Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Attila Çiner · Md Firoz Khan · Amjad Kallel ·
Jesús Rodrigo-Comino · Mario Parise · Rahim Barzegar ·
Zeynal Abiddin Ergüler · Nabil Khelifi · Imran Ali *Editors*

Recent Research on Environmental Earth Sciences, Geomorphology, Soil Science, Paleoclimate, and Karst

Proceedings of the 1st MedGU, Istanbul 2021 (Volume 4)

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Advances in Science, Technology & Innovation

IEREK Interdisciplinary Series for Sustainable Development

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ASTI series has now been accepted for Scopus (September 2020). All content published in this series will start appearing on the Scopus site in early 2021.

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About MedGU

Steps toward the creation of a Mediterranean Geosciences Union (MedGU)

Mediterranean Geosciences Union (MedGU) aims to create a unique federation that brings together and represents the Mediterranean geoscience community specializing in the areas of Earth, planetary, and space sciences.

MedGU will be structured along the lines of American Geophysical Union (AGU) and European Geosciences Union (EGU).

The plan is to establish a large organization for the Mediterranean region that is more influential than any one local geoscience society with the objective of fostering fundamental geoscience research, as well as applied research that addresses key societal and environmental challenges.

MedGU's overarching vision is to contribute to the realization of a sustainable future for humanity and for the planet.

The creation of this union will give the Earth sciences more influence in policy-making and in the implementation of solutions to preserve the natural environment and to create more sustainable societies for the people living in the Mediterranean region. It is hoped that the union will also provide opportunities to Mediterranean geoscientists to undertake interdisciplinary collaborative research. MedGU plans to recognize the work of the most active geoscientists with a number of awards and medals.

Although MedGU has not yet been officially inaugurated, its first annual meeting is planned for November 2021 in Istanbul. This will provide a forum to achieve a consensus for the formation of this non-profit international union of geoscientists. Membership will be open to individuals who have a professional engagement with the Earth, planetary, and space sciences, and related studies, including students and retired seniors.

Nabil Khélifi and Attila Çiner have taken an ambitious approach to the launch of the first MedGU Annual Meeting 2021 and hope to develop it in the near future into the largest international geoscience event in the Mediterranean and the broader MENA region. Its mission is to support geoscientists based in this region by establishing a Global Geoscience Congress.

It is expected that hundreds of participants from all over the world will attend this first MedGU Annual Meeting 2021, making it one of the largest and most prominent geosciences events in the region. So far, over 1300 abstracts have been submitted from 95 countries. The meeting's sessions will cover a wide range of topics with more details available on the Conference Tracks.

This first 2021 Annual Meeting will have a "hybrid" format, with both in-person and virtual participation. Springer, its official partner, will publish the proceedings in a book series (indexed in Scopus) as well as a number of special issues in diverse scientific journals (for more details, see Publications). The official journal of MedGU is Mediterranean Geoscience Reviews (Springer).

Conference Tracks

The scientific committee of the MedGU invites research papers on all cross-cutting themes of Earth sciences, with the main focus on the following 16 conference tracks:

- Track 1. Atmospheric Sciences, Meteorology, Climatology, Oceanography
- Track 2. Biogeochemistry, Geobiology, Geoecology, Geoagronomy
- Track 3. Earthquake Seismology and Geodesy
- Track 4. Environmental Earth Sciences
- Track 5. Applied and Theoretical Geophysics
- Track 6. Geo-Informatics and Remote Sensing
- Track 7. Geochemistry, Mineralogy, Petrology, Volcanology
- Track 8. Geological Engineering, Geotechnical Engineering
- Track 9. Geomorphology, Geography, Soil Science, Glaciology, Geoarcheology, Geoheritage
- Track 10. Hydrology, Hydrogeology, Hydrochemistry
- Track 11. Marine Geosciences, Historical Geology, Paleoceanography, Paleoclimatology
- Track 12. Numerical and Analytical Methods in Mining Sciences and Geomechanics
- Track 13. Petroleum and Energy Engineering, Petroleum Geochemistry
- Track 14. Sedimentology, Stratigraphy, Paleontology, Geochronology
- Track 15. Structural Geology, Tectonics and Geodynamics, Petroleum Geology
- Track 16. Caves and Karst, a special session on the occasion of International Year of Caves and Karst

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Preface

This proceedings volume is based on 57 papers accepted and presented during the 1st Mediterranean Geosciences Union (MedGU-21) Conference organized in Istanbul, Turkey, in 2021 under the auspices of Springer Nature. Although more than half of the contributions come from the Mediterranean region, many other countries around the globe also actively participated in developing this volume. In detail, almost half of this volume's papers (29) are related to the Environmental Earth Sciences. In the second part, a total of 19 articles contain works from Geomorphology, Soil Science, Landslides, Paleoclimate, Geoarcheology, and Geoheritage.

