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ORIGINAL ARTICLE

Distribution of quarries in the piedmont region: the regional plan of mining activities (PRAE) as a tool for mining activities regulation and characterisation

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Abstract

The Regional Plan of Mining Activities (PRAE), adopted in December 2022, represents the strategic regulation instrument pursuing the balance between environmental sustainability and economic development produced by mining activity at a regional scale. The paper proposes an overview of the main regional in-force instrument for surface and ground-water planning and management (PAI and PTA) and how these intersect with the introduced PRAE. Besides, the interaction between mining activities and the geomorphological and hydrogeological contexts in which they are located is described, defining the resulting constraints regarding their interaction with extraction areas. A significant portion of the quarries are located in the floodplain, falling both in river bands of medium–high probability of flooding and in areas involving aquifers bodies, hence these extractive sites are heavily restricted both in terms of excavation depths, never exceeding the base of the surface aquifer. The depth of the water table and the base of the aquifer represent the two fundamental parameters on which new restrictions have been defined in the PRAE in terms of the possibility of developing new quarry areas.

Keywords Piedmont region · Mining activities · Planning · Environmental recovery

Introduction

The mining industry has supplied raw materials essential for industrialized countries' economies, providing the foundation for modern life, civil innovations, and new engineering constructions. At the same time, extraction activities have represented one of the main sources of human impact on the environment and ecosystem components, both during their life cycle and after their closure (Higueras et al. 2016; Mehta et al. 2018; Boldy et al. 2021; Assumma et al. 2022). Historically, the extraction of materials took place without adequate planning criteria, neglecting that many of the alterations produced could have had negative impacts on the environment, including permanent ones. The continuous absence of standards for safeguarding and restoring the environment associated with the mining activities can therefore have significant impacts on the territory: excavation operations cause a morphological alteration of the places and some elements of the ecosystem concerned. In addition, river networks and aquifers are very sensitive to interaction with quarries, mining processes, and the type of materials involved. For this reason, protecting the systems from a geological and hydrogeological point of view remains a significant challenge that mining activities' planning and policy tools are facing (Pardo Abad 2019; Salom and Kivinen 2020).

Italian legislation in the field still dates back to Royal Decree 1443/1927 (Regio Decreto, 1927), which distinguishes, based on the extracted material, the extractive industries of the first category (mines) and second category (quarries and peat bogs). In compliance with the constitutional requirements, the competencies relating to the extraction of non-energy minerals have been transferred, at different times, to the regions (quarries: D.P.R. 24 July 1977 n.616; mines: D.lgs. 31 March 1998 n. 112 and D.lgs. 22 June 2012 n. 83). Since the 60 s and 70 s, together with the increased interest about the environment's protection, the concept of preserving the quality of the natural heritage has increasingly developed. Regional authorities have initiated

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the promotion of effective planning approaches for the utilization of natural resources. These strategies aim to balance environmental preservation and optimal opportunities for socio-economic advancement derived from raw material exploitation. The imperative to harmonize environmental conservation with the socio-economic requirements of raw material production underscores the essential public interest, thereby warranting these regional planning strategies. Considering the described context, the Piedmont Regional Plan of Extractive Activities (PRAE) configured itself as a guidance instrument, aiming at regulating the exploitation of mineral materials and their present and future mining activity, in the framework of the sustainable development and circular economy European policies. PRAE has been adopted in December 2022 by the Regional Council with D.G.R. n. 81–6285 of 16 December 2022, after its introduction on the Regional Law of Piedmont n. 23/2016 "Disciplina delle attività estrattive: disposizioni in materia di cave" (Legge Regionale, 2016). The above-mentioned Regional Law n. 23/2016 has the objective of reorganizing and expanding the discipline on the subject of extractive activities which allows for the development of quarry cultivation in harmony with respect for the environment. It takes into account the basin planning and the Hydrogeological Plan (Piano per l'Assetto idrogeologico 2023) directives of Po River, according to the Legislative Decree 152/2006 (Decreto Legislativo, 2006).

PRAE consists of a General Plan Report (Relazione Generale di Piano), the Technical Implementation Standards (Norme Tecniche di Attuazione), the Environmental Report for the VAS (Valutazione Ambientale Strategica), including the Ecological Impact Assessment and the Monitoring Plan, and the non-technical summary. The available documents are completed by the Extractive Basin files, the Extractive Poles files, and the active quarry records that do not constitute an extraction pole and the cartography. While a basin is defined as a portion of regional territory in which the presence of a specific cultivable geo-mineral resource is ascertained and which may be affected by extractive activities, a polo is a portion of territory within a basin, on which adequate mineral resources have been identified and the continuation and/or expansion of existing activities or the establishment of new activities is foreseeable.

Regarding groundwater protection, the PRAE is supplemented by the Water Protection Plan (Piano Tutela Acque–PTA 2023), aiming at individuating boundaries and recharging areas of aquifers exploited for human consumption. Specifically, the PRAE is structured according to three mining compartments, their characteristics, and fields of application: (a) aggregates for construction and infrastructures are common mineral resources (e.g., gravel, sand, or concrete); (b) industrial materials are included in a broad category of minerals employed for various industrial purposes (e.g., gypsum or bricks); (c) ornamental stones are valuable natural resources that are usually employed to realize and/or recover the historical-artistic architectural heritage (e.g., gneiss or quartzites). Methodologically, the PRAE composition has been based on a detailed definition of the characteristics of the sector and an assessment of the technical, economic, social, and environmental aspects that have already been identified as a fundamental instrument of governance of the sector in the current regional legislation.

This proposed paper aims to present and address the potential of PRAE as a tool in force within the Piedmont Region (Northern Italy) for the correct planning and management of the extraction quarry areas. First, an overview of the main instrument of surface and ground-water planning and management (i.e., Hydrogeological Plan (PAI), PTA) is provided. Second, simplified extraction site distributions, at a regional scale, are proposed by considering, respectively, the geomorphological and hydrogeological contexts.

The potential of the PRAE instrument for regulating extraction areas and achieving a better level of environmental sustainability is presented.

