Environ Earth Sci (2016) 75:1372
DOI 10.1007/s12665-016-6197-x

ORIGINAL ARTICLE

Activities permitted cartography: the integration of groundwater protection into land-use planning

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Received: 16 August 2015 / Accepted: 13 October 2016 / Published online: 19 October 2016

Abstract Groundwater is an essential resource as a source of water supply. For this reason, it is necessary to integrate and harmonise efforts to protect groundwater quality with socioeconomic activities and existing land-use patterns in any given region, as well as complying with the requirements of the EU Water Framework Directive. In addition, land management seeks to coordinate and harmonise policies with regional impacts. Water—as a public good and an essential resource for the development of life and the evolution of populations—needs to become one of the main pillars of the management of a variety of regional policies. Therefore, water resources planning does not make sense without first considering forecasted land management patterns. The objective of this study was to enhance a method used to define safeguard zones protecting groundwater bodies intended for human consumption (i.e. the groundwater protection zones method) by developing a cartography method to create a map showing permitted activities in a particular region. This provides an effective tool to assist in the management of regional land use. Delimited safeguard zones that protect groundwater intended for human consumption must be integrated into land-use planning. The proposed development of a map of permitted activities facilitates is to make recommendations and formulate restrictions and prohibitions to avoid damage to groundwater used for human consumption.

Keywords Groundwater protection · Safeguard zones · Land management · Geographical information systems

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Introduction

Groundwater is a basic resource for urban water supply in Europe. In countries such as Denmark, Austria, Germany or Italy, more than 70 % of the population's water supply comes from groundwater. The great geological and, consequently, hydrogeological diversity in Europe—along with the specific socioeconomic characteristics of each country—means that a varied proportion of surface and groundwater in each country is used for human consumption (Martinez Navarrete et al. 2008). In much of Europe, groundwater is an important resource, especially in Mediterranean countries where surface water alone cannot meet the demands of agriculture, industry and human consumption. Southern Europe, for example, is climatically characterised as a semi-arid region with a marked difference in rainfall due to seasons and topography (COST 65 1995).

The protection of groundwater became a high-priority environmental objective in European policies in 2000, through the Water Framework Directive (WFD), Directive 2000/60/CE of the European Parliament and the Council (European Union 2000). This issue was addressed more specifically in 2006, through Directive 2006/118/CE of the European Parliament and the Council, which deals with protecting groundwater against pollution and deterioration

(European Union 2006). These directives promote cooperation through coordination between different competent authorities at various levels of decision making, to benefit different social agents and society at large—which constitute the users. The last phase of this integration process needs to be an examination of new strategies in water management policies that impact regions.

According to the WFD, the existence of groundwater in sufficient quality and quantity for human consumption is an absolute necessity, and therefore, appropriate systems to protect this resource must be created and implemented. Under Article 7.3 of the WFD, the definition of groundwater protection zones (GPZs) to meet the requirements of water for human consumption is suggested as an optional but strongly recommended measure, as it enables security measures to be centralised to limit the deterioration of groundwater quality and reduces the need for water purification (Martínez-Navarrete et al. 2011).

River basin management plans, which should include a list of protected areas, coordinate and integrate the programme of basic and complementary measures developed by various authorities responsible for water protection. These measures are necessary to achieve the objectives set by EU water protection legislation, which expressly includes the protection of bodies of groundwater intended for human consumption through active, participatory planning processes (Martínez-Navarrete et al. 2011).

Basin organisation involves, through the Committee of Competent Authorities, programmes of measures drawn up by each competent administration, based on which river basins are coordinated and integrated into regions. Subsequently, the effects of the measures on water bodies are checked, with the aim of ensuring their compatibility and making the best choices. The effectiveness of the proposed measures also depends on an analysis of economic impacts. These can be related to possible changes in land use, discharge and treatment of waste water, review of use authorisations, adaptation of petrol stations, establishment of agricultural codes and land expropriation to ensure the protection of groundwater bodies.

Europe needs a sustainable groundwater management strategy to allow more efficient groundwater use and preservation. The need for sustainable, integrated management is reflected in current policies and legislation. The WFD has adopted this philosophy of sustainability in resource management by requiring EU member states to develop water basin plans, with mandatory active public participation in planning and development processes.