Last but not the least, the third part includes nine papers dealing with karst research. These were submitted to the special session on the occasion of the International Year of Caves and Karst (IYCK), declared for 2021 by the International Union of Speleology (UIS) under the auspices of UNESCO. Following the main goals of IYCK, the focus was on all spheres related to the fragile karst environment, especially regarding important issues such as the protection of caves and their natural resources and sustainability.

The book is relevant to all researchers and students on the topics mentioned above, presenting an updated view on field studies, laboratory analyses, and modeling in earth sciences.

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Kütahya, Türkiye — Zeynal Abiddin Ergüler
Heidelberg, Germany — Nabil Khelifi
New Delhi, India — Imran Ali
June 2022

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About the Editors

Attila Çiner is a Sedimentology and Quaternary Geology Professor at the Eurasia Institute of Earth Sciences at Istanbul Technical University, Turkey. After graduating from the Middle East Technical University in Ankara (1985), he obtained his M.Sc. degree at the University of Toledo, USA (1988), and his Ph.D. at the University of Strasbourg, France (1992). He works on the tectono-sedimentary evolution of basins and Quaternary depositional systems such as moraines, fluvial terraces, alluvial fans, and deltas. He uses cosmogenic nuclides to date these deposits. He primarily focuses on the glacial deposits and landscapes and tries to understand paleoclimatic and paleoenvironmental changes since the Last Glacial Maximum. Lastly, he was part of the Turkish Antarctic Expedition. He spent two months working on the site recognition and decision of the future Turkish scientific research station to be implemented on the continent. He is Editor-in-Chief of *Mediterranean Geoscience Reviews* and Chief editor of *Arabian Journal of Geosciences*, both published by Springer. He has published more than 100 peer-reviewed articles and book chapters.

Dr. Md Firoz Khan is an Associate Professor at the Department of Environmental Science and Management, North South University, since 2022 and a Leader of the AEROSOL LAB (pollutAnts-hEalth inteRactiOn eStimatiOn Lab). Before that, he taught Environmental Science and Geoinformatics for eight years in multiple countries, including Malaysia and China. His fields of expertise include but are not limited to air pollution/causes and effects, atmospheric chemistry, environmental chemistry, air pollution modeling, environmental toxicology, etc. He received his education in Japan (Ph.D.), the UK (M.Sc.), and Bangladesh (B.Sc.). He is an author or co-author of >110 peer-reviewed research articles published in many top-tiering journals. He engages with >20 research grants as a PI or CoPI received from national and international funding bodies in environmental research. Dr. Firoz is a lead lecturer and developer of a micro-credential online course titled “Chemometrics in Air Pollution” under the Future Learn Website. He evaluates research grants from the SWISS National Science Foundation (SNSF) and the Qatar National Research Fund (QNRF). Under his supervision (main and co-supervision), around 30 research students have received undergrad, postgrad, and Ph.D. degrees in air

pollution-health interaction. With immense experience in air pollution research, Dr. Firoz plays a vital role as an Associate Editor in several journals, i.e., *Observation and Modeling of Air Pollution* (a special issue of Sustainability, MDPI, Impact Factor: 3.889); *Elementa: Science of the Anthropocene* (Impact Factor 6.053, California University Press); *Frontiers in Environmental Engineering—Air Pollution Management* and *Arabian Journal of Geosciences* (Springer, Impact Factor: 1.827); and also serves as an expert member to Atmospheric Environmental Remote Sensing Society (AERSS) (Working Group-8: Air Quality, Climate, and Health).