To realistically evaluate how much and depending on which processes associated with extractive activities can constitute an element of attention and disturbance for the surface and underground water bodies, it is necessary to know, first of all, their hydrological and hydrogeological characteristics, not only in restricted areas in which the quarry operates but also in a large part of the surrounding territory. In particular, the relationship between the extractive activity and the surrounding environment appears decidedly delicate when part of it is represented by a body of surface, also and above all concerning its morphodynamic evolutions. The plano-altimetric evolutions of the surface water bodies, the relationship between them and the underground water bodies, as well as the hydrological regimes in normal periods, lean periods, or intense rainfall, must therefore be taken into due consideration when an extractive activity is planned. These considerations are important not only to guarantee correct interference between extractive activities and the evolution of water bodies but also to simplify any friction that often arises during the delicate relationships established between the activities themselves and the population that lives in the places near the mining activity.

Material and methods

Extraction activities: the regulatory framework of the Piedmont Region

Evaluating how much and according to which processes mining activities can represent a danger of pollution for surface water bodies and groundwater is increasingly necessary. A proper analysis of the morphological, geological, and hydrogeological aspects is requested, not only for the restricted area in which the quarry is located but also for the surrounding territory, to have a complete view of the characteristics of the area affected by the activity. Specific regional regulatory tools support the decision-making process, providing methodological approaches to be followed for a correct context analysis. To date, the main regulatory instruments in force are represented by PAI and PTA. Therefore, PRAE integrates with the complex planning framework at the regional level, representing a useful guiding tool for consultation and the definition of different scenarios.

The Hydrogeological Plan (PAI) is adopted and approved by law 183/1989 (Legge 1989) to ensure soil defense. PAI aims to guarantee an adequate level of safety concerning hydraulic and hydrogeological disruption phenomena through the implementation of different interventions. This action was realized with the enactment of law 37/1994 (Legge 1994) which modifies relevant aspects of the management of the river state property. As a planning tool, the PAI defines river bands according to the associated flood probability. Three areas are thus identified: A consists of the portion of the riverbed that is the predominant location, for the reference flood, of runoff; B is the portion of the riverbed affected by flooding when the event occurs and C may be inundated in cases of rare but catastrophic flood events. Since bands A and B, with high and medium flood hazards respectively, are the most potentially affected areas, the compatibility of mining activities in such areas with the river system is regulated in the PRAE. Based on these assumptions, the objectives of the PAI and PRAE are explained in the rules on the intervention planning in terms of compatibility with the hydrographical setting and recovery of the sites. This concept is particularly reinforced in Art. 22 contained in Title I, Part III of the PAI Implementation Standards (Norme di attuazione). According to what is stated in the art. 41, Title II, Part II of the PAI Implementation Standards, in the territories of A and B river bands, mining activities are allowed if they are identified within the framework of sector plans. However, the areas of the river state property are excluded from the possibility of extractive activities. The planning of mining activities is supported by an environmental compatibility analysis and a giamentological analysis, from which it is deduced that there are no possible less impactful alternatives for finding similar materials outside the A and B bands (art.29 NTA). Since the objective of the PAI is to ensure the conditions of safety by guaranteeing the natural flood runoff and the maintenance of the dynamic equilibrium conditions of the riverbed, the mining poles must be located at a predefined distance from the river to avoid instability mechanisms in the morphological and hydraulic setting. For achieving this goal, in the fluvial areas affected by high hydraulic criticality, extractive activities are severely limited both planimetrically and in terms of excavation depth. The extractive activity must include a structural intervention aimed at securing and assessing the specific risk and residual risk at the end of the intervention (art.9 PAI Implementation Standards). In addition, appropriate monitoring activities are planned to report any quarry interactions on the riverbed dynamics, such as specific phenomena possibly related to the occurrence of floods.

In coherence with articles 14 and 36 (Implementation Standards), the PAI promotes maintenance of the fluvial territory and defense works for protecting the natural characteristics of the river bed, safeguarding ecosystems, and ensuring a good condition of the hydrographic network, preventing slope instability phenomena.

Other legislation supporting the PRAE is the PTA (DCR., 2007), the regional planning document that pursues the protection and enhancement of rivers, lake and groundwater in the territory for the full achievement of the environmental objectives of the Water Framework Directive 2000/60/EC (Direttiva Quadro sulle Acque, 2000). In the planning of mining activities, the PTA is fundamental for the detection of groundwater recharge areas, where vertical downward components of groundwater flow prevail in the saturated zone, defining constraints to reduce the negative impacts of mining activities on their quality and preventing the mixing, as a result of excavation activities, of surface groundwater with deep groundwater suitable for hydropotable consumption. In compliance with the regulations, the hydrogeological study of the subsoil is required to delineate protection areas, specifying which regions are subjected to constraints, flow rates to be discharged, and the timeframe for implementing the interventions (PTA Plan Standards, art.19 2021). The construction of a conceptual hydrogeological model is based on two parameters that condition the planning of mining activity, depth to groundwater and the measure of deep aquifer base. This model should allow identifying the possible interactions between quarrying operations and groundwater bodies to better safeguard water resources, thus the construction of works and execution of activities that cause interaction between the groundwater table and the underlying deep water bodies is prohibited (PTA Plan Standards, art.32 2021).

Extraction activities: available data collection

Details regarding the operational quarries within the Piedmont Region can be accessed through the Piedmont Region website. This information is compiled in lists that are regularly updated by the respective provinces, with the latest data available up to December 31, 2022. These lists categorize mining sites based on their geographical coordinates, the materials being extracted, the type of compartment, and the responsible enterprise. According to the documented information, as of the conclusion of 2022, there were a total of 270 active quarries in Piedmont. Notably, nearly half of these quarries are situated in the provinces of Cuneo and Torino. Table 1 illustrates the provinces in descending order based on the number of active quarries present in each. Updated information useful for georeferencing basins and poles is not still available. The relevant data is provided in tabular and textual form. The proposed extraction site distributions depend on the type of data available for use as of December 31, 2022.

