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Evaluating soil quality status of fluvisols at the regional scale: A multidisciplinary approach crossing multiple variables

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Abstract

Rivers condition natural and human ecosystems, providing fertile soils and water for irrigation and consumption in rural and urban uses. However, the intensification of human activities and inherent environmental conditions (e.g., topography, slope or climate) are changing the sustainability of fluvial soil ecosystems. This is problematic, especially in the Mediterranean belt, because of a lack of studies at the regional scale that evaluates soils traditionally associated with rivers such as the "Fluvisols" (IUSS-WRB). Therefore, the main aim of this paper is to understand the current status of fluvial soils in the Málaga province (Southern Spain) within the Mediterranean belt considering: (1) different thematic maps; (2) soil profiles; and (3) a soil quality index. Fluvisols of the region were assessed using fieldwork, extensive soil data sources and soil profiles including specific information on soil physicochemical properties and crossing environmental conditions. A total of 195.22 km^2 of fluvisols can be found in Málaga. About 42.5% of the fluvisols are used for human activities such as agriculture (rainfed and irrigation fields, or woody crops such as olives or vineyards), mining, industries and services, urban areas or reservoirs. More than 58% of the fluvisols are located in the warmest territories registering the highest evapotranspiration rates and lowest rainfall amount. The soil quality index reaches lower scores for the fluvisols having mean values of 0.58 (1 = maximum possible score). We conclude that the characterization from a regional scale shed light on the current status of the fluvisols and possible responses against human impacts and river evolution dynamics.

KEYWORDS
fluvial ecosystems, human activities, Mediterranean, regional geography, soil quality index, soils

1 | INTRODUCTION

Understanding the connection between rivers and soils is a key point for the successful assessment of the past, current and future status of natural and human ecosystems (Liu, Liu, Wang, & Zhao, 2020; Pinay, Black, Planty-Tabacchi, Gumiero, & Décamps, 2000; Yan, Xie, Liang, Jiang, & Che, 2021). Fluvisols (IUSS Working Group WRB, 2015) are soils characterized by high fertility due to their location, formation and development near the rivers. Fluvisols are azonal soils, whose development and quality are closely related to the surrounding geospatial variations and character of rivers. The priority aspect would probably be its production ability paying attention to the specific ecosystem services as well as the so-called non-productive functions such as the ability to retain water but also trace or deleterious elements.

Alluvial deposits are rich in nutrients and nearby water can be used for irrigation of the flat terrain. Therefore, fluvial origin soils are highly attractive for human settlement and development, as have been historically proven in the Mediterranean (Butzer, 2005; Ruiz & Sanz-Sánchez, 2020), and also in other regions of the world such as China (Li et al., 2020; Qiu et al., 2020; Wang, Luo, Jia, & Zheng, 2018). This is also the case for the Egyptian civilization in the Nile valley (Mays, 2010; Trigger, Kemp, O'Connor, & Lloyd, 1983), Euphrates and Tigris (Altinbilek, 2004; Morozova, 2005) and the Phoenician within the Iberian Peninsula (Bierling & Gitin, 2002; Neville, 2007). Nowadays, the alluvial plains are used for crops despite that the areas are periodically flooded and require drainage for a few weeks to prevent the redox potential from being lowered and also the loss of available nutrients (Evans & Fausey, 1999; Ramasamy, ten Berge, & Purushothaman, 1997). On the other hand, fluvisols close to the coast have problems with agricultural exploitation because of the high salt content that require the use of containers and generators of ecological biodiversity to recover them (Mathew, Panda, & Nair, 2001). However, urbanization, arboriculture and intensification of agriculture have degraded the original fluvial ecosystems to the extreme. In some cases, fluvisols originate from unconsolidated and translocated soils affected by, for example, karstic lithology or characterized by a sandy texture (Soil Survey Staff, 2014). Fluvial soil subtypes could be characterized by coarse texture characteristics which render them a high permeability but a low storage capacity for water and nutrients. They facilitate tilling and rooting crops (Haghverdi, Leib, Washington-Allen, Ayers, & Buschermohle, 2015; Van Noordwijk & Purnomosidhi, 1995). As a solution, drip irrigation or small jets (plus the application of fertilizers) are considered (, 2006; IUSS Working Group WRB, 2007). However, land degradation processes (soil erosion, soil compaction, soil sealing, soil salinization and soil pollution) are triggering this vital relationship between rivers and soils. Land degradation should be considered one of the biggest concerns of humankind and the use of accurate regional analysis at large scales and long-term periods for better understanding must be necessary (Bajocco, De Angelis, Perini, Ferrara, & Salvati, 2012; Karamesouti et al., 2015; Salvati & Carlucci, 2015).

Land degradation directly reveals the deterioration of the soil ecosystem functionality and global security, thus compromising human health and biodiversity (Coelho et al., 2004). In fluvial ecosystems, one of the main contrasted causes is the overexploitation or mismanagement of the soil-water resources, which generate a loss of ecosystem productivity, deteriorate vegetation composition and default rural livelihoods (Barakat, Mahfoud, & Kwyes, 2014; Borrelli, Märker, Panagos, & Schütt, 2014; Rivera-Ferre et al., 2016). The United Nations published the Sustainable Development Goals (2015), which highlight the relevance of "the blueprint to achieve a better and more sustainable future for all." In this document, one of the global challenges to be faced includes environmental degradation in natural ecosystems, where rivers play a key role and should be conserved (Giupponi & Gain, 2017; Xu et al., 2019).

In fluvial areas, there is consensus on the effects of future climate in soil systems that are characterized as (1) higher temperatures, (2) an increase in the degree of aridity and (3) shifts in the seasonal rainfall regimes and the higher frequency of extreme events (Akter, Quevauviller, Eisenreich, & Vaes, 2018; Guo et al., 2019). These changes could affect the volume, frequency, intensity and timing of precipitation events, which largely determine the structure and functioning of Mediterranean fluvial soil ecosystems (Galia et al., 2020; Lozanovska, Rivaes, Vieira, Ferreira, & Aguiar, 2020; Martínez-Fernández, Oorschot, Smit, del Tánago, & Buijse, 2018). To unravel this complexity, it is recommendable to focus on the understanding of how biotic attributes interact with abiotic factors to ultimately drive fluvial ecosystem functioning and its soils. In the near future, a decrease in organic inputs into the soil by decreased litter cover is expected in dryland ecosystems (Brooker et al., 2008; Bullard & McTainsh, 2003; Galia et al., 2020; Maestre & Cortina, 2004). As a consequence of human activities (agriculture, urbanization, grazing and mining), soil organic carbon contents in fluvial soils would decrease, generating a reduction of soil stability and size of the aggregates, affecting fertility and biodiversity (Pulido-Fernández, Schnabel, Lavado-Contador, Miralles Mellado, & Ortega Pérez, 2013). In the long-term, these soils could experience a lower water holding capacity, lower permeability and higher probability of crust formation, with the resulting dramatic decrease in infiltration rates (Fick, Belnap, & Duniway, 2020; Li, Li, Huang, Wang, & Zhang, 2019; Rosentreter & Root, 2019). Due to the absence of available water in the soil profile, vegetation will not be able to re-establish resulting in high rates of overland flow and sediment yield (Manning, Julian, & Doyle, 2020; Wang et al., 2019). Consequently, the seed bank and nutrients contents will diminish, and a cycle of decreasing soil biodiversity and increasing land degradation will continue unabated.