Dr. Amjad Kallel is currently an Associate Professor of Environmental Geology in the Sfax National School of Engineers at the University of Sfax, Tunisia. He holds a B.Eng. in Georesources and Environment (1998) from the University of Sfax (Tunisia) and an M.Sc. degree and a Ph.D. degree in Georesources and Environment (2004) from Hokkaido University (Japan). He joined Venture Business Laboratory (VBL) at Akita University, Japan (2005–2006), as a researcher focusing on refining and recycling technologies for the recovery of rare elements from natural and secondary sources. On his return to Tunisia, he worked at the University of Gabes from 2006 to 2011, where he contributed to the elaboration of teaching programs at the Higher Institute of Water Sciences and Technologies of Gabes. Since 2011, he has joined the Sfax National School of Engineers. There, he has also been involved in various research projects related to Environmental Geology and Environmental Geotechnics. Dr. Kallel has co-organized many prestigious workshops, seminars, and international conferences. In 2016, Dr. Kallel joined the *Arabian Journal of Geosciences* (Springer) and the *Euro-Mediterranean Journal for Environmental Integration* (Springer) as Chief Editor and Managing Editor, respectively.

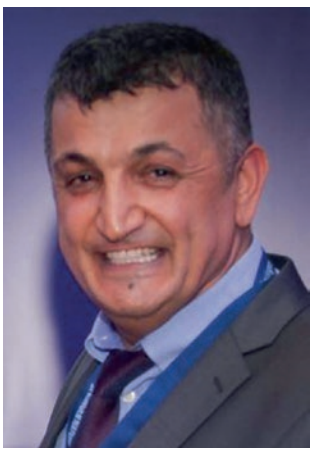
Jesús Rodrigo-Comino a graduate in Geography, currently works as an Assistant Professor at the University of Granada and was included for the second time in the World's Top 2% Scientists ranking by Stanford University. He got a Master in Territorial Planning and Geographic Information Systems (2013) at the University of Málaga/Granada, whose final work was divided into three national publications and a monograph. During his predoc stage, he obtained three scholarships for doctoral studies: DAAD (German Academic Exchange Service), La Caixa Foundation, and FPU (Ministry of Education, Spain). During this period, he completed his first doctoral thesis in Geography between the University of Trier (Germany—2 years) and Malaga (2 years) in 2018: "Actual Geomorphological Processes in Sloping Vineyards. A Comparison Between Ruwer-Mosel Valley (Trier, Germany) and Montes de Málaga (Málaga, Spain)". In 2023, he defended his second doctorate in engineering in Geomatics and Topography at the Polytechnic University of Valencia. His research career consists of four complete monographs (Nova, Springer, etc.) and some edited books (Elsevier, CRC, Nova),

>200 indexed publications in Scopus and WoS, leading international collaborations with research teams over the world. He is a regular reviewer in more than 150 indexed international journals, a member of two doctoral theses committees, and an evaluator of projects for the Ministries of Science of Chile, Peru, the United States, Serbia, Switzerland, Kazakhstan or Poland, and postgraduate scholarships for DAAD. He has organized several international scientific meetings and congresses (for example COST Actions, Biohydrology, and Fire in the Earth), sessions at international conferences (EGU, TerraEnvision, Conference of the Arabian Journal of Geosciences, etc.), oral presentations, and conference master classes (Germany, Bulgaria, Norway, Algeria, etc.). He is Editor-in-chief of the indexed journal (Scopus and ESCI; Q2) *Air Soil and Water Research* (SAGE) and *Euro-Mediterranean Journal for Environmental Integration* (Springer). In addition, he was Associate Editor at *Scientific Reports* (Nature) and *Hydrological Science Journal* (Taylor & Francis) and continues in the *Arabian Journal of Geosciences* (Springer), and *Journal of Mountain Science* (Springer). He has participated as a researcher in R+D+I projects on social issues related to housing or the census, or transfer and knowledge at a European level, such as the INTERREG Smart-Light HUB project (light pollution) or COST FIRElinks (fires). He has been invited to give lectures on agriculture, sustainable management, and erosion. He has supervised five final degree projects and three master's degrees. He has taught regulated and certified teaching at the Universities of Granada, Valencia, Málaga, León, Oviedo, Trier (in German), Quito (Ecuador), and La Habana (Cuba) on geopolitics, geomorphology, Geographic Information Systems, remote sensing, and statistical techniques. He managed some international (FIRElinks COST Action), national (BBVA Foundation), and regional projects and supervised two Ph.D. theses.