A regional geomorphological, geological, and hydrogeological context description was proposed below. Thus, by considering the above-defined regional contexts, a simplified extraction site spatial distribution analysis has been carried out.

The piedmont region: geomorphological setting

The Piedmont Region is characterised by an extremely varied morphological structure, with the presence of different orographical contexts. It includes mountainous areas belonging to both the Alpine and Apennine chains, subalpine sectors with the presence of extensive alluvial and fluvioglacial conoids at the main valley outlets, isolated hilly sectors (Turin-Monferrato hills) and adjacent to mountainous ranges (Langhe, moraine systems) and an extensive alluvial plain, that represents the western end of the Padana plain. This articulated morphological configuration corresponds to a complex geologic and tectonic context, with a large variety of structural and lithological features (Dal Piaz et al., 2003; Compagnoni et al. 2010; Beltrando et al. 2010; Molli et al. 2010; Maino et al. 2013; Piana et al. 2017).

The most updated cartographic document for the characterization of the geology of the Piedmont Region is represented by the Geological Map of Piedmont at the 1:250.000 scale, proposed by Piana et al. 2017. Considering the historical development of the Alpine-Apennine system in the Piedmont Region, different units can be categorized based on their primary paleogeographic or genetic contexts. These include the Paleo-European continental margin, Paleo-Adriatic continental margin, Ligurian-Piedmontese oceanic domain, Valais oceanic domain, Synorogenic basins of the Cenozoic and Quaternary, as well as Alpine syn-orogenetic magmatic bodies, as illustrated in Fig. 1. Regardless of the specific domain they are associated with, the rocks constituting the substrate of the succession deposited in the Quaternary can be appropriately distinguished into igneous, metamorphic, and sedimentary rocks (Barale et al. 2022).

Table 1 Number of active quarries in each province (31 December 2022–Regione Piemonte website)

Province	Aggregates	Ornamental stones	Industrial minerals	Active quarries
Cuneo	34	36	16	86
Torino	38	27	4	69
Verbania	1	27	6	34
Alessandria	26	–	1	27
Novara	16	1	3	20
Vercelli	8	1	7	16
Biella	6	–	4	10
Asti	4	–	4	8

Disregarding their detailed geographic distribution, igneous rocks are represented by acid volcanic rocks (volcanic and volcaniclastic successions) and acidic plutonic rocks represented mainly by granitic rocks; granitic magmatic bodies among the orogenic intrusions of the Oligocene (Biella, Traversella and Miagliano plutons); basic volcanic rocks are made up of andesites and pyroclastic rocks of Oligocene age. In addition, basic plutonic rocks including masses of gabbro, gabbronorite, amphibolite gabbro, diorite, and tonalite of the Mafic Complex of the Ivrea-Verbano area, and gabbros with doleritic dykes of the oceanic unit.

Among the metamorphic rocks, it is possible to recognize phyllites and slates from the Lower Cretaceous; calceschists and calcemicaschists of the Cretaceous, locally containing bodies of paragneiss, marble, carbonate breccia and oficarbonate, pertaining to the Ligurian, Piedmontese and Vallesano oceanic domain. From Jurassic-Cretaceous age, alternations of calcareous schists, quartz-mica schists and phyllites with breccia bodies carbonate attributable to the distal Palaeo-European continental margin. Dolomite marbles and marbles of different ages are distributed in many units of Piedmont; quartzites of Permian—Lower Triassic age; metabasites including metabasalts, meta-gabbros, prasinites, amphibolites, Mesozoic eclogites of oceanic units. Pre-Mesozoic metabasite lenses are also present within Paleozoic continental crust and amphibolite units with subordinate metagabbro bodies and migmatitic serpentinite and amphibolite; ultramaphytes and serpentinites which include ultrabasic rocks. Graphitic schists and upper Carboniferous graphite phyllites emerging in the Brianzone Internal Units. Micascisti and ortho-derived rocks correspond to metamorphic rocks derived from late Paleozoic magmatic rocks belonging to the metamorphic basement of the European Continental Paleo-Margin. Migmatites, granulites and schists of high metamorphic grade which are made up of felsic granulites and quartz-feldspar-garnet paragneisses, mica schists and sillimanite and garnet paragneisses (Beltrando et al. 2010; Agard 2021; Vaughan-Hammon et al. 2022).

The sedimentary rocks can instead be schematically divided into: Cenozoic terrigenous rocks represented by arenaceous, arenaceous-pelitic, marly and sandy-gravelly