Attention at the regional scale should be urgently paid to correctly manage the most vulnerable fluvial environments with the independence of the specific land uses, although agricultural ones are supposed to be especially relevant. Some representative studies can be found at the national scale, for example, in Slovakia where different soil properties are assessed and mapped following the results of a soil quality index (Koco, Vilček, Torma, Michaeli, & Solár, 2020; Vilček & Koco, 2018; Vilček, Koco, Litavcová, & Torma, 2020). Nowadays, the whole of the Mediterranean region is experiencing these degradation cycle such as has been demonstrated for natural, cultivated, abandoned and wooded areas, or burned territories (Abu Hammad & Tumeizi, 2012; Arnaez, Lasanta, Errea, & Ortigosa, 2011; Panagos, Meusburger, Ballabio, Borrelli, & Alewell, 2014). Therefore, working with geographical information data sources is fundamental for a correct and efficient land management design. For larger scales, knowledge of several variables related to climate, soil properties, landforms, hydrological processes and human interventions is essential, but could be cost-prohibitive for developing economies, and also time-consuming.

The main aim of this research is to apply different mapping techniques and a soil quality index to understand the status of fluvisols (IUSS Working Group WRB, 2015) in the province of Málaga (Southern Spain) within the Mediterranean. Fluvial soils within the study area were assessed using fieldwork, soil mapping resources and soil profiles with specific information on soil physicochemical properties and different environmental conditions. The characterization from a regional scale will shed light on a holistic perspective about the current status of fluvial soils and possible evolution due to human impacts. These kinds of regional studies are limited in the literature due to the large datasets required (Kosmas et al., 2014; Ruiz-Sinoga & Diaz, 2010).

2 | MATERIALS AND METHODS

2.1 | Study area

Málaga province is located in Southern Spain within the Mediterranean belt with numerous rivers (Figure 1). This territory has an average altitude of 560 m above sea level (asl). Starting from the south, altitude does not exceed 200 m along the coastline. The Betic paroxysm has led to a great variety of individualized mountain groups that reach average altitudes between 500 and 900 m (Montes de Málaga). From the easternmost end, mountainous territories such as the Sierra de Líbar, Bermeja or de las Nieves, or in the central area with El Torcal or eastern with Sierras de Tejeda and Almijara, exceed 1,000 m asl. Finally, from the north, between altitudes of 300 to 700 m asl, the plateaus of Ronda and Antequera carved by the meadows of the riverbeds, descend from the neighboring mountains. The mean hillslope inclination of the whole province reaches 15.9%. The geology of the province is characterized by materials from all eras. The Precambrian base forms the central nucleus on which the different reliefs are arranged, represented by rocks such as slate, schists or phyllites. Mesozoic materials are distributed throughout the central strip of the province from all periods (Triassic, Jurassic and Cretaceous) with rocks such as limestone, dolomites and marls. Concerning the Tertiary or Cenozoic era (where almost all periods are represented), clays, marls, calcarenites, sands and limestones (less resistant and crumbly) can be found. The quaternary materials are disposed of along the meadows and river valleys, both in inland and coastal areas. Thus, sands, silts, gravels or clays accumulated in the Pleistocene and Holocene have arisen to landscapes that contrast with the more mountainous ones.

The climate is typically Mediterranean type, classified as Csa (Peel, Finlayson, & McMahon, 2007). It is characterized by dry summers and wet autumns, which are concentrated in a few extreme precipitation events. The mean average temperature is close to 17.5°C and the annual ETP (evapotranspiration values) is higher than 700 mm (Rodrigo-Comino, 2014). Soil moisture regime ranges from xeric to aridic most of the year along the coasts and plains, but in some mountainous areas on the West part can reach the ustic regime (Soil Survey Staff, 2014). The main vegetation patterns are typical Mediterranean scrubs, afforested pines plantations mixed with a wide diversity of oaks, cork trees, chestnuts, walnuts and poplars among others.

2.2 | Fluvial soils: Fluvisols (IUSS-WRB, 2015)

In this research, special attention is given to fluvisol types with origin on river deposits and conditioned by their spatiotemporal evolution, but also by human activities (Figure 2). Fluvisols are typically fluvial soils and this term comes from the Latin word *fluvius* (river). In other soil classifications, these soils correspond to alluvials (Russia),