Mario Parise Graduated with honors in Geology at the Faculty of Sciences of the University Federico II, Naples, Italy. Since 1990, he has developed research mainly into the geological and geomorphological analysis of slope movements, namely with the identification of the areas susceptible to different types of slope movement (from debris flows, to deep-seated gravitational slope deformations, to general mass wasting processes) by means of stereoscopic interpretations of aerial photographs and field surveys. Particular focus is given to multi-temporal analysis, aimed at understanding the likely evolution of slopes, even in relationship with anthropogenic activities, and/or as a consequence of specific triggering events (rainfall, earthquakes, etc.). For several sites in southern Italy, he has outlined a framework of the influence of weathering in the predisposition of slope movements. He has also contributed to the analysis of rapid landslides (debris avalanches, rock avalanches) in different geological settings in Italy and abroad, and to studying the occurrence of debris flows and erosional processes in areas recently affected by wildfires. He has

studied various landslides in Italy and the USA, and within this research activity he has developed an expertise in the recognition and investigation of slope failures, production of thematic maps, and also collaborating in the interpretation of monitoring data and in slope stability analyses. In addition, since 2002 he is working in the field of karst research, focusing on the evaluation of the natural and anthropogenic hazards occurring in karst territories, with particular regard to sinkholes and to underground instability and failures. This research is carried out also thanks to the caving activity in which he is active since 1998. He is the author of over one hundred papers published on international journals and proceedings of international conferences. He has given several presentations in international symposium and workshops. He has acted as Guest Editor in 10 special issues for ISI international journals, and has published three books with the Geological Society of London. He is a Member of the Editorial Board of *Natural Hazards and Earth System Sciences*, *Journal of Mountain Sciences*, *Carbonates and Evaporites*, *Natural Hazards*, *Bulletin of Engineering Geology and the Environment*, *Opera Ipogea*, and *Journal of Cave and Karst Studies*.

Dr. Rahim Barzegar is a Postdoctoral Fellow in the Department of Bioresource Engineering at McGill University in Canada. Before joining McGill in 2019, he obtained a Ph.D. and M.Sc. in Hydrogeology and a B.Sc. in Geology from the University of Tabriz, Iran. He has worked as a postdoctoral researcher in joint projects at the University of Tabriz in Iran and Wilfrid Laurier University in Canada. His main research focuses on the exploration of new methods in machine learning- and deep learning-based hydrological modeling. His other research activities also revolve around time series analysis, water quality assessment, water resources management, and climate change impacts on water resources. Dr. Barzegar also acts as an Associate Editor for the *Arabian Journal of Geosciences* (Springer publication), *Earth Science Informatics Journal* (Springer publication), *Communications Earth and Environment* (Nature publication), and Topic Editor for *Water Journal* (MDPI).



Prof. Dr. Zeynal Abiddin Ergüler is a Full Professor at the Geological Engineering department at Kutahya Dumlupinar University (Turkey). Dr. Erguler holds a B.Sc. (1998), an M.Sc. (2001), and a Ph.D. degree (2007) in Geological Engineering from Hacettepe University (Turkey). His research interests mainly focus on rock mechanics, engineering geology, environmental geology, and soil mechanics. His current investigation is to understand and model the thermo-hydro-mechanical behavior of shale rocks in the area of shale gas production. In addition to performing many types of research and industry-funded projects, he has also taught and supervised undergraduate and graduate students. In 2017, Dr. Erguler joined the *Arabian Journal of Geosciences* (AJGS) as an Editor responsible for evaluating submissions in the fields of rock mechanics, engineering geology, environmental geology, and soil mechanics.

