.; Kuan, S.H., (2017). A review of sustainable development in the Chilean mining sector: past, present and future. Int. J. Min. Reclamat. Environ. 31(2): 137–165 **(29 pages)**.

Glasson, J.; Therivel, R., (2019). Introduction to Environmental Impact Assessment. 5th ed. Routledge, London.

Gómez, I., (2016). Propuesta metodológica para la evaluación del impacto ambiental en la explotación a cielo abierto "cantera Begoña" Final Project Thesis. Department of Agrochemistry and Environment, The University Miguel Hernandez of Elche, ES.

Handjaba, J., (2012). Estudio minero-ambiental de la cantera El Cacao. Cien. Futuro., 2(4): 49-58 **(10 pages).**

IGN, (2020). Geology and tectonics of the Betic Cordillera. Ministry of Transport, Mobility and Urban Agenda, Madrid, ES.

Jain, R.K.; Cui, Z.C.; Domen, J.K., (2016). Environmental Impact of Mining and Mineral Processing. Elsevier Inc., Boston, USA.

Jiskani, M.I.; Cai, Q.; Zhou, W.; Shah, S.A., (2021). Green and climate-smart mining: A framework to analyze open-pit mines for cleaner mineral production. Resour. Policy., 71: 1-13 (**13 pages**).

Johnson, F.; Bell, D., (1975). Guidelines for the identification of potential environmental impacts in the construction and operation of a reservoir. Department of Forestry, Agricultural Experiment Station, University of Illinois at Urbana-Champaign, Illinois, US.

Khabali, H.; Kamal, EK., (2013). Quarrying in coastal Kenikra and its area of influence: environmental impact study. Est. andaluces., 30: 1-26 **(26 pages).**

Köppen, W., (1936). The Geographical System of Climates. Borntraeger Science Publishers, Berlin, DE.

Lad, R.J.; Samant, J.S., (2014). Environmental and social impact of stone quarrying- a case study of Kolhapur District. Int. J. Curr. Res. 6(3): 5664-5669 **(6 pages)**.

Law 34, (2007)., of 15 November, on air quality and atmospheric protection. Boletín Oficial del Estado. Madrid, ES. 275: 46962-46987 **(26 pages)**.

Law 42, (2007)., of 13 December, on Natural Heritage and Biodiversity. Boletín Oficial del Estado, Madrid, ES. 299: 51275-51327 **(53 pages)**.

Law 33, (2015)., of 21 September, which amends Law 42/2007, of 13 December, on Natural Heritage and Biodiversity. Boletín Oficial del Estado, Madrid, ES. 227: 83588- 83632 **(45 pages)**.

Law 21, (2013)., of 9 December, on environmental assessment. Boletín Oficial del Estado, Madrid, Spain. 296: 98151-98227 **(77 pages)**.

Law 9, (2018). 5 December, amending Law 21/2013, of 9 December, on environmental assessment, Law 21/2015, of 20 July, amending Law 43/2003, of 21 November, on Forestry and Law 1/2005, of 9 March, regulating the greenhouse gas emission allowance trading scheme. Boletín Oficial del Estado, Madrid, ES. 294: 119858-119905 **(48 pages)**.

Leopold, L.; Clarke, F.; Hanshaw, B.; Balsley, J., (1971). A Procedure for Evaluating Environmental Impact. Geological Survey Circular 645, Washington, US.

Luna, JA., (2015). El impacto Ambiental por la actividad de explotación de canteras en la localidad de Usme y sus principales medidas de manejo. Master´s thesis, Military University Nueva Granada. Bogotá, CO.

Maponga, O.; Munyanduri, N., (2001). Sustainability of the dimension stone industry in Zimbabwe - challenges and opportunities. Nat. Resour. Forum. 25: 203-213 **(11 pages)**.

MET, (2018). Estadística Minera de España 2017. Ministry for Ecological Transition. Madrid, ES.

MET, (2019). Methodological Guide for Environmental Impact Assessment in Natura 2000 Network. Madrid, ES.

Miñarro, A., (2018). Estudio de impacto ambiental de la cantera "La Chica". Final Project Thesis. Department of Mining, Geological and Cartographic Engineering, Polytechnic University of Cartagena, ES.

Montes de Oca-Risco, A.; Ulloa-Carcassés, M., (2013). Recovery of areas damaged by mining in the Los Guaos Quarry. Revista Luna. Azul., 37: 74-88 (**15 pages**).

Mora-Barrantes, J.; Molina-león, O.; Sibaja-Brenes, J., (2016). Application of a method for the environmental impact assessment of university construction projects. Tecnol. Marcha., 29(3): 132-145 (**14 pages**).

Moreno, M.A., (2021). Estudio de impacto ambiental de una cantera de calizas en el valle de Escombreras. Master´s Thesis, Polytechnic University of Cartagena, ES.

Order ITC 2585, (2007)., of 30 August, approving Complementary Technical Instruction 2.0.02 "Protection of workers against dust, in relation to silicosis, in the extractive industries", to the General Regulations on Basic Standards for Mining Safety. Boletín Oficial del Estado, Madrid, ES. 215: 36828-36833 **(6 pages)**.

Parrota, J.A.; Knowles, O.H., (2001). Restoring tropical forests on lands mined for bauxite: Examples from the Brazilian. Ecol. Eng. 17: 219-239 (**21 pages**).

Pchalek, M., (2019). The legalization of unpermitted projects in the light of requirements of the EIA directive. Eur. Energy. Environ. Law. Rev. 28(3): 101–106 **(6 pages)**.

Retief, F.P.; Fischer, T.B.; Alberts, R.C.; Roos, C.; Cilliers, D.P., (2020). An administrative justice perspective on improving EIA effectiveness. Impact. Assess. Proj. Apprais. 38(2): 151–155 **(55 pages)**.

Royal Decree 212, (2002). 22 February 2002, regulating noise emissions in the environment due to certain outdoor machinery. Boletín Oficial del Estado, Madrid, ES. 52: 8196-8238 **(43 pages)**.

Sheoran, V.; Sheoran, A.S; Poonia, P., (2010). Role of hyperaccumulators in phytoextraction of metals from contaminated mining sites: A Review. Crit. Rev. Env. Sci. Technol. 41(2): 168-214 (**47 pages**).

SITMURCIA, (2019). Advance of the territorial management plan for mineral resources in the Region of Murcia. Regional Ministry of Employment, Universities, Enterprise and Environment, Murcia, ES.

Sort, X.; Alcañiz, J.M., (1996). Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. Land Degrad. Dev. 7(1): 69-76 (**8 pages**).

Stehouwer, R.; Day, R.; Macneal, E., (2006). Nutrient and trace element leaching following mine reclamation with biosolids. J. Environ. Qual. 35: 1118-1126 **(9 pages)**.

Timofeeva, S.S.; Murzin, M.A., (2020). Assessing the environmental risk of mining enterprises by the integral indicator of dust emission. Earth. Environ. Sci. 408: 1–5 **(5 pages)**.

UN, (2003). Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context. United Nations. Kiev, UA **(28 pages)**.

Villalba, V., (2017). Estudio de Impacto Ambiental de un proyecto de rehabilitación de una cantera en el término municipal de Alfarp (Valencia). Master's thesis. Department of Road, Canal and Port Engineering, Polytechnic University of Valencia, Valencia, ES.

Yildiz, T., (2020). The impacts of EIA procedure on the mining sector in the permit process of mining operating activities & Turkey analysis. Resour. Pol. 67: 1-17 **(17 pages)**.

Zhou, W.; Yin, W.; Peng, X.; Liu, F.; Yang, F., (2018). Comprehensive evaluation of land reclamation and utilisation schemes based on a modified VIKOR method for surface mines. Int. J. Min. Reclam. Environ., 32: 93-108 **(15 pages)**.

Zhou, Y.; Zhou, W.; Lu, X.; Jiskani, I.M.; Cai, Q.; Liu, P.; Li, L., (2020). Evaluation Index System of Green Surface Mining in China. Min. Metall. Explor. 37: 1093-1103 **(11 pages)**.

AUTHOR (S) BIOSKETCHES

Peñaranda Barba, M.A., Ph.D. Candidate, Departamento de Agroquímica y Medio Ambiente. Universidad Miguel Hernández de Elche Edif, Alcudia, Avda, de la Universidad, Alicante, Spain. Email: *marianpeba@gmail.com*

Alarcón Martínez, V., Ph.D., Professor, Departamento de Organización Industrial y Electrónica. Escuela Superior de Ingeniería y Tecnología, Universidad Internacional de la Rioja, Madrid, Spain. Email: *virgiky23@hotmail.com*

Gómez Lucas, I., Ph.D., Professor, Departamento de Agroquímica y Medio Ambiente. Universidad Miguel Hernández de Elche Edif, Alcudia, Avda, de la Universidad, Alicante, Spain. Email: *ignacio.gomez@umh.es*

Navarro Pedreño, J., Ph.D., Professor, Departamento de Agroquímica y Medio Ambiente. Universidad Miguel Hernández de Elche Edif, Alcudia, Avda, de la Universidad, Alicante, Spain. Email: *jonavar@umh.es*

HOW TO CITE THIS ARTICLE

Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, I.; Navarro Pedreño, J., (2021). Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas. Global J. Environ. Sci. Manage., 7(4): 1-22.