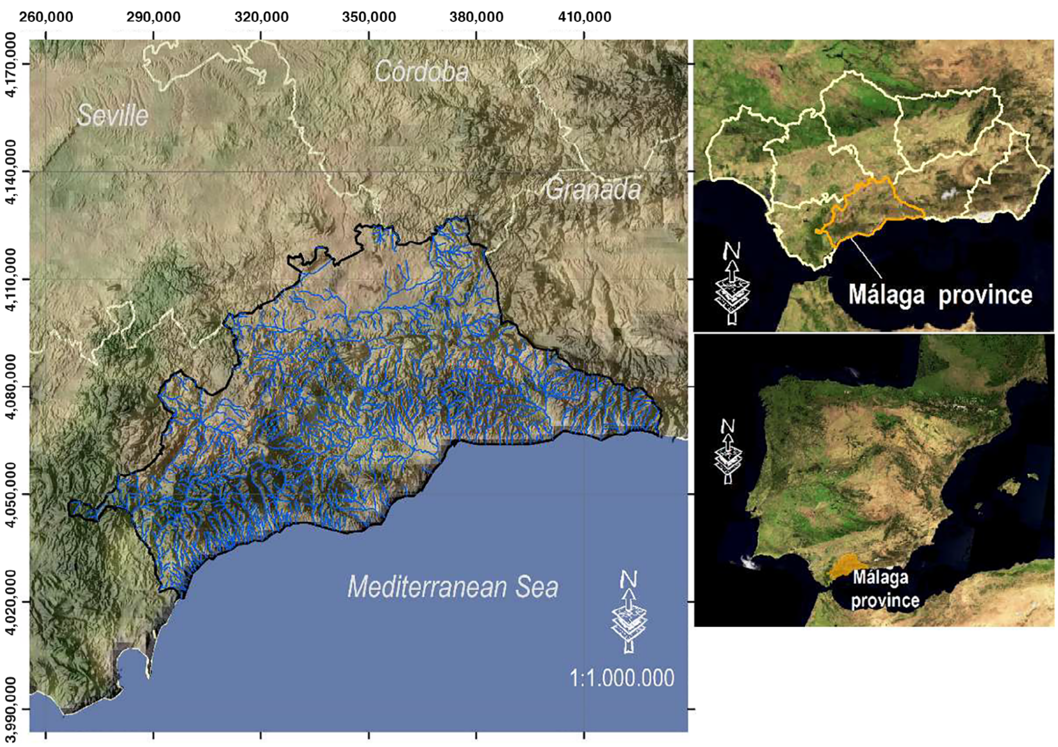

FIGURE 1 Location of the Málaga province and the main fluvial courses [Color figure can be viewed at wileyonlinelibrary.com]

neossolos (Brazil), fluvents or fluvaquents (USDA). They are characterized by a clear azonality and are genetically considered young soils. Fluvisols are commonly associated with alluvial deposits, although they can also be related to the lake and marine sediments. They can be located on alluvial plains, river fans and valleys, coastal marshes or periodically flooded coastal areas. They could be more abundant due to the elevated number of river beds. However, increased urbanization and agrarian processes have reduced their extension. Fluvisols register an evident stratification and weak differentiation among horizons of the epipedion, although the superficial ones can be distinguished by organic matter (OM) content. They have redoximorphic features which are more prevalent in the lower parts.

2.3 | Methodological steps and soil data sources

Figure 3 shows a flowchart of the methodological steps. After the United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification in 1994, the Spanish government established the LUCDEME project ("Lucha contra la Desertificación en el Mediterráneo"—desertification control program; https://www.mapa.gob.es/es/desarrollo-rural/temas/politica-forestal/desertificacion-restauracion-forestal/lucha-contra-la-desertificacion/lch_lucdeme.aspx) that aimed to (1) assess natural resources and factors that play a key role in the desertification processes such as soil types, zoology, water erosion, aeolian erosion, vegetation cover,

FIGURE 2 Examples of fluvisols in the delta del Vélez (first and second photo) and Guadalhorce River (third photo) in the Málaga province [Color figure can be viewed at wileyonlinelibrary.com]

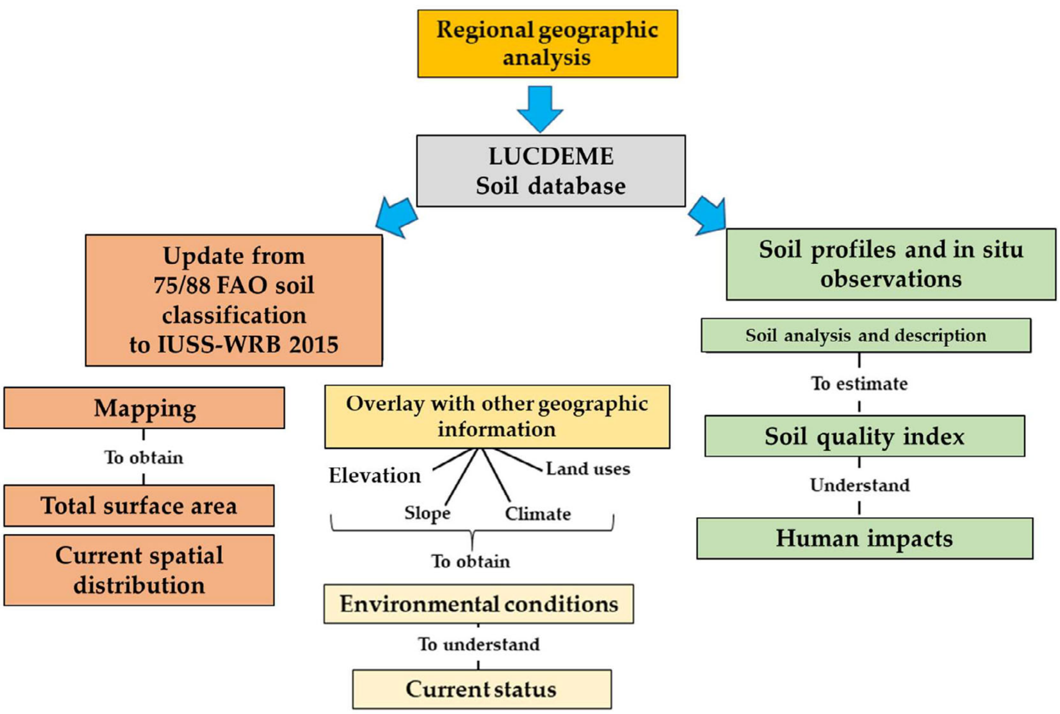

FIGURE 3 Flowchart describing the steps of the methodology [Color figure can be viewed at wileyonlinelibrary.com]

geomorphology, hydrology, desertification, water quality, land management, climate conditions, livestock, human impacts or agrarian soil capacity; (2) determine possible methods for sustainable management systems; and (3) promote the specialization of new experts to be able to face the new challenges. LUCDEME project evaluated more than 30,000 km^2 and made 1,300 soil profile descriptions including territories of Málaga, Granada, Almería and Murcia provinces (Southern Spain). The database was established in polygon shapefile format following the oldest FAO soil classifications dated in 1975 and 1988. Also, only the first three columns in the attribute table that correspond to the main soil associations could be used. The main reason is the overlapping data in the same map, subsequently, losing information. A list of qualifiers that appear on the map does not reflect any type of land and are more typical of a land-use map. Therefore, it was necessary to correct the nomenclatures using ArcMap 10.5 (ESRI, USA), manually. Moreover, all the soil types were updated to the most recent soil classification developed by IUSS-WRB in 2015 (IUSS Working Group WRB, 2015).

A total of 72 soil profiles were included in our analysis containing some physicochemical properties such as soil texture, OM, N, C/N, $CaCO_3$, available soil water content at 33 and 1,500 kPa, pH, Na, K, Mg, soil cover, stoniness, erodibility, and degree of erosion, and other environmental conditions such as inclination and land use.