Nabil Khelifi undertook fellowships at the System for Analysis, Research and Training (START) in 2005 and the German Academic Exchange Service (DAAD), as part of my Ph.D. studies in Marine Geosciences at the University of Kiel in Germany (2006–2010). After my Ph.D., I received a research grant from the German Science Foundation (DFG) to conduct research projects at the GEOMAR Ocean Research Centre in Kiel on oceanography and climate reconstructions in the North Atlantic and the Mediterranean (2010–2013). My research findings have been presented at international conferences and published in esteemed journals. From 2009 to 2013, I co-organized with my Kiel colleagues two workshops on the Pliocene climate at the University of Bordeaux, France (2009), and the University of Bristol, UK (2013), funded by the European Science Foundation (ESF). In late 2013, I received the Swiss Government Excellence Scholarship to pursue my postdoctoral research career. In 2014, I joined Springer (now Springer Nature) in Heidelberg, Germany, as an Editor, and was promoted to Senior Editor in 2017 responsible for developing their publishing program in the Middle East and Africa, which consists of managing 20 journals and two book series. From 2015 to 2022, I was active in educational seminars for authors, reviewers, and editors to help improve publication output and quality. In 2015, I was also a visiting lecturer at King Saud University, KSA, and University of Sfax, Tunisia, where I gave lectures on publishing techniques. Recently, I launched two international conferences (more details at www.emcei.net and www.medgu.org) aiming at promoting two journals that I was managing at Springer. In 2016, I was awarded the Africa Green Future Leadership Award for my promotion of publications from Africa. In 2020, I received the Saudi Society for Geosciences Award.

Prof. Imran Ali is a world-recognized academician and researcher. He completed his Ph.D. at the Indian Institute of Technology Roorkee, Roorkee, India. Professor Ali is known globally due to his great contribution to pharmaceutical analysis by chromatography and capillary electrophoresis, the development of anticancer drugs, nanotechnology for water treatment, and water splitting for hydrogen green fuel generation. He has published more than 500 papers in reputed journals including papers in Nature and Chemical Reviews of more than 72 impact factors. He has also written six books published by Marcel Dekker, Inc., USA; Taylor & Francis, USA; John Wiley and Sons, USA; John Wiley and Sons, UK; Elsevier, The Netherlands; and Springer, Germany. His total citation is 35,500 with an h-index of 102 and an i10-index of 323. He is a member of various scientific societies globally. He is Editor-in-Chief of 02, Editor of 03, Associate Editor of 06 journals, and is on the editorial board of 40 journals.

Lead Removal from Water Solutions Using Alginate-Immobilized Peach Stone Particles

Zorica Lopičić, Jelena Milojković, Tatjana Šoštarić, Anja Antanasković, Marija Koprivica, Vladimir Adamović, and Linda Mitić

Abstract

Fruit processing industries generate millions of tons of organic waste annually, often improperly disposed of at open landfills. Based on the circular economy and waste management concepts, reusing these bio-waste materials is one of the future sustainable demands. Furthermore, recent investigations have shown that this material type can be reused as high-quality sorbents, with certain modifications that should be applied. Considering this, we have investigated the possible application of lignocellulosic waste-peach stones (*Prunus Persica* L.), immobilized in sodium alginate, as heavy metals sorbent. The immobilized particles (IPS) were utilized to remove metals from synthetic water solutions. Among all metals (Pb, Cu, Cd, and Zn), IPS has shown superior performance in Pb removal, governing further investigations. Dried IPS spheres were characterized by FTIR, SEM/EDX, and TG techniques. The batch reaction system investigated the effects of the contact time, initial Pb concentration, and mass-to-volume ratio. Optimized operational parameters were used in kinetic and isotherm studies. Obtained data were modeled using a nonlinear form of pseudo-first, pseudo-second, Elovich, Freundlich, and Langmuir equations. The results showed pseudo-second-order kinetics with Freundlich isotherm fitting Pb removal, indicating a heterogeneous IPS surface with the multilayer adsorption and adsorbed molecule interaction. As obtained from Langmuir isotherm, IPS particles have removed Pb by saturation capacity of 80.40 mg Pb/g. These preliminary results indicate that IPS can be applied to purify waters contaminated with lead metal.

Keywords

Waste biomass · Immobilization · SEM/EDX · Lead removal

1 Introduction

The growth of industrial activity and uncontrolled or improper release of pollutants into the environment induced the need for new methods and materials that might be used to solve environmental pollution issues. Many techniques have been developed for different pollutant removal. Still, most of them are often ineffective, economically or technically demanded, especially if the pollutant concentration (e.g., metals) falls below 100 mg/L (Abdolali et al., 2014). Sorption techniques using low-cost, abundant lignocellulosic waste (LCW) material might be applied for that purpose. Although LCWs pose some disadvantages concerning their direct applications as purification agents (Abdi & Kazemi, 2015; Abdolali et al., 2014), their properties might be improved by different modifications and immobilization in various polymer matrices (Chatterjee & Schiewer, 2014).