DOI: 10.22034/gjesm.2021.04.0*

url: http://gjesm.net/***

AgriEngineering

Article

Restoration Techniques Applied in Open Mining Area to Improve Agricultural Soil Fertility

María Ángeles Peñaranda Barba [1,*], Virginia Alarcón Martínez [2], Ignacio Gómez Lucas [1] and Jose Navarro-Pedreño [1,*]

[1] Department of Agrochemistry and Environment, Edif. Alcudia, Miguel Hernández University of Elche, Avda. de la Universidad, s/n, 03202 Elche, Spain; ignacio.gomez@umh.es

[2] Department of Industrial and Electronic Organization, Higher School of Engineering and Technology, International University of La Rioja, C/Almansa, 101, 28040 Madrid, Spain; virgiky23@hotmail.com

* Correspondence: marianpeba@gmail.com (M.Á.P.B.); jonavar@umh.es (J.N.-P.)

Abstract: Open pit mining causes damage in natural and rural regions; that is why soil restoration is necessary in order to recovery soil–plant systems. The application of waste can be a good solution for rehabilitation, and it clearly complies with the circular economy and the zero-waste strategy. This study was carried out in a quarry restoration area in the southeast of Spain, where experimental plots were designed and fertilized with different amendments (commonly used inorganic fertilizer N-K-P, pig slurry, pruning waste and urban solid wastes) with the objective of studying ways to improve the restoration of the soil by using these residues and increase the soil fertility before planting. The treatments applied were evaluated in the short term (two and four months from their addition to topsoil) and medium term (nine months) in order to determine if the restored soils will be adequate for agriculture based on nutrients' availability. The results showed that in all the treatments, the pH exceeded 8.5 due to the nature of the soil matrix, but after 9 months of the application, in the plots treated with NPK and pig slurry, the pH decreased. In general, with the application of the treatments, soil macro- (N, P, K, Na, Ca and Mg) and micro-nutrients (Fe and Cu) were increased. However, pig slurry and urban solid waste favored N and P, respectively.

Keywords: circular economy; organic amendments; pig slurry; recycled waste; soil restauration; semi-arid ecosystems; zero waste

Citation: Peñaranda Barba, M.Á.; Alarcón Martínez, V.; Gómez Lucas, I.; Navarro-Pedreño, J. Restoration Techniques Applied in Open Mining Area to Improve Agricultural Soil Fertility. *AgriEngineering* **2023**, *5*, 1599–1613. https://doi.org/10.3390/agriengineering5030099

Academic Editor: Eugenio Cavallo

Received: 31 July 2023
Revised: 6 September 2023
Accepted: 11 September 2023
Published: 13 September 2023

1. Introduction

Open-pit mining is an important activity basic for the development of human society [1,2]; moreover, it occupies an important position in global economic development [3]. At the same time, mining is considered the most destructive anthropogenic activity and affects ecosystems [4], causing damage to both geomorphology and geological structures and leading to habitat loss [5].

Mining activity significantly affects the environment due to the pollution of air, soil, surface and groundwater, landscape degradation and damage to biodiversity [6–10]. The problem of environmental degradation is aggravated in arid and semi-arid climates and, in particular, in the Mediterranean ecosystems, due to the scarcity of water and torrential rainfall, high solar radiation and low plant cover that favors the erosion processes [11].

Surface mining establishes new infrastructure, fragments natural habitats and is thus acting as a threat to biodiversity [12,13]. In addition to the habitat loss caused by open-pit mining, it alters the soil and topographic structure [14] and disrupts surface and subsurface water regimes [15]. Regarding the ES (ecosystem services) loss, open-pit mining development has also led to a series of ecological and environmental issues, such as air pollution, surface seepage, soil quality decline and soil erosion [15–17]. As a result, agricultural and environmental rehabilitation are challenges in these areas in order to improve landscape recovery and combat global warming.

In the Region of Murcia (Spain), the exploitation of geological resources was always linked to the extraction of minerals and rocks. Specifically, the last one is represented by the extraction of marble, marble limestone and limestone aggregates [18]. Currently, the mining regulations require the rehabilitation of the land after exploitation [19]. In areas degraded by open-pit mining in arid and semi-arid zones, ecological restoration is aimed to support the development and establishment of long-term, healthy and self-sustaining ecosystems with good vegetation cover [20].

Therefore, the restoration of the quarries is necessary to accelerate the recovery of the soil–plant system, and a way of solving these problems could be the use of organic amendments [21]. The model of sustainable development of the mining requires responsible land use and the restoration of affected soils [22–25]. To achieve greener mining with fewer impacts, it is necessary to reduce the pollution and affections produced by activities in the air and water and those produced by noise as well as the need to recover the land and its uses (forest, agriculture, landscape. . .) after the finishing of the activities on the exploitations [26]. Land cover change is the main force driving changes in ES [27,28]. Understanding the response of ES to changes in open-pit mining is vital for achieving ecosystem sustainability and thus requires more attention [3]. One of the most important services is food production, and mining restoration would be an opportunity to recover agricultural soil uses after the exploitation activities and maintain the economy of a region after the end of the mining exploitation. This is the case of some quarries exhausted to obtain cement that have undergone transformations to maintain cultivated areas in the southeast of Spain.

Soil properties constitute the material basis for soil services, so a sustainable perspective needs to be borne in mind when analyzing multiple soil services and to bring about an overall soil functioning improvement and sustainable development [29]. Arid and semi-arid ecosystems cover a significant area of the planet, around 45% [30], and they are expected to increase in the future due to negative climate change effects. So, there is a need to restore these ecosystems through methodologies that are appropriate and successful. Thus, in mining areas under arid and semi-arid climates, it is appropriate to address this recovery with organic amendments as it increases organic matter content, improves water retention and stimulates soil microorganisms compared to unamended soils [31]. Knowing these positive effects, soil nutrient status is the next step to ensure a good development of plant cover both for agriculture or landscape.

In addition to the degradation of the environment, the generation and agglomeration of waste is one of the greatest global concerns. For this reason, the EU (European Union) has created a zero-waste strategy through the circular economy [32]. For the recovery of soils and landscape after mining activities, a good option is to use organic wastes. In this way, its accumulation is avoided, and it contributes to the circular economy and the European Zero Waste strategy [19,33,34]. The recovery of the soil, the implementation of productive activities such as agriculture and the improvement of the landscape are objectives derived from the application of organic waste and the implementation of the circular economy in the restoration of quarries.

The aim of this study was to evaluate the improvement of soil restoration in open-pit mining areas by using wastes as a part of the zero-waste strategy. It is intended to evaluate the success of different restoration treatments by using four treatments (inorganic fertilizer NPK 15-15-15, pig slurry, pruning waste and urban solid wastes) on the physicochemical properties and nutrient availability of the soil in limestone quarries, trying to facilitate the implementation of rain-fed agriculture. These amendments have been applied because of their presence and high production in the Region of Murcia and the problem of their elimination. The treatments applied are intended to be evaluated in the short term (two and four months from the addition to the soil) and in the medium term (nine months) in order to determine if the restored soils will be suitable for agriculture landscape recovery based on the availability of nutrients. In addition, degraded soils without the application of any treatment were selected as reference and for comparison with the treated plots.

2. Materials and Methods

2.1. Study Area

The study was carried out on a limestone quarry, whose activity is the extraction of ornamental rock and carbonate aggregates, with an average slope of 8%, situated in the southwest of Cehegín, Murcia, Spain. The quarry is located at latitude 38°4′42.47″ N and longitude 1°48′23.65″ W (Figure 1).

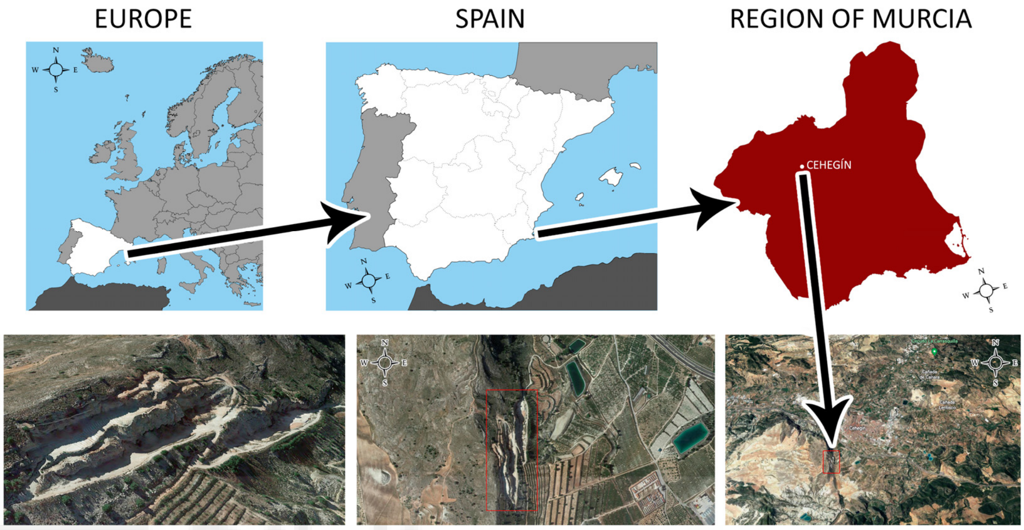

Figure 1. Location of the limestone quarry in Europe.