The implementation of these measures through policies with regional impacts should be accompanied by an assessment of socioeconomic impacts on both populations and associated ecosystems. For this reason, effective protection of groundwater bodies used for human consumption requires more severe and detailed regulations that allow the possibility of establishing more concrete measures in smaller areas of land. Therefore, priority needs to be given to safeguarding the financial resources necessary to centralise measures in areas where protection is essential. This is the GPZ method's objective: the establishment of safeguard zones in different geological and hydrogeological contexts.

Delimited safeguard zones should be integrated into land-use planning. To this end, a method of producing activities permitted maps needs to be developed, based on which recommendations can be made and restrictions and prohibitions proposed in order to avoid damaging water used for human consumption.

Furthermore, according to Gómez Orea (2002), any model of water management will be inadequate if it fails to include predictions and measures for balanced, sustainable land development. Water is essential to land use, so all land-use planning must take into account the question of water management. However, the fragmentation of responsibilities in land management means that the ground-level reality is not well known; so it is necessary to define clearly the relevant competences, as well as relationships between land management and urban planning (Hildenbrand Scheid 2006). The preferential position given to water planning, whereby it can play an integrative role in land management, is derived from the self-evident importance of the public good being planned (i.e. a limiting factor that determines territorial arrangement) and groundwater's characteristics as a natural resource (i.e. scarce and limited).

The WFD has established a framework for European Community action in the field of water policy, which the WFD regards as a key concept of integration, understood as the synergy of disciplines involved in managing programmes that protect water and associated ecosystems. Allowed activities are determined by the assessed risk of contamination of the entire body of groundwater, which permits differentiation between—and definition of—which activities can be integrated or not in the areas in question. These findings are then included in land management plans. It is also necessary to evaluate and assess the socioeconomic consequences of establishing appropriate security measures for water intended for human consumption, in order to establish specific regulations (François et al. 2010; Hovratin and Bailey 2001; Vinnari 2006).

The WFD has established that river basins are the core of the river basin district approach, wherein the measures included in water planning are included. This geographical unit allows coverage of entire regions and integrates natural and ecological dynamics, which are very important to unite and integrate decisions related to regions. In addition, according to Pallarès Serrano (2007), water planning is the best way to apply the concept of sustainable and coordinated development, highlighting the role of water councils as organisations that integrate the various forms of political will that exist in relation to land management.

To achieve the WFD's goals and to integrate groundwater protection into land-use management, the present study sought to develop a method for mapping permitted activities, as a land-use instrument to be applied directly when making appropriate decisions regarding the introduction of new activities, modification of existing ones or location of new groundwater extraction points.

Background

To establish adequate protection measures, authorities need to consider criteria such as characterisations of the intensity of pressure on resources, evaluations of intrinsic vulnerability, risk analyses of groundwater contamination and assessments of wellhead protection areas. According to the WFD, 'pressure' is defined as any human activity that could have a negative environmental impact on water. In relation to groundwater, pressure is subdivided into five types: point contamination sources, diffuse contamination sources, water abstractions, artificial recharge and seawater intrusion. As a consequence of these activities, pollutants may be introduced into the water by, for example, agricultural activities, livestock, urban settlements, industrial activities, hazardous waste storage and landfills. In addition, physico-chemical properties of water may be modified by artificial recharge, geothermal energy use or landfills. Chemical characteristics can also be transferred inside aquifers, or there can be a reduction of water resources (i.e. water abstractions). The present research, thus, emphasises COST Action's methodological approach to assessing a hazard index (Zwahlen 2004).

Vulnerability to contamination is aquifers' susceptibility to groundwater contamination due to the impacts of human activity. A distinction can be made between intrinsic and specific vulnerability (Foster 1987). Intrinsic vulnerability is the susceptibility of groundwater to contamination generated by human activity in function of the geological and hydrogeological characteristics of a given area, although this vulnerability is independent from the nature of the contaminating agents. Specific vulnerability, in turn, is the susceptibility of groundwater to a contaminating agent or group of specific contaminating agents in function of their characteristics and their relationship with intrinsic vulnerability components (Zwahlen 2004). Researchers have developed, over the years, various methods for evaluating inherent vulnerability to contamination based on different methodological approaches, including GOD, DRASTIC, SINTACS, ISIS, AVI and EPIK (Gogu and Dassargues 2000).

Risk of contamination takes into account different aspects such as the presence and danger of pressures, vulnerability to pollution and, in some cases, the socioeconomic and ecological importance of the resource. Therefore, risk of contamination is defined as the probability that groundwater will be contaminated by pressures located at the surface (Foster 1987; Zwahlen 2004).