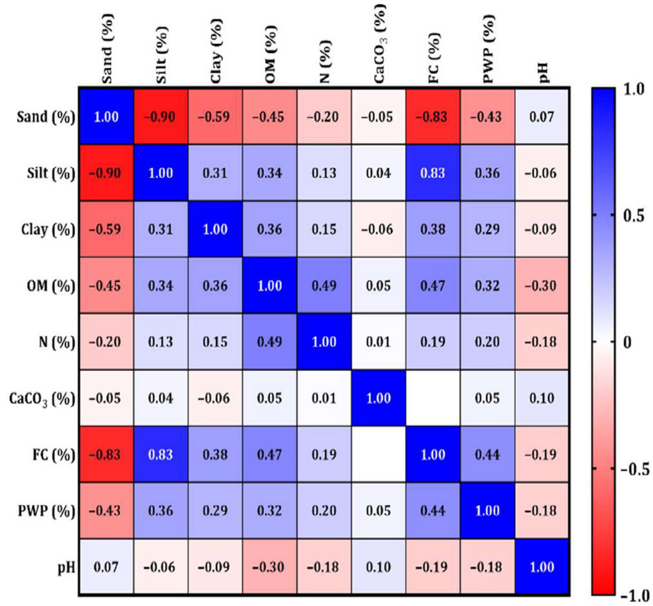

FIGURE 4 Pearson's correlation analysis of selected soil physicochemical parameters for the fluvisols in the Málaga province. Blue color indicates a positive correlation, while red color exhibits a negative correlation at $p < .05$. Blank boxes represent no correlation among parameters [Color figure can be viewed at wileyonlinelibrary.com]

2.4 | Environmental conditions of the fluvial soils

After updating the soil database, altitude, slope, land uses, temperatures, precipitation and ETP maps were generated in order to characterize the environmental conditions where the fluvial soils originated (Figure 4). The Digital Elevation Model was developed from a topographical map of scale 1:10,000. Contour lines of the Andalusian relief were delimited to the Málaga Province. Then, the equidistance between curves was set to 100 m, although an intermediate curve (50 m) is added between the first curve and the coastline to add precision. The information is the result of the selection and generalization of the level curves that appear on the 1:10,000 vectorial Topographic Map of Andalusia, produced by the Andalusian Institute of Cartography (obtained from the spatial information website of the Junta de Andalucía, https://www.juntadeandalucia.es/institutodeestadisticaycartografia/DERA/index.htm). We used the tool *Topo to raster* tool to generate the altitude map. Also, it was possible to create a slope map with the following intervals of 0–3, 3–8, 8–16, 16–21, 21–31, 31–46, 46–76 and 76–100%. Land uses and vegetation data were obtained from the Corine Land Cover program in 2006. Climate maps (temperatures, precipitation and ETP) were generated through ordinary kriging interpolation methods using the altitude as an auxiliary variable and the climatological data obtained from AEMET (State Meteorological Agency) for the stations located in the province of Malaga and some of the adjoining provinces. We coincide with previous research (Azpurua & Ramos, 2010; Gentile, Courbin, & Meylan, 2013; Keblouti, Ouerdachi, & Boutaghane, 2012) that Inverse Distance Weighted (IDW) is intuitive and efficient, being effective with evenly distributed points like the SPLINE functions and sensitive to outliers, considering unevenly distributed data clusters results in introduced errors. Also, the lack of some thermometric stations at points where the relief would alter the distribution of the isotherms could affect the quality of the interpolated data. Therefore, statistical extrapolations using linear estimates and intersections of axes (Rodrigo-Comino, 2013; Senciales González, 1997) were used to generate to complete the series with new points based on the altitude (e.g., Maroma and Navachica, El Chamizo, Sierra Arcas or Los Reales de Estepona, El Viento, Pico de los Enamorados).

All the obtained results were transformed into shapefile format in order to calculate the average values of each environmental factor for the mapped fluvisols. The polygons of the fluvisols were firstly separated from other ones according to the intent of the analysis. The attribute tables were generated using layer merging and crossed operations for the separated fluvisols. "Merging" was finally applied as a process in GIS where input features are joined into a single and new output feature class from multiple input sources (of the same data type and geographical coordinates).

2.5 | Soil quality and key properties explaining fluvial soils at the regional scale

The values of the whole dataset considering the selected soil quality indicators (SQI) were analyzed using the software SPSS 23.0 (IBM, USA). In order to obtain the minimum feasible dataset to calculate a soil quality index, specific parameters based on the main parent materials (limestones and marls), land uses (grazing, rainfed agriculture, fruits and vegetables, forestry, riparian vegetation) (Fernández et al., 2020; Keshavarzi et al., 2020; Pulido, Barrena-González, Badgery, Rodrigo-Comino, & Cerdà, 2018; Rodrigo-Comino, Keshavarzi, Bagherzadeh, & Brevik, 2019) and from the literature (Armenise, Redmile-Gordon, Stellacci, Ciccarese, & Rubino, 2013; Guo, Sun, Ouyang, Han, & Li, 2017; Sun, Zhou, & Zhao, 2003; Triantafyllidis, Kosma, & Patakas, 2018; Yu, Liu, Zhang, Li, & Zhou, 2018) such as soil texture (sand and clay), OM, $CaCO_3$, total N, pH, available water at 33 (field capacity) and 1,500 KPa (wilting point) were selected. After this, a universal soil quality index was designed to establish representative indicators by assigning weights for the selected SQI to allow estimating and interpreting a unique index. Equation (1) developed by Qi et al. (2009) was used to generate the index:

$$\mathrm{IQI} = \sum_{i=1}^{n} W_i . N_i \quad (1)$$

where W_i represents the selected weight, N_i is the indicator score and n represents the number of SQIs selected. In this study, the weight of each characteristic of soil quality was determined by Pearson's correlation analysis. We investigated the correlations among the nine selected soil physicochemical parameters at $p < .05$ for a two-tailed test using R-software v.4.0.3. This analysis was based on 72 complete observations (i.e., cases with non-missing values). Sand, silt, clay and FC were highly correlated with each other (at $p < .05$). Different indicator units were needed to develop a standard scoring function (Andrews et al., 2002; Karlen & Stott, 1994; Mukherjee & Lal, 2014). Since there is no information about the upper and lower thresholds in the specific Fluvisols of Málaga province, the minimum and maximum observational values of the variables in the region were considered as lower and upper thresholds, respectively, as Pulido et al. (2018) carried out for rangelands in SW Spain (Fernández et al., 2020). Weight for each indicator method was assigned by the commonality of each indicator calculated by mathematical statistics of standardized factor analysis (FA) (Shukla, Lal, & Ebinger, 2006; Sun et al., 2003). Table 1 shows the scoring functions, limits (upper and lower ones) of each indicator. Finally, the analytic hierarchy process (AHP) (Saaty, 1990) was needed to establish the hierarchy to those variables. The AHP method was conducted using expert choice software (https://journals.sagepub.com/doi/abs/10.1177/089443939701500209?journalCode=ssce) following the necessary steps highlighted by previous authors (Bagherzadeh, Gholizadeh, & Keshavarzi, 2018; Fernández et al., 2020; Keshavarzi et al., 2020).