According to the geological description, the quarry is part of the outcrop of the Zegrí Formation, Veleta Formation and Upper Ammonitic Rosso Formation (Betic mountain ranges in the southeast of Spain). The lithology of the study area is mainly gray and red limestone strata interspersed with some red marls, and limestones and limestones with flints belonging to the Veleta Formation, all of which are superimposed on gray limestones belonging to the Zegrí Formation (Toarcian–Domerian transition). On the surface, there could be found a large amount of ammonite, belemnite and foraminiferal fauna. Analyzing the hydrology of the quarry, about two kilometers to the south of the quarry, the river Quipar and a little closer Cañada Lengua ravine, which is a tributary of this river, are found. The ravines in the area are shallow, increasing in depth as the slope decreases, and run through loamy materials.

The climate is Mediterranean (Csa) with a hot summer according to the Köppen–Geiger climate classification [35], the coldest months reach, as a minimum temperature −3 °C, the maximum being 18 °C. The summer is hot, with the average of the hottest month exceeding 22 °C. Precipitation exceeds evaporation, and there is seasonal rainfall. The summer is dry, so the minimum rainfall is quite marked and coincides with the period of highest temperatures. The rainiest seasons are autumn and spring.

The land use of the area is basically rain-fed agriculture and scrubland, composing a traditional Mediterranean landscape. The following vegetation units have been found in the area: disperse pine forest, scrubland (rosemary, esparto grass. . .), rocky vegetation, bare soil and rain-fed crops. The main species of natural plants presented are the following: *Juniperus oxycedrus*, *Rosmarinus officinalis* L., *Stipa tenacissima* L., *Pinus halepensis* Miller and *Olea europaea* var. *Sylvestris*. The main rain-fed crops were esparto grass and hemp but under abandonment because of the low economic profitability, facilitating the soil erosion accentuated by the loss of vegetation cover.

2.2. Experimental Design

The study was carried out on one of the four quarry faces exploited in the area on a bench of 8.2 m high (wall) and 105 m long (front). After the selection of the study area and the information collected, the plots were established. The first task was the removal of all the materials that cannot be used in the conditioning and subsequent leveling of the area. The area was filled with tailings as the terrain was irregular, and the surface was horizontally leveled (slope under 0.5%). The work was carried out following the relieve contour lines to avoid erosion. After that, 380 m^3 of topsoil was added from old alluvial terraces of long-time abandoned fruit cropping areas, with an approximately depth of 20 cm, covering an area of 2500 m^2.

Once the area was ready, it was divided into 55 experimental plots of 5 × 4 m, leaving a separation of 1 m between them. The inorganic and the three organic amendment treatments were placed on the superficial layer of the soil and mixed with the topsoil with a mechanical backhoe; the soils that were not treated also carried out this mechanical process but without applying any amendment, keeping the characteristics of the original soil from the abandoned alluvial terraces.

The treatments were established and randomized on the bench. Each of the treatments was applied in 11 plots, and 11 control plots were left without any treatment. The treatments applied were the following (see also Table 1):

(i) The addition of granulate inorganic fertilizer (NPK 15-15-15) in the amount of 1 kg per plot; this mineral fertilizer is composed as follows: 15% TN (total nitrogen), 15% total phosphorus (P_2O_5) and 15% water-soluble potassium (K_2O), and it also contains 25% of sulfur (SO_3). This treatment was applied since it is a common agricultural fertilizer that is easy to apply (since it is a solid granule); in addition, it contains the 3 elements most demanded by plants from the soil, and its slow dissolution allows the relatively slow release of nutrients into the soil.

(ii) The addition of pig slurry in the amount of 5.4 kg per plot based on the contribution of nitrogen equivalent to the inorganic fertilizer. The application of pig slurry is of special interest in regions where the management of the pig industry represents a serious environmental problem due to its large volume produced, like the Region of Murcia. One of the main concerns is how to treat them in an environmentally sound way [36]. The pig slurry was obtained from a pig farm in the Murcia region, located in Fuente Álamo, where conventional purification systems are used, in which the solid is separated from the liquid. The slurry obtained on the farm was transported to the treatment plots where it was applied.

(iii) The incorporation of composted urban solid wastes (USWs) from the Cañada Hermosa waste treatment center in the northwest of the Region of Murcia in the amount of 60 kg per plot. The Cañada Hermosa treatment center is a benchmark for innovation, and it changes the vision of waste as garbage to turn it into resources [37], which is in continuous progress to the circular economy.

(iv) The application of woody pruning waste (variable size over 5 to 20 cm long), from olive trees, vines and almond trees of the region, in the amount of 60 kg per plot. The almond tree represents more than 12% of the farmland in the Region of Murcia, and it is intended to take advantage of these crops for restoration and mitigate the problem of abandoning agriculture or carrying out uncontrolled incineration [38]. The vineyard and the olive trees are in regression due to abandonment, especially in marginal areas and terraces. The abandonment of crops and soil conservation measures cause a collapse of the terraces and the appearance of different forms of associated erosion [38,39]. The composition of the pruning remains was equally divided between remains of olive trees, vines and almond trees from the farmland in the Region of Murcia. These remains were crushed with a tractor shredder and transported to the treatment plots on which these residues were spread.

The rest of the plots, without any fertilization or amendments added, were the control treatment. These consisted of soil situated on the carbonate tailings, which were used for leveling the terrain, as the rest of the treatments, but in this case, this soil was used to understand the evolution of the properties without any intervention, considering that the substrate is close to an agricultural non-treated soil [40]. All the organic treatments were applied directly to the plots and mixed with the topsoil.

Table 1. Name assigned to each treatment.

T0	T1	T2	T3	T4
Control	Inorganic fertilizer NPK	Pig slurry	Urban solid wastes	Woody pruning wastes

Soil samples were taken at a 10 cm depth for each plot and treatment (11 samples per treatment), at two (S1), four (S2) and nine (S3) months from the beginning of the fertilization treatments (at short and medium term). Samples were taken to know the state of the soil in the first stages and at the end of a reasonable period to achieve some stability previously to planting crops.

2.3. Methods of Soil Analysis

Soil samples dried at room temperature were sieved at 2 mm. After that, pH was determined in a soil/water extraction (ratio of 1:2.5 *w/v*) [41,42]. The $CaCO_3$ equivalent was determined by using the FAO volumetric calcimeter method [43]. Clay, silt and sand were measured with the Bouyoucos method based on Stokes' law [44]. Soil nitrogen was determined by the Kjeldahl method as well as phosphorus by using the Olsen method [45,46].

K, Ca, Mg and Na were determined in the soil by using the ammonium acetate 1 N extraction, and Fe, Cu and Zn were determined by the DTPA-TEA method [47]. After the extraction, Ca, Mg and micronutrients were measured by atomic absorption spectrometry and Na and K were measured by atomic emission spectrometry.

2.4. Organic Wastes

The same parameters were analyzed in the organic amendments, pH and nutrients, following the Official Methods of the Ministry of Agriculture of Spain [48], according to Royal Decree 824/2005 and Royal Decree 506/2013 for organic by-products. The pH level was measured in an aqueous extract 1:5 *w/v* [49]; nitrogen was determined by the Kjeldahl method. The elemental composition of K, Ca, Mg and Na and micronutrients Fe, Cu and Zn were determined by atomic absorption or emission spectrometry in the aqueous solutions resulting from dissolving with HCl (1:1) the ashes from the calcination of the organic samples. Phosphorus was determined by the spectrophotometry at 440 nm indicative for the complex formed in the presence of ammonium molybdate and vanadate (yellow color in acid medium). The composition of organic amendments is given in Table 2.

Table 2. Composition of organic amendments.

Parameter	Pig Slurry	USW Compost	Woody Pruning Wastes
pH	7.63	7.01	4.71
N (g/kg)	27.7	12.95	5.1
P (g/kg)	2.36	7.00	0.63
K (g/kg)	3.84	3.81	0.63
Ca (g/kg)	4.28	33.5	1.06
Mg (g/kg)	0.76	2.25	0.11
Na (g/kg)	0.88	1.3	0.016
Fe (mg/kg)	252	10050	33
Cu (mg/kg)	46.8	203	3.7
Zn (mg/kg)	85.2	611	9.2

There is a remarkable and important amount of N presented in pig slurry, which is followed by USW and woody pruning wastes. The last one has an acid pH, which will be associated with the presence of organic acids derived from the plant material. However, opposite to N, P was greater in the composted USW. Moreover, USW also had the highest concentration of Ca as well as the major content of Fe, Cu and Zn.