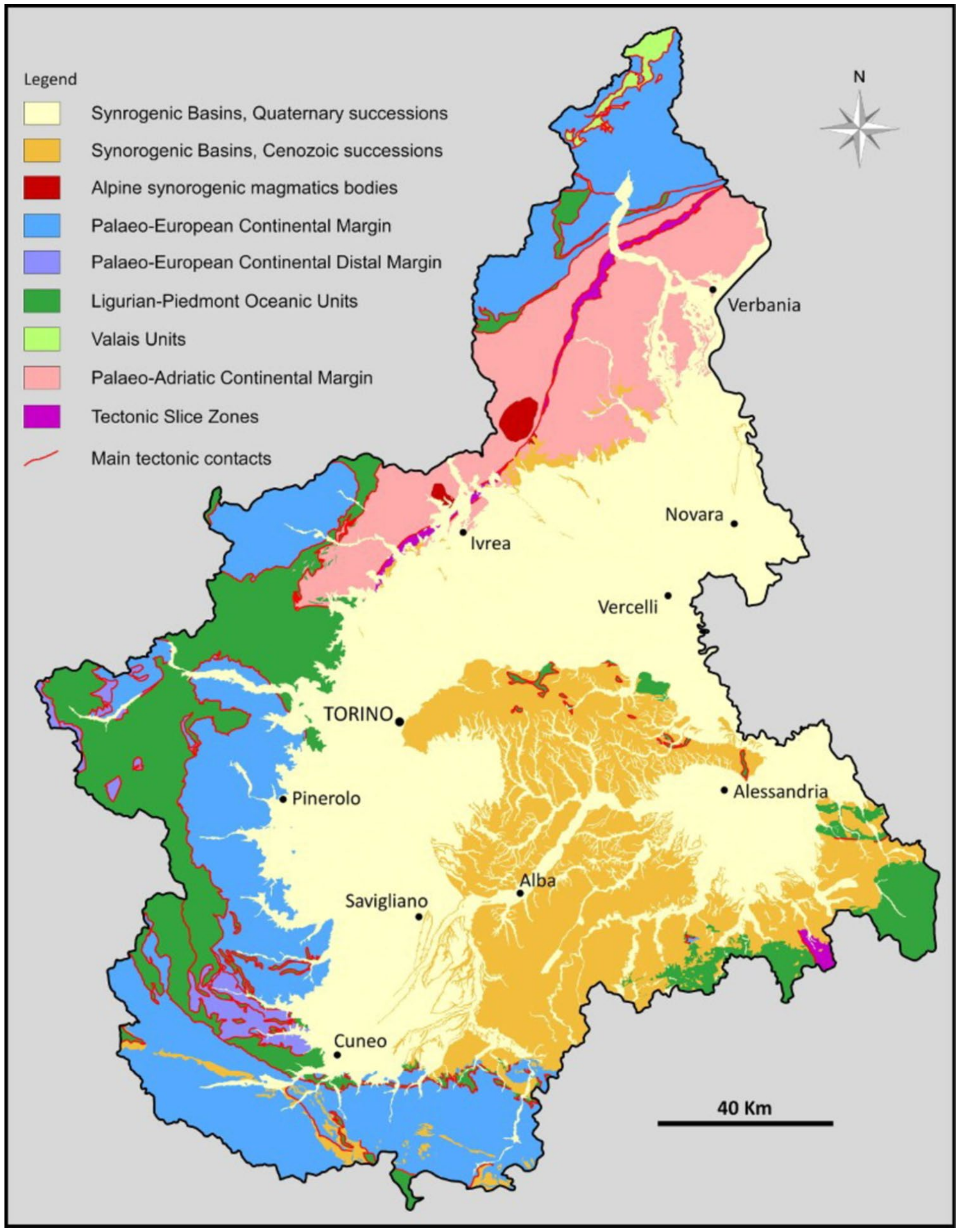

Fig. 1 Distribution of the palaeogeographic domains and geologic units belonging to the other main categories adopted to construct the Map Legend of the Geological Map of Piedmont at the 1:250.000 scale (Piana et al. 2017)

successions of middle Eocene-Miocene age emerging in the Piedmontese Tertiary Basin (BTP); arenaceous-pelitic successions of the upper Eocene–Oligocene lower foreland. In addition, pliocene pelitic and arenaceous successions and marly conglomeratic successions present in the Ligurian units of Monferrato; Mesozoic terrigenous rocks including Lower Triassic quartzoarenites, upper Triassic pelites; varicolored clays, pelites and arenites (Ligurian units of the Maritime Alps; Ligurian units of the Northern Apennines); Cenozoic allochemical rocks made up of calcarenite and calcirudite from the Eocene to Miocene (BTP; Alpine foreland basin) and turbidic calcareous-marly successions of the Eocene (Ligurian units of Monferrato). Mesozoic allochemical rocks, which include Middle Triassic—Jurassic limestones and Cretaceous marly calcareous successions of the Paleo-European continental margin; Middle Triassic—Jurassic limestones and dolomites of the Paleo continental margin -Adriatic (Southern Alpine sedimentary succession) and calcareous-marly turbidite successions of Cretaceous age (Ligurian units of the Maritime Alps; Ligurian units of the northern Apennines). Orthochemical rocks, represented by primary and resedimented evaporitic gypsum (BTP), gypsum lenses, and anhydrites along tectonic contacts, speleothems.

The plain sectors of the Piedmont Region are mainly represented by the western portion of the Po Valley and, secondly, by the Savigliano and Alessandria basins. The evolution and current configuration of the western Po Valley are mainly linked to the dynamics of the Po River in the sector between the confluence of the Sangone and the Ticino and is separated from the Savigliano basin by the Moncalieri threshold, connected to the lifting of the anticlinal structure of the Turin Hill resulting in different dynamics and morphologies of the hydrographic pattern north and south of this threshold. The western Po Valley is instead separated from the Alessandria Basin by the confluence sector between the Po, Tanaro and Scrivia (Maino et al. 2013; Forno et al. 2018, 2022).

The piedmont region: hydrogeological setting

To ensure proper management of extraction activities, it is crucial to guarantee that interferences with surface water bodies and aquifers do not result in significant changes in the groundwater regime and its vulnerability in terms of potential pollution risk. In this context, having a thorough understanding of the hydrological and hydrogeological context in which operations are conducted is essential. It is also important to determine the depths of existing aquifers and the position of the water table relative to ground level, as this factor can directly influence the type of excavation and recovery.

Information about the Piedmont Region hydrological and hydrogeological settings and related parameters are available on the Geoportale Piemonte, provided by the regional authority, Geoportale Arpa Piemonte of the Regional Environmental Agency, PAI and PTA documents. Besides, an updated 1:300.000 scale hydrogeological map of the western Po Plain was proposed by De Luca et al. 2020. Also, an updated water table level map and water table depth map is contained therein. According to the available information, the hydrogeological conceptual model of Piedmont plain is composed of superimposed complexes represented, from top to bottom, by Alluvial deposits complex (lower Pleistocene-Holocene), Villafranchiano transitional complex (late Pliocene–early Pleistocene) and Marine complex (Pliocene) (Bove et al. 2005; Civita et al. 2005; Barbero et al. 2007; Vigna et al. 2010; Forno et al. 2018). The unconfined aquifer located in the Alluvial deposits complex, comprised mainly of coarse gravel and sand from fluvial or fluvioglacial origins, incorporates subordinate silty-clayey intercalations. This complex typically has a thickness ranging between 20 and 50 m and exhibits high permeability ($k = 5*10^{-3} \div 5*10^{-4}$ m/s). Deeper aquifers are situated in the underlying fluvial-lacustrine 'Villafranchiano' complex and the Pliocenic marine sediments. These deeper aquifers commonly serve as crucial sources of drinking water in the Piedmont plain due to their productivity and superior groundwater quality compared to the shallow aquifer (De Luca et al., 2019).