3 | RESULTS

3.1 | Localization of fluvisols in the Málaga province

Figure 5 shows the spatial distribution of the soil types found in the Málaga province. There is a significantly different number of soil types that can be found in this territory, highlighting the heterogeneity of the environmental factors that are explained in the following sections. Leptosols and Regosols occupy 2070.3 (33.0%) and 1764.52 km^2 (28.1%), respectively, being the most predominant. These results give us a first territorial diagnosis, which translates into more than 60% of the soil layers in the Malaga province that are characterized by their location in the mountain areas. In comparison, a total of 195.22 km^2 of fluvisols are mapped in Málaga, of which 134.61 km^2 are calcic fluvisols and 60.61 km^2 eutric fluvisols.

3.2 | Environmental conditions associated with fluvisols

Figure 6 shows the spatial thematic maps of the main environmental factors of climate (temperature, precipitation and ETP), topography (altitude and slope) and land uses of the study region. In order to characterize the fluvisols, we summarized the percentage of the total area

TABLE 1 Scoring functions and upper and lower limits for each specific indicator

Scoring function	Upper limit (UL)	Lower limit (LL)	Function[a]	Indicator
$f(x)=\begin{cases}1 & x<L\\ 1-0.9\dfrac{x-L}{U-L} & L\le x\le U\\ 0.1 & x<U\end{cases}$	88.00	0.00	L	$CaCO_3$
	95.58	5.50	L	Sand
$f(x)=\begin{cases}0.1 & x<L\\ 0.9\dfrac{x-L}{U-L} & L\le x\le U\\ 1 & x<U\end{cases}$	9.31	0.45	M	OM
	0.84	0.02	M	N
	44.00	0.50	M	Clay
	49.20	1.00	M	FC
	52.00	0.50	M	PWP
	8.80	5.00	M	pH

Abbreviation: SSF, standard scoring function.
[a]L means "less is better"; M represents "more is better". In the two displayed equations, x is the monitoring value of the indicator, $f(x)$ is the score function of the indicators ranging from 0.1 to 1.0, and LL and UL are the lower and the upper threshold values, respectively.

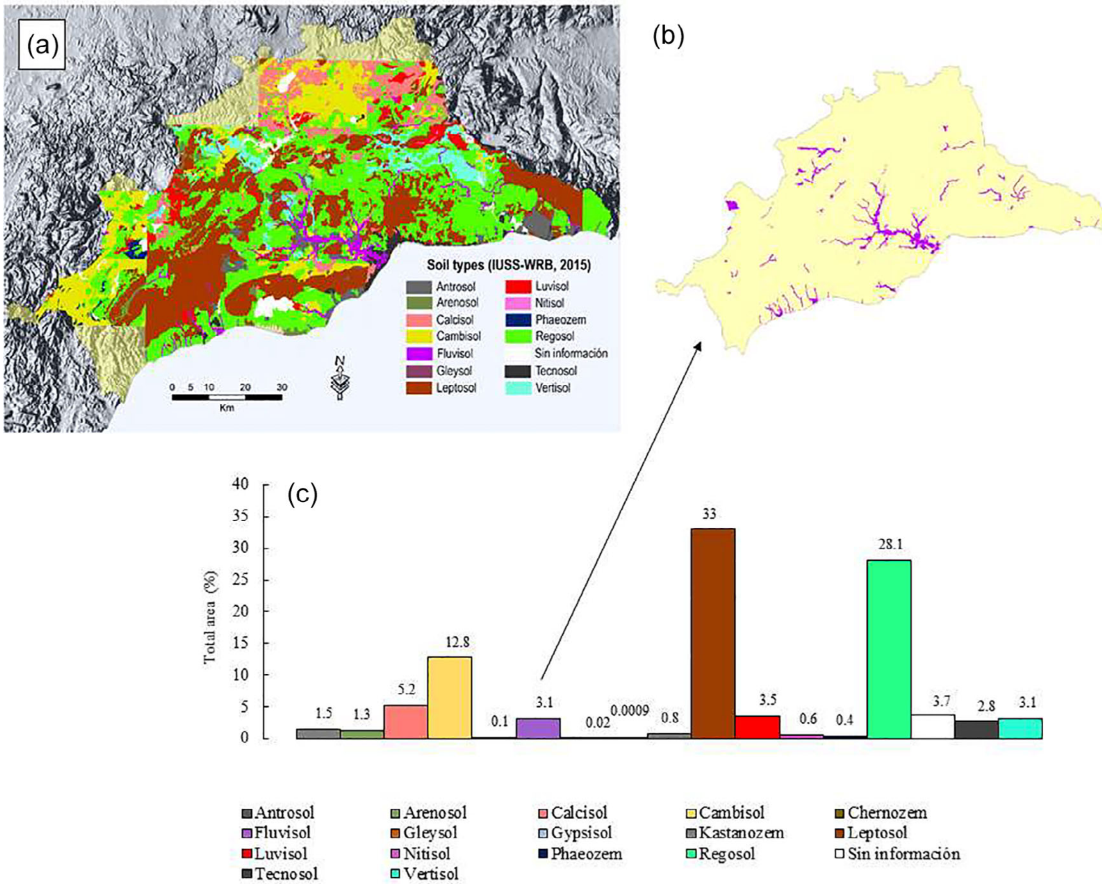

FIGURE 5 Soil types and percent total area found in the Málaga province. (a) Soil types in the Málaga province; (b) Fluvisols in the Málaga province; and, (c) Total area (%) per soil type in the Málaga province [Color figure can be viewed at wileyonlinelibrary.com]

of each environmental condition and presented them in Table 2. Considering the land uses, 29.5 and 23.9% of fluvisols contain scrubs and Mediterranean low forest associations and forests, respectively, which use to be ribera or riparian species. Other natural or semi-natural lands uses of the fluvisols are beaches and sandy areas (1.2%), and rivers, lakes, lagoons and wetlands (2.9%). This means that all of the fluvisols may depend on different rivers to generate new layers or be depleted. On the other hand, a total of 42.5% of the fluvisols are used for human activities such as agriculture relating to rainfed and irrigation fields, or woody crops such as olives or vineyards, mining, industries and services, urban areas or reservoirs.