2.5. Statistical Analysis

The descriptive statistics, mean value and standard deviation were calculated for each treatment. Data were tested for homogeneity of variance, and differences between individual means were evaluated by Tukey's post hoc test at $p < 0.05$. Mean values with the same letter in the tables are not significantly different. After that, a one-way ANOVA test was applied to compare the treatments [50].

3. Results

The results obtained for soil pH, equivalent $CaCO_3$, and texture fractions (clay, silt and sand) are presented in Table 3.

Table 3. pH, equivalent $CaCO_3$, clay, silt and sand for the first sampling period (S1), second sampling period (S2) and the third one (S3).

Treat. S1	pH		CaCO3 (%)		Clay (%)		Silt (%)		Sand (%)	
T0	8.9 ± 0.1	a	89 ± 1	a	32 ± 1	a	20 ± 1	a	48 ± 1	ab
T1	8.6 ± 0.1	b	72 ± 1	b	32 ± 1	a	21 ± 1	a	47 ± 1	b
T2	8.9 ± 0.1	a	85 ± 2	cd	32 ± 1	a	20 ± 1	a	48 ± 1	ab
T3	8.8 ± 0.1	a	85 ± 1	c	30 ± 1	a	20 ± 1	a	50 ± 1	a
T4	9.0 ± 0.1	a	87 ± 1	d	31 ± 1	a	22 ± 1	a	47 ± 1	b
ANOVA	***		***		ns		ns		ns	
Treat. S2	pH		CaCO3 (%)		Clay (%)		Silt (%)		Sand (%)	
T0	8.8 ± 0.1	a	89 ± 1	a	31 ± 1	a	21 ± 1	a	48 ± 1	a
T1	8.7 ± 0.1	a	70 ± 1	b	32 ± 1	a	21 ± 1	a	47 ± 1	a
T2	8.8 ± 0.1	a	81 ± 1	c	31 ± 1	a	20 ± 1	a	49 ± 1	a
T3	8.9 ± 0.1	a	84 ± 1	c	30 ± 1	a	20 ± 1	a	50 ± 1	a
T4	9.1 ± 0.1	b	88 ± 1	a	31 ± 1	a	19 ± 1	a	50 ± 1	a
ANOVA	***		***		ns		ns		ns	
Treat. S3	pH		CaCO3 (%)		Clay (%)		Silt (%)		Sand (%)	
T0	8.8 ± 0.1	a	89 ± 1	a	30 ± 1	a	20 ± 1	a	50 ± 1	a
T1	8.6 ± 0.1	b	76 ± 1	b	31 ± 1	a	21 ± 1	a	48 ± 1	a
T2	8.7 ± 0.1	a	81 ± 1	cd	32 ± 1	a	20 ± 1	a	48 ± 1	a
T3	8.9 ± 0.1	a	84 ± 1	c	30 ± 1	a	19 ± 1	a	51 ± 1	a
T4	9.2 ± 0.4	c	86 ± 1	a	30 ± 1	a	20 ± 1	a	50 ± 1	a
ANOVA	***		***		ns		ns		ns	

Mean values with the same letter in a column for each sampling period (S1, S2, S3) do not differ significantly according to Tukey's test at $p < 0.05$; ANOVA test: ns: not significant; *** significant at 0.001.

Soil pH showed significant differences ($p < 0.001$) between all the treatments applied and the control plots (T0) both in sampling 1, 2 and 3 (Table 3). Throughout the nine months of sampling (S3), it was observed that the pH slightly decreased over time except in those plots amended with woody pruning waste (T4). Although this amendment had the lowest pH value (Table 2), the effect was not noticed in the soil.

The equivalent $CaCO_3$ in the soil, after two months of sampling did not showed significant differences between pig slurry and USW compost (T2 and T3) nor did it have significant differences between pig slurry (T2) and woody pruning waste (T4) (Table 3). In the sampling period 2 (S2) (Table 3), there were no significant differences between the control plots and the pruning plots, but there were significant differences between these plots and the rest of the treatments ($p < 0.001$). After nine months of application of the amendments (S3), considering this time enough for an initial stabilization of the soil before planting, there were no significant differences between the plots treated with USW compost (T3) and the plots treated with woody pruning waste (T4). In fact, the presence of carbonates due to the nature of the substrate is too high, and it would be expected that within time, the carbonates presented in the subsoil and the topsoil will determine poor differences between treatments. Probably, the application of NPK 15:15:15 (T1) affected the carbonates, diminishing the presence in the topsoil by an initial acidification favored by the fertilizer.

Regarding the percentage of clay, silt and sand, no significant variation in the mineral fraction granulometry was observed in all the treatments (Table 3), although minor changes were noticed regarding the sand fraction in the plots treated with NPK (T1) that can be, in part, associated to an initial acidification due to the reaction of the NPK fertilizer with the soil matrix.

Considering the presence of macronutrients and their availability, significant differences were observed between treatments (Table 4). In the case of Kjeldahl nitrogen, after two (S1) and four months (S2), there were significant differences ($p < 0.001$) between all treatments and control plots. After 9 months (S3), T1 and T3 had similar values, but there were significant differences ($p < 0.001$) between NPK (T1) and USW compost (T3) and the rest of the treatments. After nine months of application (S3), in T0, T1 and T2, the soil N decreased, and in T3 and T4, it increased. In general, the N in the topsoil decreased except for in the plots of T3 and T4, where organic waste treatments were applied (Table 4).

P significantly varied between all treatments in both sampling 1 and 3 ($p < 0.001$). In sampling 2, no significant differences between the NPK treatment (T1) and the woody pruning waste (T4) were observed, but there were significant differences ($p < 0.001$) between these two treatments with the rest of the treatments. After nine months (S3), this nutrient decreased in the control plots, while in the plots treated with NPK (T1), pig slurry (T2) and USW compost (T3) increased at four months (S2) and decreased at nine months (S3), which was opposite to the behavior shown in the plots treated with woody pruning waste (T4) (Table 4). However, special attention should be given for this nutrient regarding the calcium carbonate nature of the soil and the possible lack of this nutrient to supply crops necessities because of a possible precipitation of calcium phosphates favored in high pH soil solution.

The available Ca varied between treatments, but the amount in all the treatments was expected to be high enough for plant nutrition, and this macronutrient showed the highest values comparing with the rest analyzed. The available Ca showed some differences in the treatments and along the time. However, treatment T2 (pig slurry) was that which favored the highest values. After nine months (S3), calcium availability decreased in the control plots and those treated with pig slurry (Table 4).

Although Mg varied with the treatments and the sampling period, these variations did not follow the same pattern like Ca. After two months (S1), Mg did not show significant differences between USW compost and woody pruning waste (T3 and T4) but showed significant differences ($p < 0.01$) between both and the rest of the treatments. However, in sampling 2, Mg did not show significant differences between T2 and T3, but these differences appeared between the plots treated with pig slurry (T2) and those treated with woody pruning waste (T4) with the rest of the treatments. In sampling 3, the differences among treatments were reduced.

Table 4. Macronutrients (N, P, Ca, Mg, K and Na) for the first sampling period (S1), second sampling period (S2) and the third one (S3).

Treat. S1	N (g/kg)		P (mg/kg)		Ca (g/kg)		Mg (g/kg)		K (g/kg)		Na (g/kg)	
T0	0.11 ± 0.01	a	5.9 ± 0.2	a	7.84 ± 0.08	a	0.63 ± 0.01	a	0.13 ± 0.02	a	0.80 ± 0.04	a
T1	0.83 ± 0.02	b	10.4 ± 0.1	b	7.05 ± 0.05	b	0.75 ± 0.02	b	0.23 ± 0.01	b	1.95 ± 0.01	b
T2	0.94 ± 0.01	c	11.4 ± 0.1	c	8.36 ± 0.08	c	0.70 ± 0.01	c	0.24 ± 0.03	b	1.70 ± 0.02	c
T3	0.66 ± 0.03	d	12.1 ± 0.1	d	6.70 ± 0.10	d	0.62 ± 0.04	d	0.23 ± 0.01	b	2.17 ± 0.02	d
T4	0.48 ± 0.02	e	9.6 ± 0.4	e	6.70 ± 0.23	d	0.61 ± 0.01	d	0.2 ± 0.01	c	2.09 ± 0.01	e
ANOVA	***		***		***		**		***		***	
Treat. S2	N (g/kg)		P (mg/kg)		Ca (g/kg)		Mg (g/kg)		K (g/kg)		Na (g/kg)	
T0	0.11 ± 0.01	a	5.9 ± 0.1	a	7.14 ± 0.05	a	0.62 ± 0.01	a	0.13 ± 0.01	a	0.84 ± 0.05	a
T1	0.84 ± 0.01	b	8.0 ± 0.04	b	7.62 ± 0.14	b	0.73 ± 0.02	b	0.24 ± 0.01	b	1.94 ± 0.02	b
T2	0.75 ± 0.01	c	12.0 ± 0.1	c	7.63 ± 0.08	b	0.66 ± 0.01	c	0.24 ± 0.01	b	1.39 ± 0.01	c
T3	0.56 ± 0.02	d	15.3 ± 0.5	d	7.69 ± 0.10	b	0.65 ± 0.01	c	0.23 ± 0.01	b	1.96 ± 0.01	b
T4	0.41 ± 0.01	e	8.8 ± 0.1	b	7.00 ± 0.37	a	0.58 ± 0.01	d	0.17 ± 0.01	c	2.02 ± 0.02	d
ANOVA	***		***		***		***		***		***	
Treat. S3	N (g/kg)		P (mg/kg)		Ca (g/kg)		Mg (g/kg)		K (g/kg)		Na (g/kg)	
T0	0.10 ± 0.02	a	3.4 ± 0.1	a	6.80 ± 0.08	a	0.58 ± 0.06	ab	0.13 ± 0.01	a	0.81 ± 0.02	a
T1	0.77 ± 0.02	b	6.9 ± 0.1	b	7.28 ± 0.10	b	0.72 ± 0.08	b	0.23 ± 0.02	b	1.62 ± 0.02	b
T2	0.92 ± 0.01	c	13.9 ± 0.1	c	7.60 ± 0.03	c	0.66 ± 0.07	ab	0.20 ± 0.01	b	1.39 ± 0.01	c
T3	0.74 ± 0.02	b	11.8 ± 0.1	d	7.40 ± 0.09	d	0.64 ± 0.60	ab	0.23 ± 0.02	b	1.96 ± 0.01	d
T4	0.57 ± 0.01	d	9.6 ± 0.1	e	6.79 ± 0.16	a	0.55 ± 0.09	a	0.20 ± 0.01	b	1.75 ± 0.01	e
ANOVA	***		***		***		*		***		***	