This paper investigates the possibility of lead (Pb) removal by immobilized LCW peach stone particles. Lead was chosen as a high-toxicity heavy metal, resistant to chemical or biological degradation, presenting a hazard to living and non-living environments (Check & Marteel-Parrish, 2013). On the other hand, recent investigations have shown that LCW generated by the fruit processing industry represents a stable matrix that might be efficiently used in wastewater purification (Lopičić et al., 2017). Therefore, to improve the sorption properties of the raw

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material as well as the overall separation process, we have immobilized mechanically treated peach stones (*Prunus Persica* L.) in the sodium alginate and applied it as an efficient sorbent in lead removal.

2 Materials and Methods

All the chemicals used in this study were of high purity. Peach stones (PS) were obtained as waste from a local juice factory. After washing, grinding, and sieving (to a diameter less than 0.1 mm), mechanically treated PS particles were immobilized in Na-alginate according to the method described by Yuan and Viraraghavan (2001). Formed alginate beads (IPS) were further used for the characterization and sorption experiments.

Dried IPS spheres were characterized by FTIR (Thermo Fisher Scientific Nicolet IS-50 spectrophotometer, ATR mode), SEM/EDX (model JEOL JSM-6610LV), and TG (Netzsch STA 409 EP) technique.

Sorption experiments were done in triplicate in a batch reactor with mixing (200 rpm) at constant temperature (25 °C) with optimization of operational parameters. Obtained values were further used in kinetic and isothermal studies. The analytical Pb(II) measurements were done using AAS (Perking Elmer AAS Analyst 300). The percent of Pb(II) removal, R (%), as well as the amount of Pb(II), sorbed per unit mass of IPS, q (mg/g), was calculated as described in Lopičić et al. (2017).

3 Results

3.1 IPS Sorbent Characterization

Figure 1a, b shows SEM images of the IPS sphere. IPS represents a regular sphere of 5 mm average diameter, with PS evenly entrapped within the matrix, regularly exposed to a highly developed surface. Opposite to native material (Lopičić et al., 2019), the presence of macro pores is not evident. EDX analyses showed typical LCW composition (Lopičić et al., 2019) with higher Ca picks than in native material, while after Pb(II) sorption, reduced peaks of Ca, as well as a new peak of Pb(II), are observed in the EDX spectrum (image not shown). Figure 1c presents a TG/DTA analysis of the IPS sample. The first negative peak at 86 °C on the DTA curve is assigned to the loss of free water and water linked through hydrogen bonds. The second mass loss corresponds to the thermal decomposition of IPS composite with the fracture of glycosidic bonds and release of H_2O, with a degradation peak moved from lower (pure alginate) to a higher temperature (333 °C). This result suggests the composite sorbent poses high thermal stability than the alginate itself. The final step of mass loss with a peak at 443 °C may be attributed to the carbonate formation, partial lignin, and cellulose degradation.

All bands' characteristics for raw PS have been seen on the FTIR spectrum of IPS (not shown), but due to the presence of the alginate with reduced intensity. The identified chemically active IPS groups were characterized as polysaccharides, cellulose, hemicellulose, and lignin, all present in composite material.

3.2 Batch Sorption Results

The immobilized particles of *Prunus Persica* L. waste biomass (IPS) were utilized to remove heavy metals from the synthetic water solutions. Among all metals (Pb, Cu, Cd, and Zn), IPS has shown superior performance in Pb(II) removal, so further sorption experiments were performed only with this pollutant. According to the literature review, the initial pH was set to 5.00 and was not adjusted during the sorption process. A significant decrease in pH (up to 3.98) is observed by the end of the process, owing to the presence of carboxylic groups as the main cation exchangers. The effect of the sorbent dose on the amount of Pb(II) sorbed by IPS and its corresponding removal percentage was investigated in the range 0.25–20 g/L. The results have shown an increase in percentage in Pb(II) removal (from 27.4 up to 90.8%) with an increase in IPS dose from 0.25 to 2.0 g/L. Further, an increase in sorbent dose increased R but significantly decreased Pb(II) sorbed. The influence of contact time revealed slow kinetics (equilibrium up to 24 h), which was the best fit by the pseudo-second-order model (Fig. 2a). Isotherm data showed the best correlation with the Freundlich model (Fig. 2b), indicating a multilayer sorption mechanism onto complex IPS surfaces.