Human activities can cause deterioration in the quality of groundwater. In order to protect water obtained by acquisitions, a perimeter of protection needs to be defined around these and the required regulations applied to various activities. The United States Environmental Protection Agency (USEPA 1991) has defined the scope of protection as surface and subsurface areas around a water collection system or a group of these used to supply the population, within which pollutants can reach the groundwater extracted. The wellhead protection area of water abstraction points for drinking water is a measure broadly reflected in the water protection legislation of different EU countries, where the definition of this area's boundary has been addressed differently (Martínez-Navarrete et al. 2011). Moreover, the protection measures established vary greatly between EU countries.

In the present study, first, the risk of contamination of groundwater was assessed by combining characterisations of pressure intensity and assessments of intrinsic contamination vulnerability. Second, existing supply catchments were identified, and their feeding grounds were delimited in order to prioritise protective measures to be established in each area. For this reason, safeguard zone is the appropriate concept on which to establish adequate protection measures as these zones combine all criteria historically applied in this field of research. Last, the delimitation of safeguard areas were integrated through spatial planning based on maps of permitted activities as a tool to be applied directly to the region in question.

Study area

The Sierra de Cañete (i.e. the Subbetic Zone) is located in the Western Mediterranean, in southern Spain (see Fig. 1). This mountain range has a surface area of approximately 55 km^2 and receives a mean annual precipitation of over 1000 mm. The materials in outcrops are Jurassic limestones and dolomites that have been made permeable through fissures and karstification. The karst topography is poorly developed. The most representative exokarstic landform is limestone pavements in Penibetic materials. There are extremely few areas of preferential infiltration