Mean values with the same letter in a column for each sampling period (S1, S2, S3) do not differ significantly according to Tukey's test at $p < 0.05$; ANOVA test: * significant at 0.05; ** significant at 0.01; *** significant at 0.001.

Regarding soil K, in sampling 1 and 2, there were no significant differences between the plots treated with NPK, pig slurry and USW compost (T1, T2 and T3), and, in sampling 3, there are no significant differences between plots of the treatments T1, T2, T3 and T4. In the control plots, soil K is lower than in the rest of the plots where the amendments were applied, as it happened with the rest of nutrients except Ca and Mg, which would be due to the nature of soil matrix (Table 4). From two (S1) to nine months (S3) after the application of the treatments, the soil K in the plots treated with NPK, USW compost and woody pruning waste (T1, T3 and T4) maintained its availability, and in the plots treated with pig slurry (T2), it decreased (Table 4).

In the case of Na, significant differences were observed, as it would be expected because of the nature of the amendments and inorganic fertilizer used (T1). There were significant differences in soil Na between all the treatments and the control plots in both S1 and S3. In S2, there were no significant differences between the plots treated with NPK (T1) and those treated with USW compost (T3), but there were significant differences between T1 and T3 and the rest of treatments. In sampling 3, we observed a decrease since the first sampling in T1, T2, T3 and T4. In general, the highest values of extractable Na were obtained in treatments T3 and T4 (Table 4). All the treatments increased the availability of sodium.

There were significant differences in Fe between all the applied amendments and the control plots (T0) in both S1 and S3. In sampling 2, there were no differences in soil Fe between the plots treated with NPK (T1) and those treated with USW compost (T3), but there were significant differences between T1 and T3 and the rest of the treatments. From two months (S1) to nine months (S3), a decrease in Fe was determined in the control plots (T0) and T4, and in T1, T2 and T3, the availability of Fe increased. The treatments that provide the most available Fe were NPK (T1) (45 mg/kg) followed by pig slurry (T2) (42.6 mg/kg) (Table 5).

Table 5. Micronutrients (Fe, Cu and Zn) for the first sampling period (S1), second sampling period (S2) and the third one (S3).

Treat. S1	Fe (mg/kg)		Cu (mg/kg)		Zn (mg/kg)	
T0	26.8 ± 0.1	a	6.7 ± 0.1	a	2.6 ± 0.1	a
T1	40.2 ± 0.2	b	11.4 ± 0.1	b	2.3 ± 0.1	b
T2	41.3 ± 0.4	c	14.6 ± 0.1	c	3.6 ± 0.1	c
T3	37.6 ± 0.2	d	11.6 ± 0.1	b	4.4 ± 0.1	d
T4	34.0 ± 0.4	e	11.3 ± 0.2	b	2.8 ± 0.2	a
ANOVA	***		***		***	
Treat. S2	Fe (mg/kg)		Cu (mg/kg)		Zn (mg/kg)	
T0	23.3 ± 0.1	a	6.2 ± 0.4	a	2.4 ± 0.1	a
T1	38.6 ± 0.3	b	10.5 ± 0.1	b	2.4 ± 0.1	a
T2	40.0 ± 0.7	c	14.5 ± 0.7	c	4.2 ± 0.2	b
T3	38.1 ± 0.1	b	11.4 ± 0.3	d	3.5 ± 0.2	c
T4	33.7 ± 0.1	d	10.1 ± 0.1	e	2.6 ± 0.3	d
ANOVA	***		***		***	
Treat. S3	Fe (mg/kg)		Cu (mg/kg)		Zn (mg/kg)	
T0	24.1 ± 0.6	a	6.0 ± 0.2	a	2.7 ± 0.3	a
T1	45.0 ± 0.1	b	11.6 ± 0.3	b	2.6 ± 0.2	a
T2	42.6 ± 0.1	c	15.3 ± 0.2	c	4.7 ± 0.1	b
T3	38.8 ± 0.1	d	10.4 ± 0.1	d	3.3 ± 0.1	c
T4	31.9 ± 0.6	e	12.0 ± 0.1	b	2.1 ± 0.1	d
ANOVA	***		***		***	

Mean values with the same letter in a column for each sampling period (S1, S2, S3) do not differ significantly according to Tukey's test at $p < 0.05$; ANOVA test: *** significant at 0.001.

Regarding soil Cu, in S1, no significant differences were observed between the plots treated with NPK, USW compost and woody pruning waste (T1, T3 and T4), but there are significant differences ($p < 0.001$) between T1, T3 and T4 and the rest of the treatments. In S2, significant differences ($p < 0.001$) were observed between all the treatments and the control plots (T0). In S3, no significant differences were observed between the plots treated with NPK (T1) and those of woody pruning waste (T4), but there were significant differences ($p < 0.001$) between T1 and T4 and the rest of treatments. From two (S1) to nine months (S3) after the application of the treatments, it was observed that soil Cu decreased in the control plots and T3 and increased in T1, T2, and T4 (Table 5).

The availability of Zn in the soil showed no differences between the control plots (T0) and those treated with woody pruning waste (T4) in S1, but there were significant differences ($p < 0.001$) between T0 and T4 and the rest of the treatments. After four (S2) and nine months (S3) of the application of the treatments, there were no significant differences between T0 and T1, but there were significant differences ($p < 0.001$) between T0 and T1 and the rest of the plots. From two (S1) to nine months (S3) after the application of the treatments, it is observed that the Zn of the soil decreases in T3 and T4 and increases in T0, T1 and T2.

The extractable Fe, Cu and Zn from S1 to S3, maintained, more or less in each treatment, the same amount of micronutrient availability. The T1 and T2 treatments showed the highest values for Fe and Cu, while Zn showed the highest extractable value in T2 (4.7 mg/kg), although the USW compost (T3) was where those micronutrients were presented in the highest elemental concentration in the waste composition (T3) (Table 5).

As shown in Table 5, the high content of Fe, Cu and Zn in the USW compost did not affect the quality of the treated soil; even lower availability was obtained in some cases comparing with the other treatments.

4. Discussion

In all the treatments, even in the control plots (T0), the pH exceeds 8.5, and therefore, it is an alkaline soil due to calcareous matrix due to the nature of the area, with a high presence of calcium carbonate. In other studies [51,52], it was observed that the presence of calcium carbonate from the marble in the mine areas increased the pH level of the soil, remaining stable for at least one year. The values similar to those obtained in this study were found in a study carried out in 2016 [53], in which several combinations of organic amendments (sewage sludge and compost from domestic organic waste) and mulches (gravel and woodchip) were applied in a quarry in a semi-arid climate. In another study carried out in 2017 [54], the pH was increased to values close to neutrality due to the presence of carbonate in the wastes; marble waste and pig slurry were used to rehabilitate a mining waste dam. With the application of other waste, for instance, from the olive oil industry, an increase in the soil pH was also found [55,56] even in calcareous soils. In our study, after nine months (S3) from the addition of the amendments, it was observed that the plots treated with NPK and pig slurry (T1 and T2) slightly decreased the pH, but it was still lower than in the control plots (T0) (Table 3). Similar results were observed in a study carried out in 2020 [57], where the application of sewage sludge from urban waste water treatment plants and compost from domestic solid waste in degraded soils from calcareous quarries with a semi-arid climate reduces pH levels over time. In [58], the pH values were maintained between 8 and 8.74. On the contrary, in our experiment (Table 3), nine months (S3) after the application of the USW compost and woody pruning waste amendments (T3 and T4), the pH slightly increased.