4 Discussion

IPS characterization revealed a spherical sorbent shape with a high surface area and plenty of functional groups suitable for lead removal. This sorbent type posed higher thermal stability than the alginate itself and higher ash content than the raw PS, owing to crosslinked Ca in its matrix. Lead removal was superior to other sorbates investigated (thanks to ion exchange Ca–Pb). The typical overall adsorption efficiency (R(%)) was between 27% (for 0.25 mg/L of 1 M Pb solution) and 99% for the final value of 20 g of IPS/L. This removal efficiency did not appreciably increase with an increase in the mass-to-volume ratio higher than 2 g/L, and this operating parameter was selected for kinetic and isothermal investigations. Investigating the influence of contact

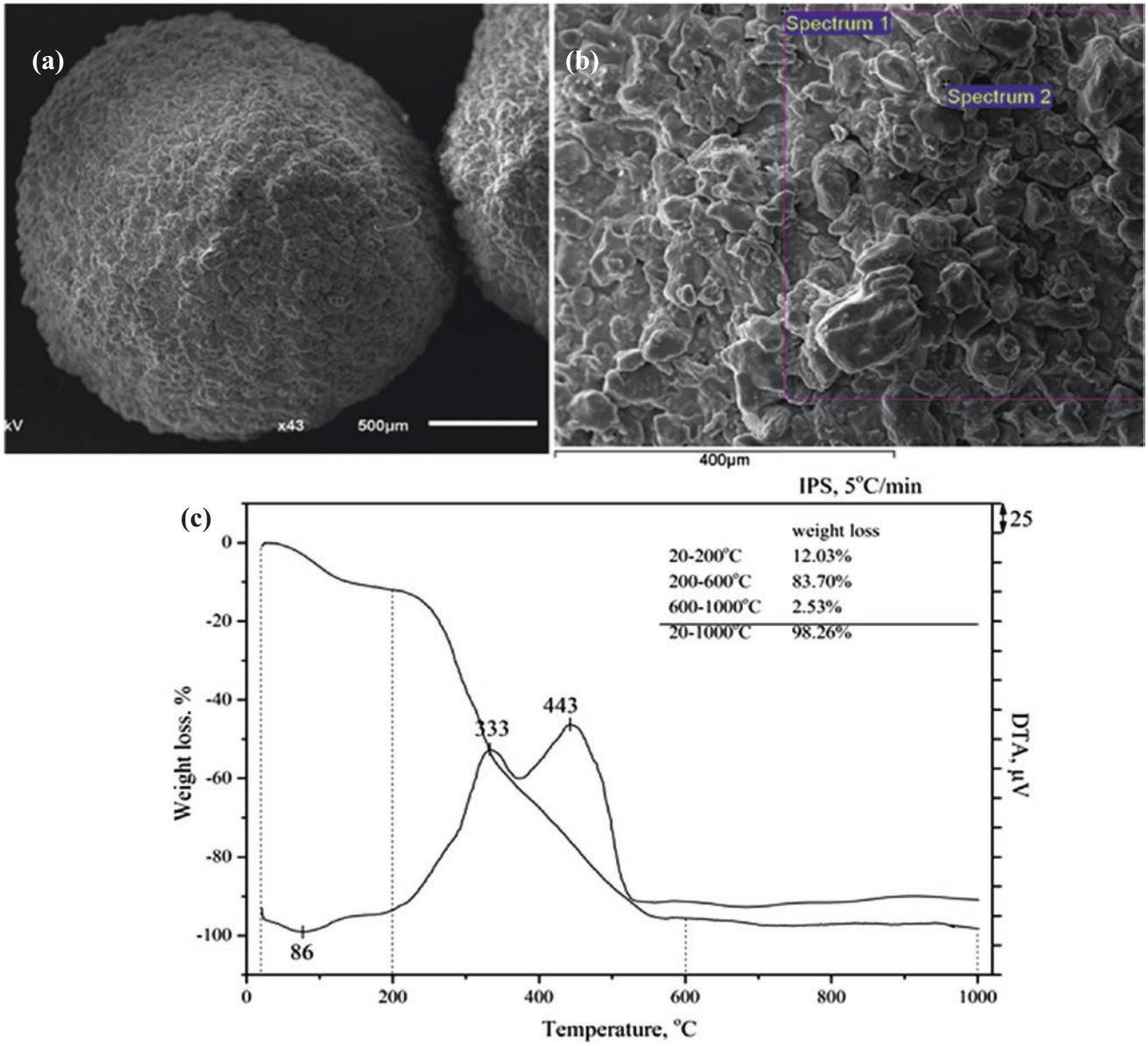

Fig. 1 **a** and **b** SEM micrographs of IPS at different magnitudes and **c** TG/DTA analysis of IPS sample

time showed slow kinetics best fitted by a pseudo-second-order equation. The results of isotherm investigations have demonstrated that the Freundlich isotherm fits better with the removal of Pb, indicating a heterogeneous IPS surface with multilayer adsorption and interaction between adsorbed