More than 58% of the fluvisols are located in the warmest areas registering mean annual temperatures from 15°C. On the other hand, fluvial soils are less extended along with the coldest areas which are mountainous. A total of 40.5% of the fluvisols are located in areas with precipitation amount between 500 and 700 mm and 21.8% between 1,000 and 1,100 mm, corresponding to the Southeast part of the province and the occidental one, respectively. Similar trends are observed with the ETP that shows the highest values in the most important extension of fluvisols: 20.9% for 750–800 mm, 21.9% for 900–950 mm and 22.4% for ETP > 950 mm. As expected, the fluvisols are found within the flat areas with lower altitudes (<400 m asl) and gentle slopes (lower than 16%).

3.3 | Soil quality index and relationships among properties

The soil properties used to estimate the soil quality index are depicted in box plots in Figure 7a–f. Fluvisols of the Málaga province are classified as sandy loam as they consist of a maximum sand fraction of 95.3% and a minimum of 5.5%. The clay content is close to 14%, with a maximum value of 44% and a minimum of 0.5%. Related to these values, the FC and permanent wilting point (PWP) reached mean values of 20.6 and 8.8%, respectively. The OM content averages 2.8%, with a maximum of 9.3% and a minimum of 0.4%. With the $CaCO_3$, a maximum value of 88% and a mean value of 16.5%, were registered for the soils.

Figure 7h,g depicts the soil quality index that shows the current status of the 72 sampled soils using the defined score weights. In general, the soil quality index does not yield the best results (1 being the maximum score) for the fluvisols in Malaga. The soil quality index registers a mean value of 0.58, 12 of which fell below 0.5 points.

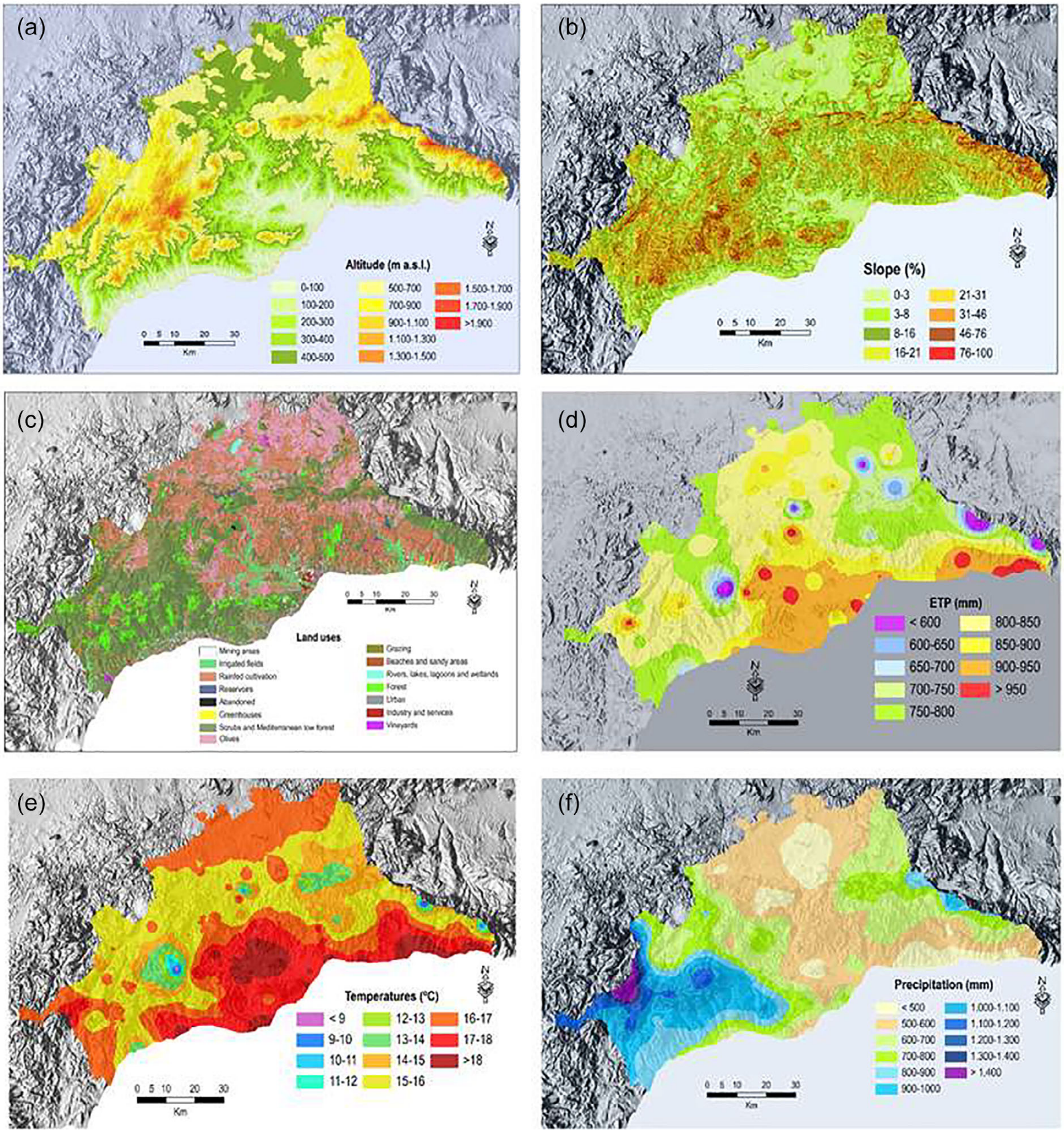

FIGURE 6 Thematic maps used to assess the environmental conditions of the fluvisols in the Málaga province. (a) Soil texture; (b) Soil available water content (FC: Field capacity; PWP: Permanent Wilting Point); (c) Organic matter; (d) Nitrogen; (e) Carbonates; (f) pH [Color figure can be viewed at wileyonlinelibrary.com]

4 | DISCUSSION

Our study shows that the landscape, soils and climate of the Malaga province are highly heterogeneous. It is the situation within the paroxysm of the Baetic System which has an elevated lithological and structural heterogeneity, whose influence on the current landscape connotes difficulties when generating global ideas about this territory. Approximate altitudes of 1,500 m of the mountain ranges and the counterpoint of the coast generate a highly varied topographic and morphological imprint on the rivers, which also acts as an ecological limit, generator of bioclimatic variations, and subsequently, its fluvisols. The human landscape alteration (crops, urban areas, development of tourist activities, construction of infrastructures, etc.) has caused evident modifications of the quality of fluvisols such as nutrient loss, erosion, sealing and so on. This study confirms the necessity to consider the use of the different environmental parameters (climate, topography, land uses, etc.) to allow a complete study of territory at the regional or even national scale (Kosmas et al., 2014). These types of studies from the regional point of view can clearly show the extremely dependence between rivers, soils, but also on humans