The Water Protection Plan (PTA) still represents today a crucial source of hydrogeological information for the Piedmont Region. Its drafting, in fact, was preceded by a lengthy and in-depth analysis of the available information on the water heritage of the Piedmont Region. A detailed reconstruction of the hydrogeological model of regional aquifers, together with a definition of the hydrogeological complexes, was carried out and adopted as a baseline reference for the necessary planning and protection actions for underground water resources. Using water level measurements from wells and piezometers uniformly distributed in the Piedmont plain between June and July 2002, along with data from the Piedmont Region monitoring network, a piezometric map at a 1:100.000 scale was developed. The water level data were validated and then processed using computer interpolation methods to obtain values for the depth of the groundwater table. The proposed classification into 5 classes of groundwater table depth remains a valuable tool for understanding regional hydrogeological settings, aiding in the proper management and protection of surface water resources (Fig. 2). Besides, shallow aquifer's base levels were made available at a scale 1:50,000, providing valuable quantitative information in terms of

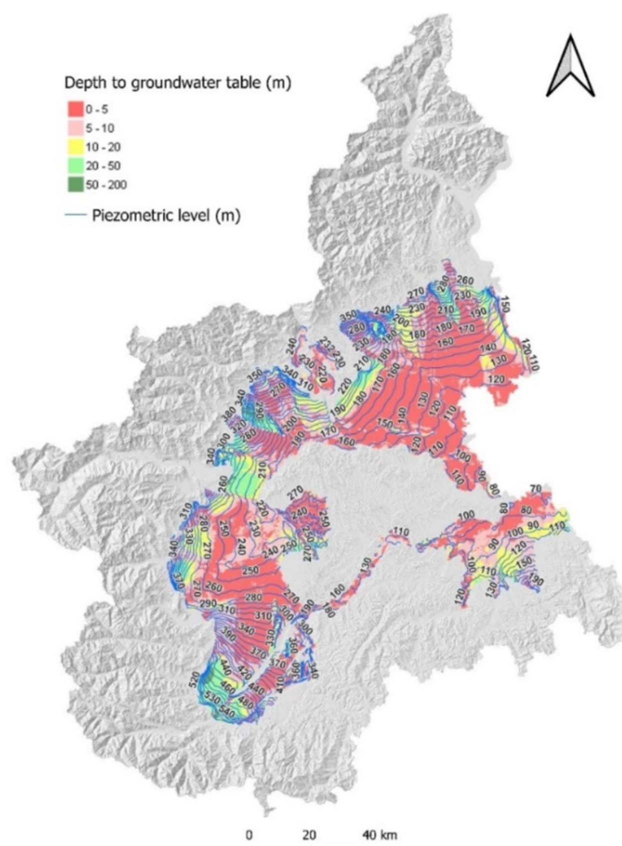

Fig. 2 Depth to groundwater map from Bove et al. 2005

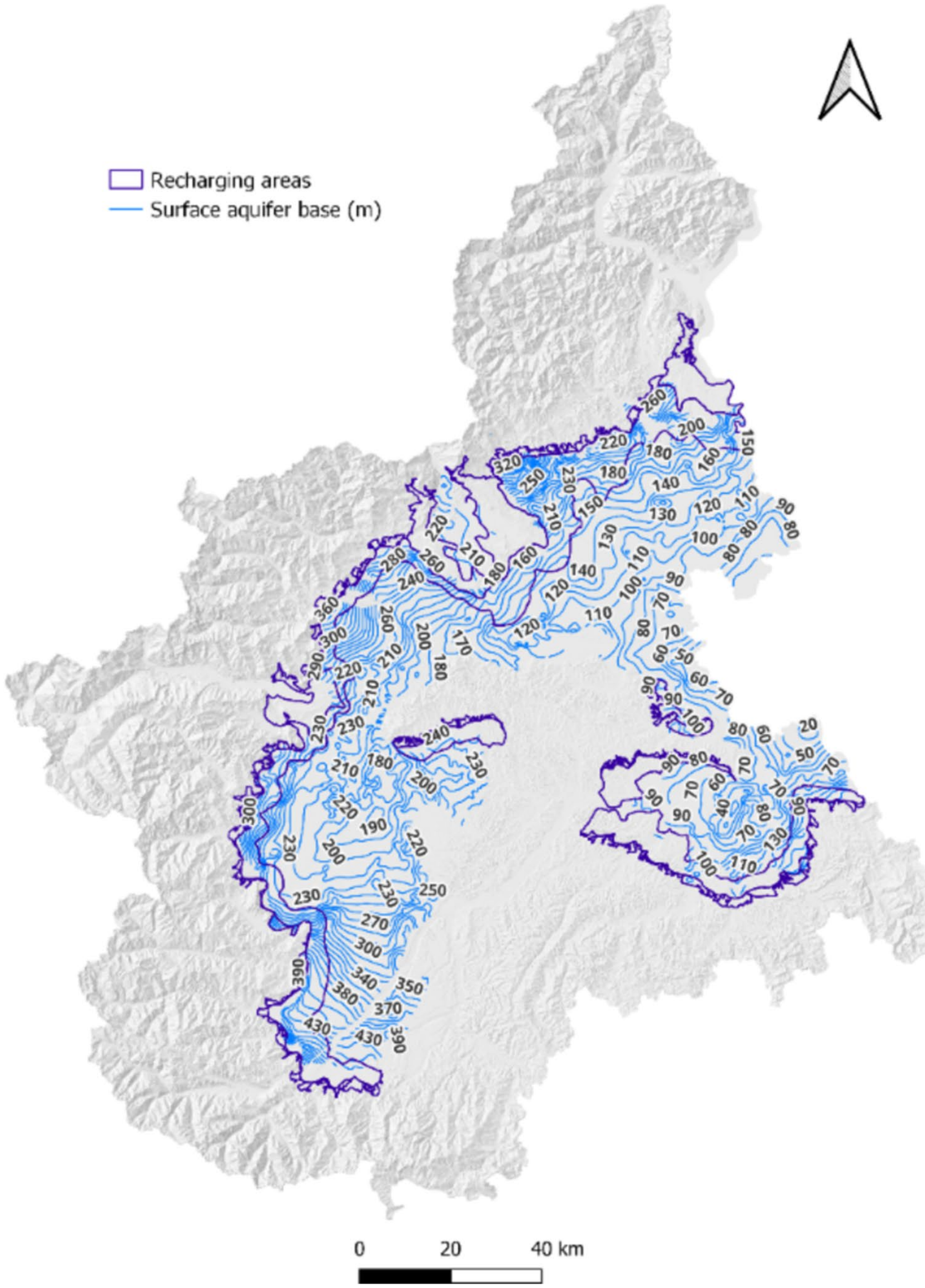

Fig. 3 Base of surface aquifer map distributed in the Piedmont plain

the vertical separation between shallow and deep aquifer bodies (Fig. 3).

Results and discussion

Available data elaboration and distribution

In accordance with what has already been reported by Bottero et al. 2020, considering the updated data presented in Table 1, aggregate pits turn out to be the most abundant in the provinces of Torino, Cuneo, and Alessandria, owing to the significant presence of alluvial plain areas characterized by sedimentary rocks and/or deposits. In contrast, the province of Cuneo has a notable number of active quarries for industrial minerals, while extraction sites for ornamental stone are found in the mountainous areas of Cuneo, Torino, and Verbania. Verbania ranks as the third province with the highest number of total quarries. Unlike the other provinces, ornamental stone quarries are predominant in its area. In the province of Novara, the majority of quarries are dedicated to aggregate production, while in Vercelli, almost half of the quarries extract alluvial materials and clay. In contrast, in the provinces of Alessandria, Biella, and Asti, no quarries are designated for ornamental stone mining.