molecules. Calcium alginate-immobilized PS particles have removed Pb by a saturation capacity of 80.40 mg Pb/g, as obtained from Langmuir isotherm. This value is much higher than the one for raw PS, which was calculated as 28.64 mg Pb/g under the same operational conditions. During the sorption process, calcium, added as a crosslinking agent, was exchanged with lead due to the affinity of the weak acid cation exchanger, the carboxyl group, which has a higher selectivity toward the lead.

5 Conclusions

Although LCW often has limited sorption capacity compared to current commercial sorbents, a good sorbent selection with a proper modification can considerably improve its sorption properties. Furthermore, based on the circular economy and waste management concepts, the reuse of LCW materials is one of the future demands in achieving economic and environmental sustainability. Preliminary results presented in this paper indicate that IPS can be applied to purify waters contaminated with lead metal. Thus, further investigations into the IPS application should be conducted.

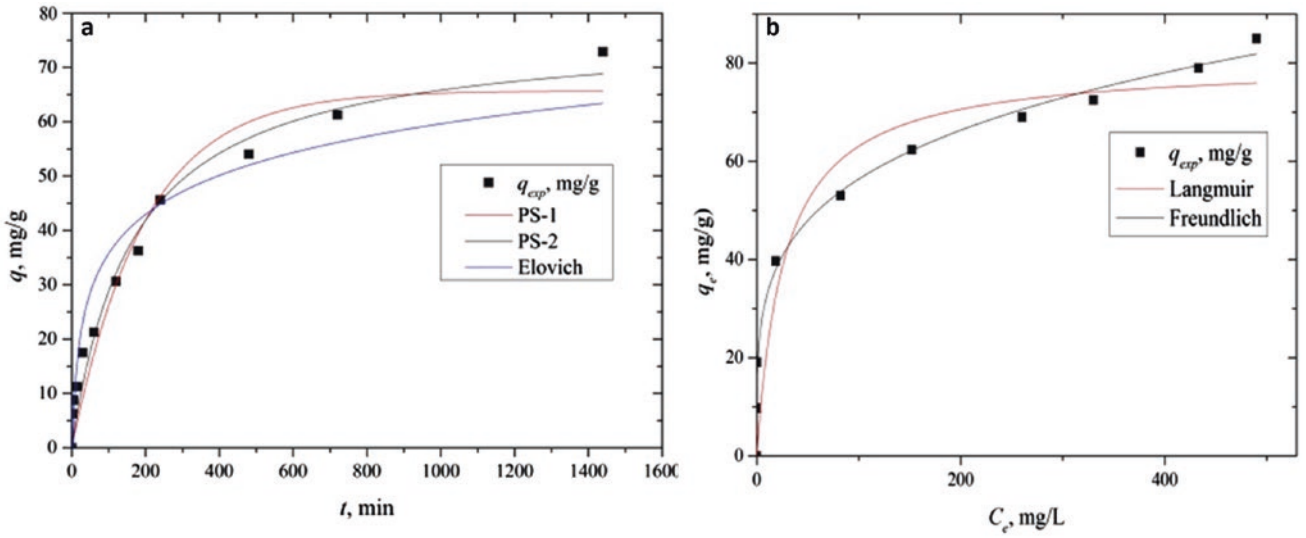

Fig. 2 **a** Kinetics and **b** equilibrium of Pb(II) uptake by IPS

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