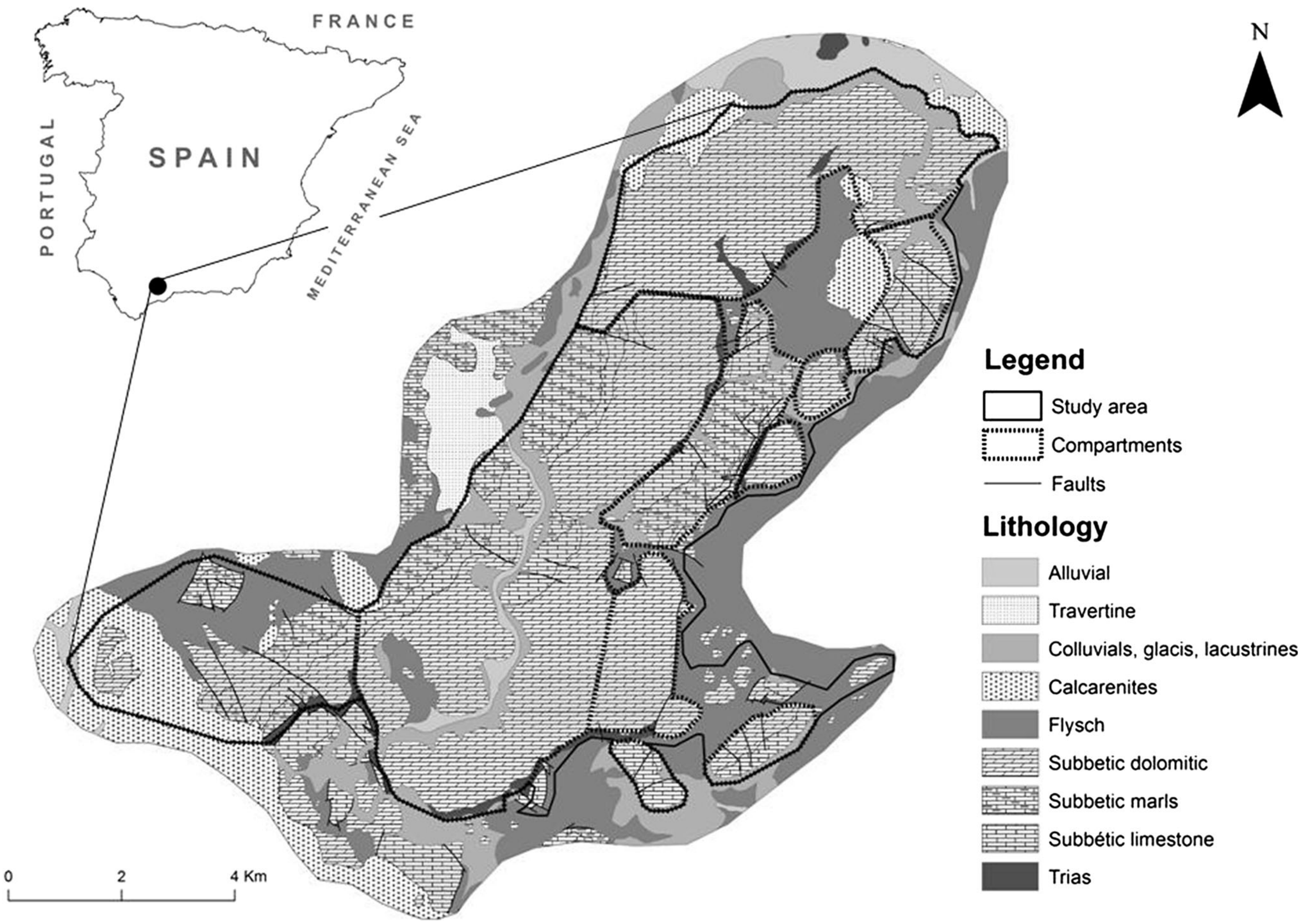

Fig. 1 Geographical and hydrogeological setting of Sierra de Cañete

(e.g. dolines and uvalas), and only occasional small, shallow sinkholes are present (Jiménez-Madrid et al. 2011).

The average annual rainfall varies between 560 mm in the eastern end and 760 mm in the southern part. The average annual temperature is 18 °C, and the mean value of the potential evapotranspiration is 950 mm/year.

Due to tectonic phenomena, the Sierra de Cañete is divided into several aquifers (i.e. compartments) (see Fig. 1 above). These aquifers are recharged by rainwater infiltration. Groundwater flow occurs through fissures and conduits towards discharge springs that are located at different topographical heights according to aquifer divisions. A moderate karstic regime is apparent (Junta de Andalucía 2002).

The groundwater resources of the Sierra de Cañete are used by nine municipalities. The main economic activity is related to agriculture, with wheat crops and olive groves occupying the largest areas. Tourism-related activities are scarce, and they gain some importance only in larger municipalities, such as Campillos and Olvera. Still, in recent years, an increase in rural tourism has been observed. Unemployment rates in all the municipalities studied are around 6–8 % of the total population. With respect to existing land use in the Sierra de Cañete, larger areas correspond to parcels dedicated to rainfed agriculture (23.91 %) and lands occupied by oaks (22.81 %) and scrub (21.11 %).

Methodology

According to the WFD (i.e. Article 7.3), GPZs are areas to be established as an optional method by which appropriate protective measures are applied to limit deterioration in the quality of groundwater used for human consumption and to reduce the amount of purification required. This option is strongly recommended given the extremely large dimensions of groundwater bodies in many EU member states.

Jiménez-Madrid et al. (2011) propose the GPZ method for determining safeguard zones as a way to protect carbonate groundwater bodies used for drinking water supplies. In this method, the first step is to establish the risk of groundwater contamination (RI index) by combining a characterisation of external pressures (IP index) and an evaluation of intrinsic vulnerability to contamination (DRISTPI index). The second step is to identify existing supply points and their inputs, that is, the areas within the region that provide water used for human consumption. This objective is independent of other measures that may be required in other areas to comply with WFD requirements. Last, the existing protection perimeters are identified in the relevant protection zones.

Pressures need to be characterised in as much detail as possible during the same inventory. Under the GPZ method, based on the hazard index developed by COST 620 Action, the IP index is used to assess the intensity of pressures for the relevant Internet protocol address (i.e. amount or harmfulness of pressures) and to define thresholds that classify the polluting potential of the proposed pressures (Jiménez-Madrid et al. 2011).

To assess the vulnerability to contamination, the DRISTPI index, which is based on the DRASTIC method, is used to assess the inherent vulnerability to contamination of any type of aquifer because of the presence of different materials in any given body of water. To characterise an aquifer, this new method requires the definition of two scenarios to identify the most karstified aquifer of the rest areas in question. Key changes include the methodological foundations of the proposed DRISTPI index, which emphasise the preferential infiltration factor when characterising areas (Jiménez-Madrid et al. 2013).

Risk of groundwater contamination characterisation is based on the product of the indices that assess the intensity of pressures and vulnerability to pollution (Jiménez-Madrid et al. 2011). To this end, the RI index was defined in this study based on an interpretation of a double-entry matrix whose values were reclassified between 1 (minimum value) and 5 (maximum value) (see Table 1).