TABLE 2 Environmental conditions for fluvisols origination

Landuses	Area (%)	T° (°C)	%	Pp (mm)	%	ETP (mm)	%	Slope (%)	%	Height (m)	%
Mining areas	3.0	13–14	2.0	<500	13.4	<600	–	0–3	16.6	0–100	19.3
Irrigation fields	3.3	14–15	9.9	500–600	14.0	600–650	2.8	3–8	20.5	100–200	35.5
Rainfed cultivation	14.2	15–16	23.0	600–700	13.1	650–700	4.9	8–16	41.8	200–300	2.4
Reservoir	1.6	16–17	6.4	700–800	3.5	700–750	4.8	16–21	18.0	300–400	17.5
Greenhouse	0.2	17–18	21.8	800–900	8.2	750–800	20.9	21–31	3.2	400–500	2.1
Scrubs and Mediterranean low forest	23.9	>18	37.0	900–1,000	3.1	800–850	12.4	31–46		500–700	10.3
Olives	0.2			1,000–1,100	21.8	850–900	9.9	46–76		700–900	7.8
Grazing	8.8			1,200–1,300	5.3	900–950	21.9	>76		900–1,100	5.0
Beach and sandy areas	1.2			1,300–1,400	3.2	>950	22.4			1,100–1,300	
Rivers, lakes, lagoons and wetlands	2.9			1,400–1,500	12.3					1,300–1,500	
Forests	29.5			1,500–1,600	2.0					1,500–1,700	
Urban	9.5			1,600–1,700						1,700–1,900	
Industries and services	0.2			>1,700						>1,900	
Vineyards	1.5										

Abbreviations; ETP, evapotranspiration; Pp, precipitation; T°, temperatures.

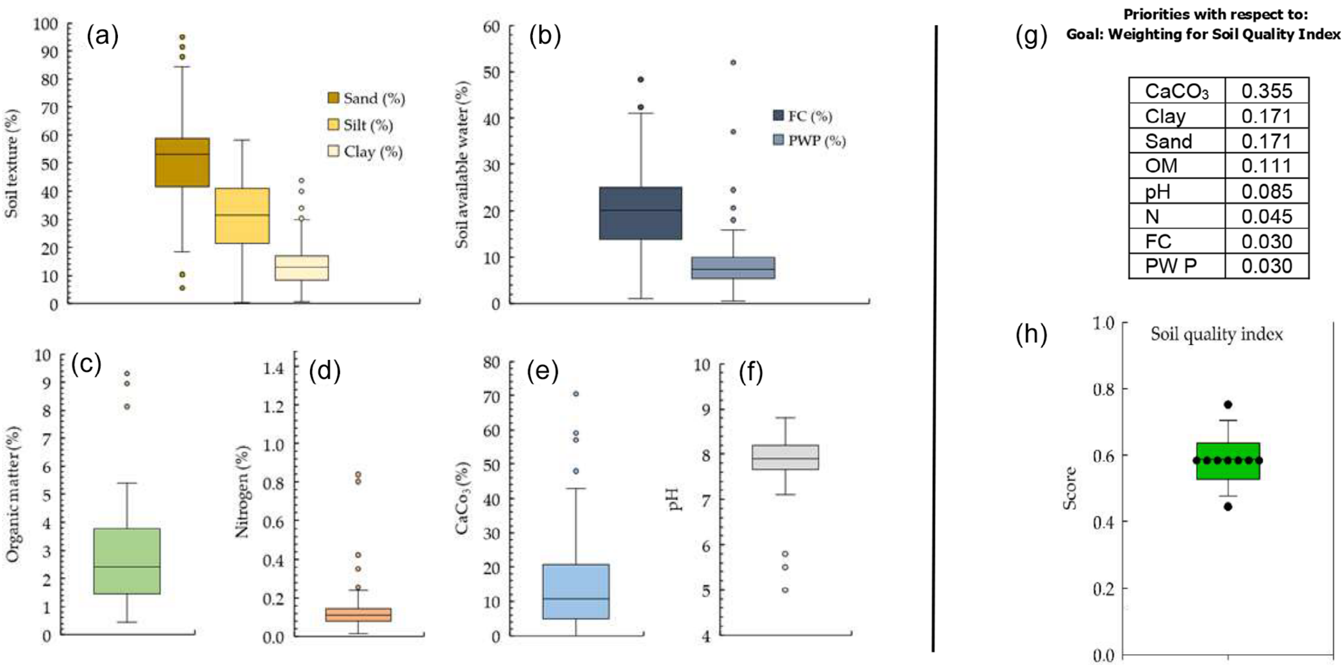

FIGURE 7 Box plots depicting the main soil properties used to estimate the soil quality index of the fluvisols in the Málaga province (a–f) and calculation of soil quality index (g and h) [Color figure can be viewed at wileyonlinelibrary.com]

(Flügel, 1995; Haregeweyn et al., 2017; Hou, O'Connor, Nathanail, Tian, & Ma, 2017; Yu & Jia, 2014). It is also relevant to highlight the importance of finding common sources and methods with other disciplines such as soil geography, soil sciences, biology, biogeography or geomorphology among others, thus adding considerable value to the wealth of the different interdisciplinary studies (Rodrigo-Comino, Senciales, Cerdà, & Brevik, 2018). In geographic science, a change in the scale of work is an indispensable tool to address assignments over large territories, thus helping to extrapolate data from microscales to larger ones (Meentemeyer, 1989; Sayer, 1989; Terlouw, 2001). It should be noted that as we increase the scale, the variety of soil types also increases (Behrens et al., 2005; Grunwald, 2010; Zeraatpisheh et al., 2020). For this reason, a key step was to update and correct the soil classification database.

To study a river ecosystem, there is no other way than to rely on a method that is developed as much as possible. Some authors highlighted the importance of including labels or giving names to soils, to order to transfer knowledge and dwell on the experiences obtained in different studies to other geographical or scientific areas (Baldwin, Kellogg, & Thorp, 1938; Brevik et al., 2016; Fenton, 2006). Our research allows the possibility of differentiating edaphic layers according to established criteria of international relevance, which allow the exchange of information and conclusions between specialists from all over the world (IUSS Working Group WRB, 2007). The realization of soil maps with specific information about fluvisols contributes to the knowledge of the territory. This has an incalculable value for the river ecosystem management and planning tasks (Rodrigo-Comino, Senciales González, & Ferre Bueno, 2014; Vargas, 1988; Vargas & Rodríguez, 2020).