A simplified distribution of mining sites was proposed by considering the regional geomorphology, thus accounting for the distribution of quarries at different altitudes. As a result, there are more mining sites in hilly areas, precisely 98 (36%), followed by 92 sites in the plains (34%), and then 80 mountain quarries (30%). Therefore, there is an almost uniform distribution of quarries across the territory (Fig. 4a). The distribution of the three compartments in the mountain, hill, and plain contexts allows for the identification of a correlation between morphology and lithological formations, indicating the materials involved in extractive activities (Fig. 4b). In the plain area, quaternary alluvial and moraine deposits are predominant, along with clay layers. Similarly, the hill context is characterized by alluvial deposits and sedimentary successions with a significant presence of sedimentary rocks and sediment, i.e., sand, marly siltstones, and clay marls, which are widespread in the Monferrato and Langhe areas (Sinorogenic basins, as indicated in Fig. 1). Additionally, traces of metamorphic rocks (i.e., serpentinites) can be found in the province of Turin (Ligurian-Piedmontese oceanic units). The province of Cuneo is distinguished by the prevalence of limestone in the hill areas. Concerning the mountain context, formations such as gneiss, calcareous schist (Paleo-European continental margin and Ligurian-Piedmontese oceanic units), and granites are more widespread, with even traces of serpentinites and a minority of sandstones. Some of the quarries are entirely within a specific area, such as Verbania, which is located in a mountainous environment, and therefore a substantial presence of ornamental stone quarries is to be expected due to the geological formations characterizing this setting. Similarly, provinces such as Alessandria and Novara extend over hill and plain areas and consequently extractive activities for aggregates should be prevalent over other compartments (Fig 5).

As mentioned earlier, 34% of extraction sites are located in the alluvial plain areas of the Piedmont region. Of these, 91% is represented by aggregate extraction sites. Most of these sites turn out to be subjected to hydraulic and hydrogeological constraints: the 42% of quarries fall within river bands, the 15% in recharge areas and the 46% in areas with surface groundwater. About the 7% of quarries are included in all three cases. Precisely, the number of quarries falling within the river bands as defined by the Hydrogeological Plan, reported in chapter 2.1 is determined. Out of the 270 active quarries analyzed, 191 are hydraulically constrained, corresponding to 71% of the total, at least half of which are dedicated to the production of aggregates. This is because mining activities in the first compartment have a more significant interaction with the fluvial setting (Fig. 6). As previously mentioned, the Po plain is rich of alluvial deposits, thus leading to spread of quarries along the main rivers flowing in this area, therefore making extractive activities exposed to the possibility of flooding. Most of quarries involved, particularly those located in the floodplain, fall within area with high (A river band) and medium (B river band) probability of floods.

Considering the guidelines outlined in the PRAE, coordinating tool between the PAI regulations and the planned extraction area, the area involved in extractive activities