The availability of nutrients such as potassium, calcium and magnesium would be associated with the calcium carbonate matrix because they are more mobile at pH above 6 [59]. In addition, it was shown that with the application of the organic amendments used and the inorganic fertilizer, soil macronutrients were considerably increased (N, P, K, Na to a greater extent and Ca and Mg to a lesser extent) in reference to the control plots (T0), as it was expected. However, it was observed that after nine months (S3), the content of these nutrients was still higher than in the control plots except for Ca and Mg (Table 4).

The increase in N content is very positive, since this macronutrient is an essential element for vegetation growth and for microbial communities, which are responsible for many of the necessary processes for plant nutrition. Therefore, its increase contributes to the improvement of soil nutritional conditions and to the growth and development of introduced crops [54] after the restoration process.

Similar results are observed in a study carried out in a limestone quarry in a semi-arid climate [53] in which organic amendments (sewage sludge and compost from domestic organic waste) were applied, where the soils showed higher N, P and K content than the soil without treatments. Another study [54] also showed that the application of amendments (marble waste and pig slurry) significantly increased soil N in an old mining waste dam recovery in a semi-arid climate. The application of pig manure increased soil N [59]. In an abandoned mine tailing under a semi-arid climate, the application of compost made from pig slurry also increased the N and nutrient (mainly K and P) contents in the soil solution [60]. The sewage sludge from urban waste water and compost from domestic solid waste also significantly modified soil chemical properties, increasing nutrient (N) availability in a limestone quarry with an arid/semi-arid climate [57].

The micronutrients (Fe and Cu) also increased significantly with the application of the amendments used in this study (Table 5). Regarding Zn, it increased in the plots treated with pig slurry and USW compost (T2 and T3) after nine months (S3) from the application of the treatments. The soil treated with NPK (T1) has similar Zn values as the control plots (T0), and in the soils treated with woody pruning waste (T4), the Zn concentration in the soil decreased from sampling 1 to sampling 2, and it was even lower than in the control treatment (T0). In a study carried out in an abandoned mining waste dam, it was observed that with the application of pig slurry and marble waste, the Zn concentration decreased after two years of the application of the amendments [54], and the application of compost made from pig slurry also reduced Zn concentration in the soil [60].

Long-term pig slurry applications have a cumulative effect on the availability of N and other nutrients [61,62]. The use of pig slurry as fertilizer increases the concentrations of N, K, P, Ca, Mg and Na [55]. The high nutrient content of pig slurry, mainly N and P, could be a positive for plant growth, as also shown in a study carried out in soil from a mining area in a semi-arid climate [63]. Furthermore, its use is of great interest, since it provides many nutrients to optimize the growth of the vegetation cover [37].

Woody pruning waste has been recognized as limiting the loss of water by evaporation, improving filtration and root growth in addition to establishing vegetation and reducing soil erosion [64–67]. The establishment of plant cover will provide great benefits particularly in arid and semi-arid areas [68]. Along with crop establishment, woody pruning waste increases the stability of soil aggregates [65]. Other strategies can be applied instead of woody pruning waste such as plastic or stones, which improve water filtration [69–71]. However, by applying pruning residues as mulch or incorporated to the topsoil, we avoid their uncontrolled incineration, since this incineration forms a source of disease and expels large amounts of CO_2 into the atmosphere without positive effect regarding the mitigation of the negative effects of climate change. Moreover, its abandonment in boulevards and vacant land helps the spread of diseases and pests and generates a significant risk when there is torrential rain [20].

USW compost induces an increase in TOC (total organic carbon) and glomalin content in the soil, as several works showed [72–74]. The increase in the TOC content of the compost is caused by the stable nature of the amendment [73]. The compost increases microbial biomass and modifies community composition to form a fungal-dominated community, and these fungi are capable of degrading more recalcitrant organic material [74]. In addition, the growth of a mulch on compost-treated soils can improve the uptake of cellulose and lignin into the soil [75]. By using USW compost, we reduce our carbon footprint, avoid incineration, reduce the risk of disease spread (because USW can attract rodents, animals, and insects and can act as disease vectors), and furthermore, we promote the circular economy. Moreover, as this work shows, the availability of plant nutrients is key to understanding the use of this composted matter.

Pig slurry has a significant amount of organic matter; furthermore, it supplies macronutrients such as N, P, K, Na, Mg and Ca that favor the development of vegetation. Even more, exchangeable cations (Ca^{2+} and Mg^{2+}) positively affect soil aggregation. Opposite to this positive effect, the presence of Na mainly causes the aggregates to be unstable and the clay particles to spread [76]. The spreading of the aggregates can form crusts on the soil; this generates a slow filtration of water into the soil and also causes the particles to move faster due to surface runoff. In addition, exchangeable cations (Ca^{2+} as Mg^{2+}), in limestone soils, decrease clay dispersion [77].

The addition of pig slurry increases soil fertility and therefore improves the colonization of vegetation [78]. It also increases N and TOC, improves the soil structure and supplies nutrients to plants microbial populations, which are very important for recovery of the ecosystems [79]. The increase in soluble labile organic matter in pig manure can generate greater microbial growth [80].

5. Conclusions

The addition of the amendments used in this experiment to the soil was very beneficial, increasing the availability of plant nutrients in the soil and therefore facilitating the achievement of soil conditions for the development of crops. Moreover, in this area, this strategy could favor the implementation and the recovery of rain-fed Mediterranean agriculture that also contributes to landscape recovery.

All of the treatments favored the availability of nutrients but with several differences. The inorganic fertilization, the application of NPK fertilizer, increased the N and P, as it was expected. However, pig slurry increased the soil N and USW of the P content; both nutrients presented in their composition in significant amounts, respectively. Moreover, the last one favored the presence of the micronutrients studied (Fe, Cu and Zn). However, the high presence of calcium carbonates in the soil matrix controlled the high availability of Ca and Mg. In general, the values obtained for the nutrients analyzed in the soil do not pose any risk to the environment, and their availability can favor the development of the plant cover. Several considerations should be undertaken if the recovery of the soil for agriculture has a main role of restoring the landscape or looking for higher yield, and in such a case, more studies should be conducted.

The use of these wastes in the restoration of mining areas is feasible. Recovering the soil–plant systems is a necessary strategy for landscape, agriculture and forestry in restored areas. In addition, if organic amendments are used, the development of the circular economy will be promoted as well as the zero-waste strategy.

Author Contributions: Conceptualization, M.Á.P.B. and V.A.M.; methodology, M.Á.P.B., V.A.M., I.G.L. and J.N.-P.; software, I.G.L.; validation, I.G.L. and J.N.-P.; formal analysis, M.Á.P.B. and I.G.L.; investigation, M.Á.P.B.; resources, M.Á.P.B., V.A.M., I.G.L. and J.N.-P.; data curation, I.G.L. and J.N.-P.; writing—original draft preparation, M.Á.P.B.; writing—review and editing, M.Á.P.B., V.A.M., I.G.L. and J.N.-P.; visualization, M.Á.P.B.; supervision, I.G.L. and J.N.-P.; project administration, M.Á.P.B. and J.N.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No data is available.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhu, X.H.; Chen, Y.; Feng, C. Green total factor productivity of China's mining and quarrying industry: A global data envelopment analysis. *Res. Policy* **2018**, *57*, 1–9. [CrossRef]
2. De Silva, M.S.T.L.; Rohitha, L.P.S.; Dharmaratne, P.G.R. Zero Waste Sustainable Mining and Processing Operation of Quartz. In Proceedings of the International Mineral Symposium, Colombo, Sri Lanka, 15 September 2018.
3. Xiang, H.; Wang, Z.; Mao, D.; Zhang, J.; Zhao, D.; Zeng, Y.; Wu, B. Surface mining caused multiple ecosystem service losses in China. *J. Environ. Manag.* **2021**, *290*, 112618. [CrossRef] [PubMed]
4. Chaturvedi, R.K.; Singh, J. Restoration of mine spoil in a dry tropical region: A review. *Proc. Indian Natl. Sci. Acad.* **2017**, *83*, 789–844. [CrossRef]
5. Ting, L.; Minghui, W.; Changqun, D.; Shiyu, L.; Chang'e, L. The effect of different restoration approaches on vegetation development in metal mines. *Sci. Total Environ.* **2021**, *806*, 150626. [CrossRef]
6. Opekunova, M.; Opekunov, A.; Somov, V.; Kukushkin, S.; Papyan, E. Transformation of metals migration and biogeochemical cycling under the influence of copper mining production (the Southern Urals). *CATENA* **2020**, *189*, 104512. [CrossRef]
7. Macci, C.; Peruzzi, E.; Doni, S. Monitoring of a long term phytoremediation process of a soil contaminated by heavy metals and hydrocarbons in Tuscany. *Environ. Sci. Pollut. Res.* **2020**, *27*, 424–437. [CrossRef]
8. Asyakina, L.K.; Dyshlyuk, L.S.; Prosekov, A.Y. Reclamation of Post-Technological Landscapes: International Experience. *Food Process. Tech. Technol.* **2021**, *51*, 805–818. [CrossRef]
9. Daraz, U.; Li, Y.; Ahmad, I.; Iqbal, R.; Ditta, A. Remediation technologies for acid mine drainage: Recent trends and future perspectives. *Chemosphere* **2022**, *311*, 137089. [CrossRef]
10. Atuchin, V.V.; Asyakina, L.K.; Serazerdinova, Y.R.; Frolova, A.S.; Velichkovich, N.S.; Prosekov, A.Y. Microorganisms for Bioremediation of Soils Contaminated with Heavy Metals. *Microorganisms* **2023**, *11*, 864. [CrossRef]
11. Bruneel, O.; Mghazli, N.; Sbabou, L.; Héry, M.; Casiot, C.; Filali-Maltouf, A. Role of microorganisms in rehabilitation of mining sites, focus on Sub Saharan African countries. *J. Geochem. Explor.* **2019**, *205*, 106327. [CrossRef]
12. Carabassa, V.; Domene, X.; Alcañiz, J.M. Soil restoration using compost-like-outputs and digestates from non-source-separated urban waste as organic amendments: Limitations and opportunities. *J. Environ. Manag.* **2020**, *225*, 109909. [CrossRef]
13. Sonter, L.J.; Ali, S.H.; Watson, J.E.M. Mining and biodiversity: Key issues and research needs in conservation science. *Proc. R. Soc. B* **2018**, *285*, 20181926. [CrossRef] [PubMed]
14. Wang, Z.Y.; Lechner, A.M.; Yang, Y.J.; Baumgartl, T.; Wu, J.S. Mapping the cumulative impacts of long-term mining disturbance and progressive rehabilitation on ecosystem services. *Sci. Total Environ.* **2020**, *717*, 137214. [CrossRef]