Once the safeguard zones are established, the activities permitted are mapped. This process produces a dynamic instrument to be applied directly in the study area to determine where pressures can be located, thereby eliminating negative impacts on the quality of groundwater intended for human consumption.

Table 1 Evaluation of risk contamination: RI index *Source*: Jiménez-Madrid et al. (2011)

RI index	Vulnerability (DRISTPI index)					Classes of risk
	1	2	3	4	5	
5*Pressure (IP index)*						
1	1	2	3	4	5	Very low
2	2	4	6	8	10	Low
3	3	6	9	12	15	Moderate
4	4	8	12	16	20	High
5	5	10	15	20	25	Very high

In the present study, the mapping of permitted activities was conducted by taking into account the risk of contamination of the entire water body included in the protected zones. To do so, the intensity of pressures was characterised according to the IP index values summarised in Table 2. These were reclassified to values from 1 (very low) to 5 (very high), based on the criteria developed by Jiménez-Madrid (2012). Vulnerability to contamination, as an intrinsic property of the medium, was evaluated on a scale from 1 to 5 using the DRISTPI method (Jiménez-Madrid et al. 2011).

By combining these parameters, the risk of contamination was determined by a double-entry matrix (see Table 1 above) as follows:

$$\text{Existing IP} \times \text{DRISTPI} = \text{Existing RI} \quad (1)$$

As can be seen in Table 1, five kinds of groundwater contamination risk were proposed. The mapping of permitted activities was based on the following algorithm:

$$(\text{Existing IP} + \text{Allowed IP}) \times \text{DRISTPI} \leq \text{moderate RI} \quad (2)$$

The goal is to allow only new activities in each zone, whose pressure intensity (see Table 2 above)—when added to that of existing activities—does not exceed the mean value (12) of the RI index. This corresponds to a moderate risk of contamination.

By integrating all available information using the spatial analysis tools of a geographical information system and implementing the necessary algorithms, a map of permitted activities was generated that can be used to manage the region in question within each cell of the pre-defined space (see Fig. 2). This approach protects groundwater supplies used for human consumption and facilitates appropriate land-use planning. Six classes of permitted activities within the safeguard zones can be distinguished:

- Class 0—Negative and 0 values mean no further activities are permitted.
- Class 1—Activities permitted provided the resulting IP index, when added to that of existing pressures, does not exceed 19.
- Class 2—Activities permitted provided the resulting IP index, when added to that of existing pressures, does not exceed 39.
- Class 3—Activities permitted provided the resulting IP index, when added to that of existing pressures, does not exceed 59.
- Class 4—Activities permitted provided the resulting IP index, when added to that of existing pressures, does not exceed 79.

Table 2 Pressures and their intensity: IP index *Source*: Jiménez-Madrid (2011)

Pressure	Pressure intensity	
	Minimum	Maximum
Urban activities	35 Waste water treatment plant	75 Recycling centre
Industrial activities	25 Quarry	100 Nuclear waste
Agricultural activities	15 Gardens	60 Irrigation with waste water
Livestock-farming activities	25 Grazing	45 Discharge of slurry