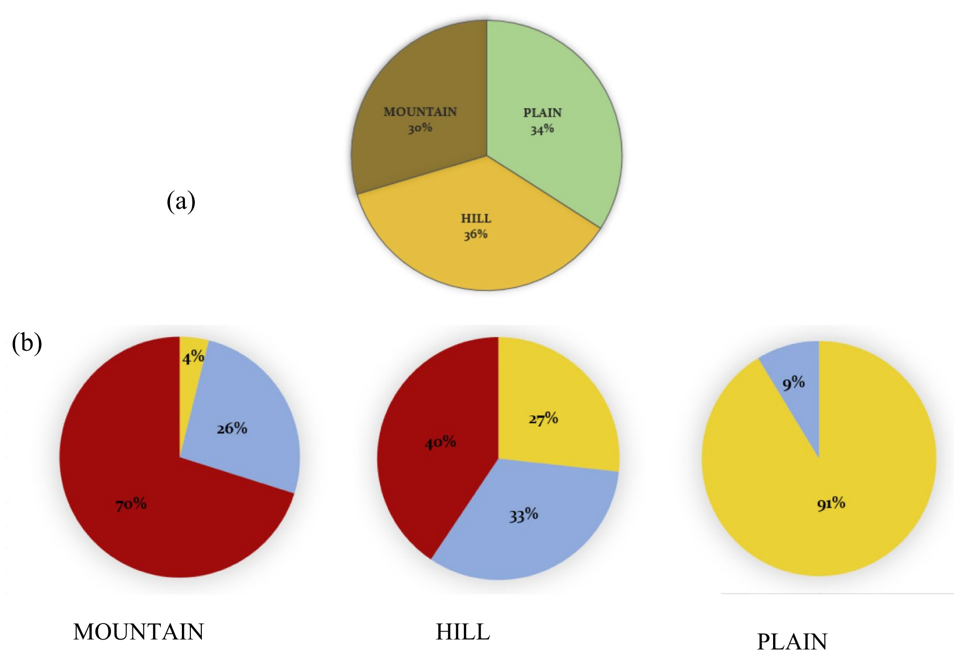

Fig. 4 **a**. Percentages of quarries distributed over three morphological contexts; **b**. Distribution of compartments according to morphological contexts (yellow: aggregates, blue: industrial minerals, orange: ornamental stones)

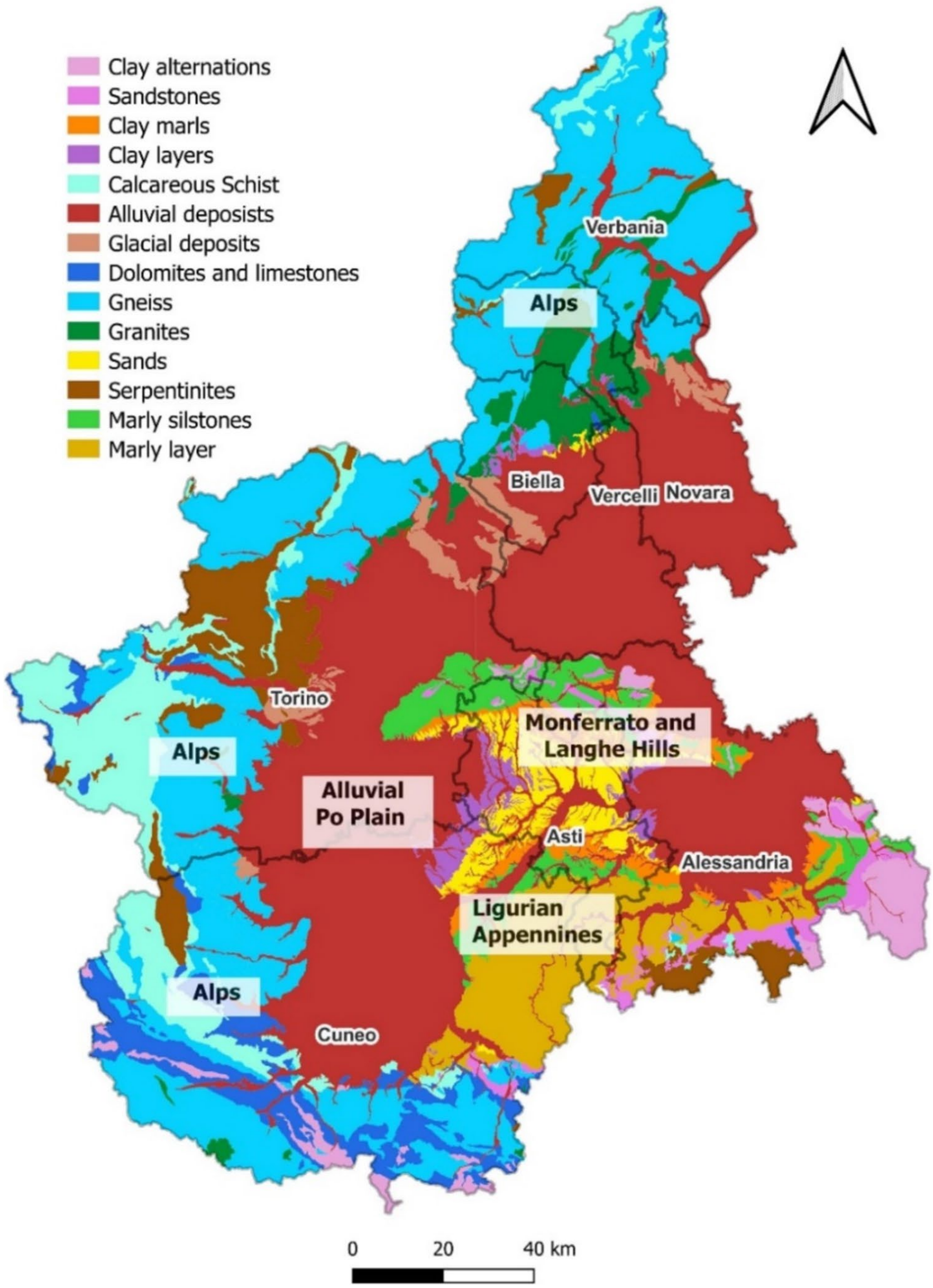

Fig. 5 Simplified geolithological map of Piedmont Region (modified from Piana et al. 2017)

and located within the aforementioned bands is subject to an environmental recovery project to be carried out at the end of cultivation. This project must be aimed at preserving the morphological and hydrogeological characteristics of the area. In the case of discontinued extraction activities, the same activity is required to contribute to the restoration of the peri-fluvial environment through re-naturalization projects, in accordance with Article 36 of the Implementation Rules of the PAI and the related specific directives. To reduce the hydrogeological and geomorphological vulnerability of the area where the extraction center is located, a peripheral strip designated for re-naturalization is planned, where agricultural land use is not allowed. Extraction activities in areas adjacent to river areas with high hydraulic and geomorphological criticality are subject to specific regulations and measures aimed at mitigating potential risks and impacts. In contrast, extraction activities in areas adjacent to river areas with high hydraulic and geomorphological criticality, such as river meanders, relict or reactivatable riverbeds, are heavily restricted both in terms of planimetry and excavation depths, never exceeding the base of the surface aquifer. In both conditions, the riverbed must be left free