15. Luo, A.K.; Hou, Y.; Hu, X.Y. Mining influence on underground water resources in arid and semiarid regions. *Earth Environ. Sci.* **2018**, *113*, 012131. [CrossRef]
16. Jing, Z.R.; Wang, J.M.; Zhu, Y.C.; Feng, Y. Effects of land subsidence resulting from coal mining on soil nutrient distributions in a loess area of China. *J. Clean. Prod.* **2018**, *177*, 350–361. [CrossRef]
17. Liu, S.L.; Li, W.P.; Qiao, W.; Wang, Q.Q.; Hu, Y.B.; Wang, Z.K. Effect of natural conditions and mining activities on vegetation variations in arid and semiarid mining regions. *Ecol. Indicat.* **2019**, *103*, 331–345. [CrossRef]
18. Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Mitigation of environmental impacts in ornamental rock and limestone aggregate quarries in arid and semi-arid areas. *Glob. J. Environ. Sci. Manag.* **2021**, *7*, 565–586. [CrossRef]
19. Peñaranda Barba, M.A.; Alarcón Martínez, V.; Gómez Lucas, J.; Navarro Pedreño, J. Methods of soil recovery in quarries of arid and semiarid areas using different waste types. *Span. J. Soil Sci.* **2020**, *2*, 101–122. [CrossRef]
20. Burger, J.; Gochfeld, M.; Kosson, D.S.; Brown, K.G.; Salisbury, J.A.; Jeitner, C. Risk to ecological resources following remediation can be due mainly to increased resource value of successful restoration: A case study from the Department of Energy's Hanford Site. *Environ. Res.* **2020**, *186*, 109536. [CrossRef]
21. Rodríguez-Berbel, N.; Soria, R.; Ortega, R.; Miralles, I. Biochemistry and metagenomic techniques in restored soils with organic amendments. *Agric. Res. Technol.* **2019**, *20*, 556140. [CrossRef]
22. Androkhanov, V.A.; Lavrinenko, A.T.; Gossen, I.N.; Kulyapina, E.D. Experience in creating a pilot production site for the reclamation of disturbed lands at the "Zarechny" open-pit mine of "Suek-Kuzbass" JSC. *Ugol* **2019**, *12*, 60–65. [CrossRef]
23. Danilov, A.; Smirnov, Y.; Korelskiy, D. Effective methods for reclamation of area sources of dust emission. *J. Ecol. Eng.* **2017**, *18*, 1–7. [CrossRef]
24. Isakov, A.E.; Barygina, K.V. Liming of acidic soils with belite sludge. *J. Ecol. Eng.* **2017**, *18*, 95–102. [CrossRef] [PubMed]
25. Ivanov, A.V.; Smirnov, Y.D.; Petrov, G.I. Investigation of waste properties of subway construction as a potential component of soil layer. *J. Ecol. Eng.* **2018**, *19*, 59–69. [CrossRef] [PubMed]
26. Zhou, Y.; Zhou, W.; Lu, X.; Jiskani, I.M.; Cai, Q.; Liu, P.; Li, L. Evaluation Index System of Green Surface Mining in China. *Min. Metall. Explor.* **2020**, *37*, 1093–1103. [CrossRef]
27. Mao, D.H.; He, X.Y.; Wang, Z.M.; Tian, Y.L.; Xiang, H.X.; Yu, H.; Man, W.D.; Jia, M.M.; Ren, C.Y.; Zheng, H.F. Diverse policies leading to contrasting impacts on land cover and ecosystem services in Northeast China. *J. Clean. Prod.* **2019**, *240*, 117961. [CrossRef]
28. Yang, S.Q.; Zhao, W.W.; Liu, Y.X.; Wang, S.; Wang, J.; Zhai, R.J. Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China. *Sci. Total Environ.* **2018**, *644*, 556–566. [CrossRef]
29. Changhong, S.; Huifang, L.; Shuai, W. A process-based framework for soil ecosystem services study and management. *Sci. Total Environ.* **2018**, *627*, 282–289. [CrossRef]
30. Bastin, J.-F.; Berrahmouni, N.; Grainger, A.; Maniatis, D.; Mollicone, D.; Moore, R. The Extent of forest in Dryland Biomes. *Science* **2017**, *356*, 635–638. [CrossRef]
31. Soria, R.; Rodríguez-Berbel, N.; Ortega, R.; Lucas-Borja, M.E.; Miralles, I. Soil amendments from recycled waste differently affect CO_2 soil emissions in restored mining soils under semiarid conditions. *J. Environ. Manag.* **2021**, *294*, 112894. [CrossRef]
32. Almendro-Candel, M.B.; Lucas, I.G.; Navarro-Pedreño, J.; Zorpas, A.A. *PHysical Properties of Soils Affected by the Use of Agricultural Waste: Agricultural Waste and Residues*; Aladjadjiyan, A., Ed.; IntechOpen: London, UK, 2018; pp. 9–28.
33. Ritzén, S.; Sandström, G.Ö. Barriers to the Circular Economy—Integration of Perspectives and Domains. *Procedia CIRP* **2017**, *64*, 7–12. [CrossRef]
34. Murray, A.; Skene, K.; Haynes, K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *J. Bus. Ethics* **2017**, *140*, 369–380. [CrossRef]
35. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1633–1644. [CrossRef]
36. Zornoza, R.; Faz, A.; Carmona, D.M.; Acosta, J.A.; Martínez-Martínez, S.; de Vreng, A. Carbon mineralization, microbial activity and metal dynamics in tailing ponds amended with pig slurry and marble waste. *Chemosphere* **2013**, *90*, 2606–2613. [CrossRef]
37. Murcia Ciudad Sostenible. Available online: https://www.murciaciudadsostenible.es/canada-hermosa/ (accessed on 20 May 2023).
38. Romero Díaz, A.; Martínez Hernández, C.; Belmonte Serrato, F. Land use changes in the Region of Murcia. The almond tree as reference crop and its relation to erosion processes. *Nimbus* **2012**, *29–30*, 607–626.
39. Canteras el Cerro. Available online: https://www.canteraselcerro.com/cal-agricola-carbonato-calcico/ (accessed on 20 May 2023).
40. MAPA. *Libro Blanco de la Agricultura y el Desarrollo Rural*; Ministerio de Agricultura, Pesca y Alimentación: Madrid, Spain, 2003; pp. 643–689.
41. Black, C.A. *Methods of Soil Analysis: Part I PHysical and Mineralogical Properties*; American Society of Agronomy: Madison, WI, USA, 1965. [CrossRef]
42. Aitken, R.L.; Moody, P.W. Interrelations between Soil pH Measurement in Various Electrolytes and Soil Solution ph in Acidic Soils. *Aust. J. Soil Res.* **1991**, *29*, 483–491. [CrossRef]