As one of the results, we have calculated the SQI; however, we did not include a map showing the distribution of this index to discuss its variability. Although the number of soil profiles is quite acceptable at this scale, we consider that the elevated variability of the environmental conditions of the Málaga province would not make appropriated to present a map showing the distribution of SQI. In the future, it will be key to increase the number of soil profiles and divide the Málaga province into specific regions to map the spatial variations of soil quality, also, considering other soil types. Finally, in the methodology used there is no parameter included that is related to the river or depositional dynamics delivering the base for the fluvisol formation, which also would give new insights into the complete pedogenesis and evolution processes of fluvisols in the Málaga province.

This research is of a didactic nature (which is not detached from the scientific one) implementing an added value to be used at all academic levels, which is only hampered, sometimes by the complexity of some qualifiers and new changes that are being added in the different revisions. This knowledge requires a continuous "recycling" of the already assimilated content. The latter reason is why many soil studies use outdated taxonomies without caring about updating the methods and sources, to the detriment of soil science. Completely correct and complete research, rather simplistic and from which many descriptive studies of the environment use, should not include the fluvial soils as a mere element of the territory and must show them as vital natural resources conditioned by river evolution and human activities. By analyzing all the aspects that condition the fluvisols in our study area, we have been able to verify the statement that we can understand the distribution and cause of the pedogenesis of the fluvisols through the environmental characteristics of the territory where they are framed and, on the other part, understand the spatial nuances of the province of Malaga due to the study of the combined resources.

These characteristics are expressed in the Malaga province in a heterogeneous way, resulting in 17 types of soils and 45 different subtypes. The two most predominant types of the study area are Leptosols (28.1%) and Regosols (33%). This allows us to conceive a general idea about the state of the soils: 61.1% of the studied soil cover is not potentially suitable due to its pedological characteristics (depth, development, structure, etc.) for agriculture, due to the slope, lithology or hypsometry, which could be potentially exposed to erosion (Ferre Bueno & Senciales González, 1991; Martínez-Murillo & Ruiz-Sinoga, 2007). Alluvial deposits and then, fluvisols are relevant to understand the connectivity of flows from the pedon to the watershed scales. Some recent papers informed about the connectivity of the flows and from this, we can observe the relevance of the fluvisols as tracers of sediment and water, and as a key information to determine the risk in different parts of the basin (Fuller & Death, 2018; Keesstra et al., 2018; Lehotský, Rusnák, Kidová, & Dudžák, 2018).

Therefore, soils such as fluvisols are extensively used and not only conditioned by river evolution. Humans, traditionally, have managed to eliminate this obstacle by adapting fluvial soils with terracing and canalization techniques or extensive rain-fed crops (Arnáez, Lana-Renault, Lasanta, Ruiz-Flaño, & Castroviejo, 2015; Chen, Wei, & Chen, 2017; Gallart, Llorens, & Latron, 1994). However, this problem is favoring the desertification of the fluvisols as we confirm with our soil quality index and by other authors in other areas over the world (Bongiorno et al., 2019; Wu, Liu, Huang, & Liu, 2019). As we increase the scale at the inclusion level, the number of soil types will increase with other taxa such as gypsisols, gleysols or kastanozems (with a lower representation on the map than it should be in reality), also associated with river evolution and its influence. However, we consider that this exhaustive information should be considered in other future research, for example, combined with the aspect map. Also, it is important to remark the importance that anthrosols and technosols should have in the province, which might have been fluvisols in the past (Blume & Leinweber, 2004; Lima, Schaefer, Mello, Gilkes, & Ker, 2002; Woodson, Sandor, Strawhacker, & Miles, 2015). This is due, as we have already argued, to the rapid and intense growth of the urbanization process closed to the rivers (Kalantari, Ferreira, Walsh, Ferreira, & Destouni, 2017) and the modifications on the edaphic mantle by agriculture through soil erosion processes by intense tillage, water utilization or climate change (Novara et al., 2020; Rodrigo-Comino et al., 2021; Taguas, Guzmán, Guzmán, Vanwalleghem, & Gómez, 2015). In addition, more than 58% of the fluvisols are located in the warmest and driest areas. This also could aggravate the reduction of the soil quality and biodiversity of fluvisols, as other authors mentioned in the past, considering aridity as a key factor of desertification (Amit, Enzel, & Sharon, 2006; Colantoni, Ferrara, Perini, & Salvati, 2015; Cook, Woodhouse, Eakin, Meko, & Stahle, 2004). Therefore, stakeholders, land managers and policymakers should consider the application of conservation measures, nature-based solutions or remediation techniques (Keesstra et al., 2018; Khan, Husain, & Hejazi, 2004; Nesshöver et al., 2017; Yu et al., 2017) and not to lose a key source of information for human development in rural areas but also for natural ecosystems close to the rivers.

5 | CONCLUSIONS

This research validates the necessity to establish the use of the different environmental parameters (climate, topography, land uses, etc.)

and techniques (available data sources, mapping and modeling approaches, and in situ observations) to holistically conduct a regional analysis at any scale focusing on rivers and associated soils. Considering the land uses, 29.5% and 23.9% of fluvisols contain scrubs and Mediterranean low forest associations and forests, respectively. Other fluvisols are situated along beaches and sandy areas (1.2%), and rivers, lakes, lagoons and wetlands (2.9%). This means that all of the fluvisols are conditioned by different rivers to generate new layers or be depleted. A total of 42.5% of the fluvisols are used for human activities such as agriculture relating to rainfed and irrigation fields, or woody crops such as olives or vineyards, mining, industries and services, urban areas or reservoirs. More than 58% of the fluvisols are located in the warmest areas registering mean annual temperature from 15 to 17 and >18°C and 40.5% in areas with precipitation values between 500 and 700 mm, corresponding to the southeast part of the province. Similar trends are observed with the ETP that shows the highest values in the most important extension of fluvisols. Moreover, the use of SQI demonstrated that the current status of the 72 sampled soils does not yield the best results, averaging a mean value of 0.58, 12 of which fell below 0.5 points. We conclude that the fluvial soils of the Málaga province are key sources for human activities and natural ecosystems. However, they are overexploited and, subsequently, degraded. Therefore, stakeholders, land managers and policymakers have to correctly find solutions to conserve them or this province will lose a vital source of goods and services for humans and natural ecosystems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors

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