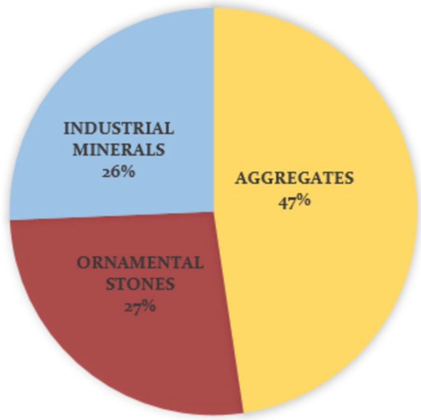

Fig. 6 Percentages of quarries falling in areas under hydraulic constraints

Table 2 Distribution of mining compartment by classes of groundwater table depth

Classes of groundwater table depth	Aggregates	Industrial minerals
(0–5 m)	37	2
(5–10 m)	50	6
(10–20 m)	19	11
(20–50 m)	11	3
(> 50 m)	–	–

to meander, also compatibly with the current conditions of anthropic land use and infrastructure. Extraction activities must not affect wetland environments as identified by current regulations, and extraction centers need to be located at a defined distance, subject to verification through hydraulic studies, in order to prevent the triggering of intense planimetric-altimetric instability processes of the watercourse. It is also important to emphasize that in extraction activities falling within river bands, there must be an adequate monitoring aimed at reporting any interactions on the dynamics of the riverbed, such as specific phenomena possibly connected to the occurrence of floods that have affected the quarry area, the groundwater regime, and interactions with environmental components.

For the purpose of preventing interference with groundwater, it is necessary to both consider the depth of the groundwater table and surface aquifer base, as the delineation of the maximum excavation depth for activities to be authorized and expanded. Considering the five classes of groundwater table visible in Fig. 2 and the percentages of quarries in alluvial plain areas in Fig. 4a, the distribution of mining activities was evaluated for each classes (Table 2).

From Table 2, it is evident that a large amount of the extraction sites, i.e., aggregates, because of the geological formations characterizing the Po plain, involve groundwater bodies in close contact with the surface. The issue of interference between mining activities affecting the saturated zone of the surface groundwater and the impermeable levels separating these aquifers from deep ones to be preserved need to be properly considered. A mining site is identified as a quarry beneath the groundwater table for values of groundwater depth less than 5 m; above or below the groundwater table, depending on local conditions and design choices, for values between 5 and 20 m; and finally, quarries above the groundwater table for values exceeding 20 m. Specifically, for quarries above the groundwater table, a minimum thickness of 1 m must be maintained between the maximum excavation depth and the groundwater level (Art. 26 PRAE NTA). On the other hand, for quarries beneath the groundwater table, a minimum thickness of 1 m must be maintained if the excavation depth is 10 m, 2 m if the depth is between 10 and 20 m, 3 m if the depth is between 20 and 50 m, and 5 m if the depth exceeds 50 m (Art. 28 PRAE NTA).

Besides, it is related to an increase in the relative permeability of sediments constituting the base of the surface aquifer, as a result of a decrease in lithostatic load due to the use of excavation techniques. The permeability increase can produce a drainage from the saturated zones above to the protected saturated zones below, triggering a potential pollution risk. To prevent the phenomena mentioned earlier, it was established a parameter that must be adhered to above the impermeable level. Consequently, the maximum depth reachable through excavation activities is defined by the base of the surface aquifer. In the PRAE General Plan Report document, the approved thickness value is set at 5 m, with the goal of avoiding any interference between surface and deep aquifers.

Conclusions

The paper illustrated the role of Regional Plan of Mining Activities (PRAE) as a tool for regulating and planning the extraction quarry areas in the Piedmont Region. For this purpose, interaction between mining activities and the geomorphological and hydrogeological contexts in which they are located is described, defining the resulting constraints regarding their interaction with mining activities. Such environmental constraints about the protection of water resources are delineated in the PAI and PTA regulations and the PRAE align with these guidelines in order to regulate the extraction of mining materials. Considering the number of active quarries distributed in each province, the percentages of three mining compartments (aggregates, industrial minerals, ornamental stones) were assessed. The aggregates compartment is distributed almost completely in the floodplain, due to the geological formations covering this area, involving the hydrographic network of Po tributaries and water bodies in close contact with the surface. A large part of the quarries are located in the floodplain, falling both in river bands of medium–high probability of flooding and in areas involving aquifers bodies, hence these extractive sites are heavily restricted both in terms of excavation depths, never exceeding the base of the surface aquifer. The depth of the water table and the base of the aquifer are two parameters on which restrictions have been defined in terms of the possibility of cultivating new quarry areas. Following art. 26 and 28 of the PRAE NTS, respectively, a minimum thickness of 1 m must be maintained between the maximum excavation depth and the groundwater level for quarries above the groundwater table; for quarries beneath the groundwater table, a minimum thickness of 1 m must be maintained if the excavation depth is 10 m, 2 m if the depth is between 10 and 20 m, 3 m if the depth is between 20 and 50 m, and 5 m if the depth exceeds 50 m. A parameter that must be adhered to above the impermeable level was introduced: the maximum depth reachable through excavation activities is defined by the base of the surface aquifer. In the PRAE General Plan Report document, the approved thickness value is set at 5 m.

It clearly emerges how the intent of the PRAE is to guarantee a proper balance between land and environmental factors, mining activities and the target market. It pursues the goal of minimizing the impacts of mining activities on the territory, reducing soil consumption, and meeting the requirements of environmental sustainability, while ensuring at the same time that the demand for material is met.

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Data availability The data that support the results of this study are openly available in Geoportale Piedmont website (https://www.geoportale.piemonte.it) and Regione Piedmont website (https://www.regione.piemonte.it).

Declarations

Conflict of Interests The authors declare no competing interests.

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