43. FAO. *Standard Operating Procedure for Analysis of Calcium Carbonate Equivalent in Soil—Volumetric Calcimeter Method*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2021.
44. Beretta, A.N.; Silbermann, A.V.; Paladino, L.; Torres, D.; Bassahun, D.; Musselli, R.; García-Lamohte, A. Soil texture analyses using a hydrometer: Modification of the Bouyoucos method. *Cienc. Investig. Agrar.* **2014**, *41*, 263–271. [CrossRef]
45. Olsen, R.S. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*; United States Department of Agriculture: Washington, DC, USA, 1954.
46. FAO. *Standard Operating Procedure for Soil Available Phosphorus—Olsen Method*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2021.
47. González, D.; Almendros, P.; Álvarez, J.M. Methods of analysis of elements in soils: Availability and fractionation. *An. Quim.* **2009**, *105*, 205–212.
48. MAPA. *Métodos Oficiales de Análisis*; Ministerio de Agricultura, Pesca y Alimentación: Madrid, Spain, 1986.
49. *UNE EN 13037:2012*; Mejoradores del Suelo y Sustratos de Cultivo. Determinación del ph. AENOR: Madrid, Spain, 2012.
50. Anderson, M.J. Permutation tests for univariate or multivariate analysis of variance and regression. *Can. J. Fish. Aquat. Sci.* **2021**, *58*, 626–639. [CrossRef]
51. Fernández-Caliani, J.C.; Barba-Brioso, C. Metal immobilization in hazardous contaminated mine soils after marble slurry waste application. A field assessment at the Tharsis mining district (Spain). *J. Hazard.* **2010**, *181*, 817–826. [CrossRef]
52. Kabas, S.; Arocena, J.M.; Acosta, J.A.; Faz, A.; Martínez-Martínez, S.; Zornoza, R.; Carmona, D.M. Syrian bean-caper (*Zygophyllum fabago* L.) improves organic matter and other properties of mine wastes deposits. *Int. J. Phytoremediation* **2013**, *16*, 366–378. [CrossRef] [PubMed]
53. Luna, L.; Pastorelli, R.; Bastida, F.; Hernández, T.; García, C.; Miralles, I.; Solé-Benet, A. The combination of quarry restoration strategies in semiarid climate induces different responses in biochemical and microbiological soil properties. *Appl. Soil Ecol.* **2016**, *107*, 33–47. [CrossRef]
54. Zornoza, R.; Faz, Á.; Martínez, S.; Acosta, J.A.; Gómez, M.D.; Muñoz, M.A.; Sánchez, R.; Murcia, F.J.; Fernández, F.; López, E.; et al. Rehabilitación de una presa de residuos mineros mediante la aplicación de lodo de mármol y purín de cerdo para el desarrollo de una fitoestabilización asistida. *Bol. Geol. Min.* **2017**, *128*, 421–435. [CrossRef]
55. Alburquerque, J.A.; de la Fuente, C.; Bernal, M.P. Improvement of soil quality after "alperujo" compost application to two contaminated soils characterized by differing heavy metal solubility. *J. Environ. Manag.* **2011**, *92*, 733–741. [CrossRef]
56. Fornes, F.; García de la Fuente, R.; Belda, R.M.; Abad, M. "Alperujo" compost amendment of contaminated calcareous and acidic soils: Effects on growth and element uptake by five Brassica species. *Bioresour. Technol.* **2009**, *100*, 3982–3990. [CrossRef] [PubMed]
57. Rodríguez-Berbel, N.; Ortega, R.; Lucas-Borja, M.; Solé-Benet, A.; Miralles, I. Long-term effects of two organic amendments on bacterial communities of calcareous Mediterranean soils degraded by mining. *J. Environ. Manag.* **2020**, *271*, 110920. [CrossRef]
58. Barker, A.V. Composition and uses of compost. In *Agricultural Uses of By-Products and Wastes*, 1st ed.; Rechcigl, J.E., MacKinnon, H.C., Eds.; American Chemical Society: Washington, DC, USA, 1997; Volume 668, pp. 140–162.
59. Zanuzzi, A.; Arocena, J.M.; van Mourik, J.M.; Faz, A. Amendments with organic and industrial wastes stimulate soil formation in mine tailings as revealed by micromorphology. *Geoderma* **2009**, *154*, 69–75. [CrossRef]
60. Martínez-Fernández, D.; Arco-Lázaro, E.; Bernal, M.P.; Clemente, R. Comparison of compost and humic fertiliser effects on growth and trace elements accumulation of native plant species in a mine soil phytorestoration experiment. *Ecol. Eng.* **2014**, *73*, 588–597. [CrossRef]
61. Yagüe, M.R.; Quílez, D. Cumulative and residual effects of swine slurry and mineral nitrogen in irrigated maize. *Agron. J.* **2010**, *102*, 1682–1691. [CrossRef]
62. Cela, S.; Santiveri, F.; Lloveras, J. Residual effects of pig slurry and mineral nitrogen fertilizer on irrigated wheat. *Eur. J. Agron.* **2011**, *34*, 257–262. [CrossRef]
63. Pardo, T.; Clemente, R.; Bernal, M.P. Effects of compost, pig slurry and lime on trace element solubility and toxicity in two soils differently affected by mining activities. *Chemosphere* **2011**, *84*, 642–650. [CrossRef] [PubMed]
64. Shao, P.; Gu, W.; Dai, Q.Y.; Makoto, S.; Liu, Y. Effectiveness of geotextile mulches for slope restoration in semi-arid northern China. *CATENA* **2014**, *116*, 1–9. [CrossRef]
65. Hueso-González, P.; Ruiz-Sinoga, J.D.; Martínez-Murillo, J.F.; Lavee, H. Overland flow generation mechanisms affected by topsoil treatment: Application to soil conservation. *Geomorphology* **2015**, *228*, 796–804. [CrossRef]
66. Laliberté, E.; Bouchard, A.; Cogliastro, A. Optimizing hardwood reforestation in old fields: The effects of treeshelters and environmental factors on tree seedling growth and physiology. *Restor. Ecol.* **2008**, *16*, 270–280. [CrossRef]
67. Valdecantos, A.; Cortina, J.; Vallejo, V.R. Differential field response of two Mediterranean tree species to inputs of sewage sludge at the seedling stage. *Ecol. Eng.* **2011**, *37*, 1350–1359. [CrossRef]
68. Bautista, S.; Robichaud, P.R.; Bladé, C. Post-fire mulching. In *Fire Effects on Soils and Restoration Strategies*, 1st ed.; Cerdá, A., Robichaud, P.R., Eds.; Science Publishers: Enfield, New Hampshire, 2009; Volume 5, pp. 353–372.
69. Wright, S.F.; Upadhyaya, A. A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant Soil* **1998**, *198*, 97–107. [CrossRef]
70. Bakker, J.D.; Colasurdo, L.B.; Evans, J.R. Enhancing Garry oak seedling performance in a semiarid environment. *Northwest Sci.* **2012**, *86*, 300–309. [CrossRef]

71. Devine, W.D.; Harrington, C.A.; Leonard, L.P. Postplanting treatments increase growth of Oregon white oak (*Quercus garryana* Dougl. ex Hook.) seedlings. *Restor. Ecol.* **2007**, *15*, 212–222. [CrossRef]
72. Luna, L.; Miralles, I.; Andrenelli, M.C.; Gispert, M.; Pellegrini, S.; Vignozzi, N.; Solé-Benet, A. Restoration techniques affect soil organic carbon, glomalin and aggregate stability in degraded soils of a semiarid Mediterranean region. *CATENA* **2016**, *143*, 256–264. [CrossRef]
73. Dearden, F.M.; Dehlin, H.; Wardle, D.A.; Nilsson, M.C. Changes in the ratio of twig to foliage in litterfall with species composition, and consequences for decomposition across a long term chronosequence. *Oikos* **2006**, *115*, 453–462. [CrossRef]
74. Boer, W.; De Folman, L.B.; Summerbell, R.C.; Boddy, L. Living in a fungal world: Impact of fungi on soil bacterial niche development. *Fems. Microbiol. Rev.* **2009**, *29*, 795–811. [CrossRef] [PubMed]
75. Baldrian, P.; Merhautova, V.; Petrankova, M.; Cajthaml, T.; Snajdr, J. Distribution of microbial biomass and activity of extracellular enzymes in a hardwood forest soil reflect soil moisture content. *Appl. Soil Ecol.* **2010**, *46*, 177–182. [CrossRef]
76. Crescimanno, G.; Iovino, M.; Provenzano, G. Influence of salinity and sodicity on soil structural and hydraulic characteristics. *Soil Sci. Soc. Am. J.* **1995**, *59*, 1701–1708. [CrossRef]
77. Amezketa, E.; Aragües, R. *Flocculation-Dispersion Behavior of Arid-Zone Soil Clays as Affected by Electrolyte Concentration and Composition*; Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria: Madrid, Spain, 1995.
78. Kabas, S.; Faz, A.; Acosta, J.A.; Zornoza, R.; Martínez-Martínez, S.; Carmona, D.M.; Bech, J. Effect of marble waste and pig slurry on the growth of native vegetation and heavy metal mobility in a mine tailing pond. *J. Geochem. Explor.* **2012**, *123*, 69–76. [CrossRef]
79. Zornoza, R.; Faz, A.; Carmona, D.M.; Martínez, S.; Acosta, J.A. Plant cover and soil biochemical properties in a mine tailing pond five years after application of marble wastes and organic amendments. *Pedosphere* **2012**, *22*, 22–32. [CrossRef]
80. Zornoza, R.; Acosta, J.A.; Faz, A.; Bååth, E. Microbial growth and community structure in acid mine soils after addition of different amendments for soil reclamation. *Geoderma* **2016**, *272*, 64–72. [CrossRef]