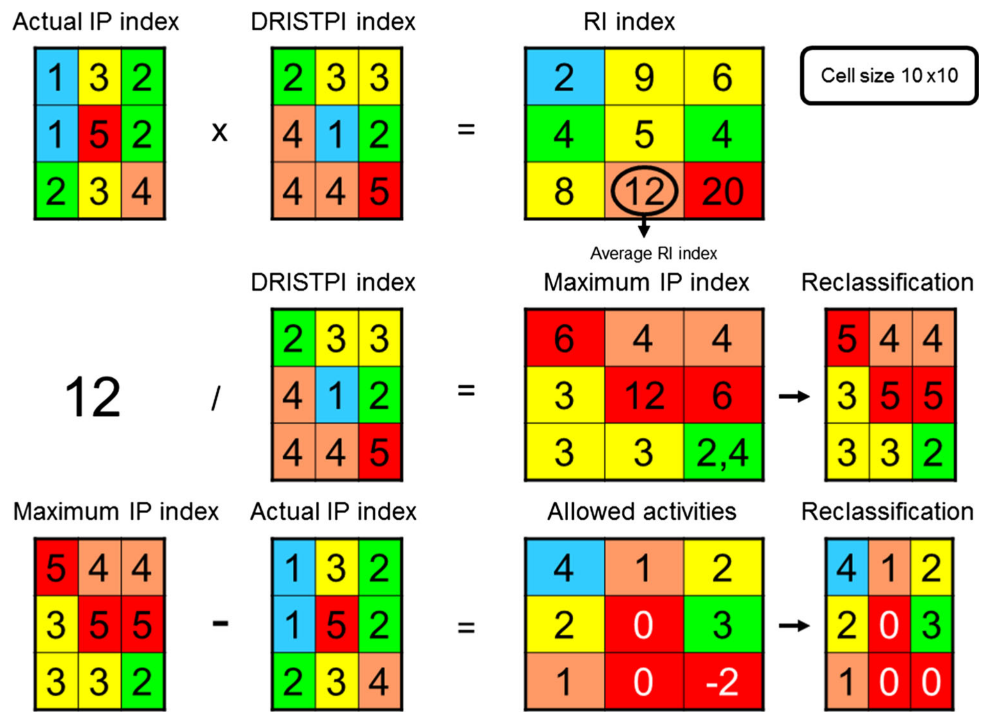

Fig. 2 Descriptions of procedures carried out to obtain maps of permitted activities

- Class 5—All activities permitted provided the resulting IP index, when added to that of existing pressures, does not exceed 100.

The map of permitted activities was obtained from the results of the IP, DRISTPI and RI indices proposed by Jiménez-Madrid et al. (2011). However, this result can be obtained using any of the existing indexes and methodologies currently employed to assess risks presented by environmental pressures and intrinsic vulnerability to contamination, provided that the indexes' results are reclassified to values from 1 (very low) to 5 (very high).

To determine the IP index from the existing pressures and the activities permitted in a given area, the index for each element must be added. In addition, the number of existing activities must be taken into consideration, as the incorporation of a particular activity in isolation—with the corresponding IP index—will not have the same effect as when 10 activities of the same type are already present.

Each class of permitted activities includes the ones below it. For example, activities in Class 3 are those whose intensity of pressure (IP index) is moderate, but those activities with a low or extremely low intensity of pressure may also be authorised.

Each class also reflects the intensity of existing pressures, but it is also necessary to consider the number of pressures. Therefore, the accumulated IP index must be considered and assessed because, even though the development of a particular activity with its respective IP index may be authorised in some of the proposed classes, they do not have the same effect if 10 activities of the same class are initiated. This is also true for several different activities with their corresponding intensity of pressure or some pressures that exceed the level established according to the criteria defined by Jiménez-Madrid (2012), because of the overlap of pressure criteria and the sum of all their intensities. In the case of Class 0 on the map of permitted activities, expropriation of land or change or relocation of activities may be necessary as long as there is a risk of defaulting on the WFD requirements for bodies of groundwater intended for human consumption.

Sometimes, the defined safeguard areas do not have the desired effect due to the already existing pollution load, as in the case of preferential infiltration areas where there are high intensity pressures. When the situation before the definition of safeguard zones and their restrictions could be unfavourable to conserving the quality of groundwater intended to human consumption, administrators may need to take the additional measures deemed appropriate based on the existing data on the water supply's quality.

Results

Protection of drinking water in the study area, the Sierra de Cañete, would require 81.3 % of the area to be defined as GPZ with different degrees of restriction. Figure 3 (Jiménez-Madrid et al. 2011) shows the map of permitted activities created for these safeguard zones, and the respective percentages of the total study area. As can be seen, the activities permitted are mainly those with a moderate or lower IP index—accounting for 45.9 % of the surface area.

Figure 3 reveals that, in 2.1 % of the area, no further activities can take place. Class 0 zones are located mainly in quarries where there is preferential flow and current activities are already contaminating the water supply. The zones where only activities with an extremely low pressure intensity (i.e. Class 1) are allowed account for 2.9 % of the surface area. These zones correspond to riverbeds, where infiltration occurs, and the north-western part of the study area, where the thickness of the unsaturated zone is relatively less and the aquifer is more vulnerable to possible contamination events.

In total, 23.2 % of the region is classified as Class 2, which allows the introduction of activities considered to imply low or quite low pressure intensity. This class of permitted activities is located in carbonate outcrops where grazing currently takes place, including the karrenfelds of Sierra del Padastro and Sierra del Padrastrillo. Activities with a moderate or lower IP index (i.e. Class 3) are allowed in 45.9 % of the total study area, which constitutes the remaining limestone materials where environmental pressures are at present non-existent.

Class 4 of permitted activities, that is, those with an IP index not exceeding 79, can take place in 7.2 % of the region, where outcrop materials are less permeable and vulnerable to contamination. Class 5, which allows

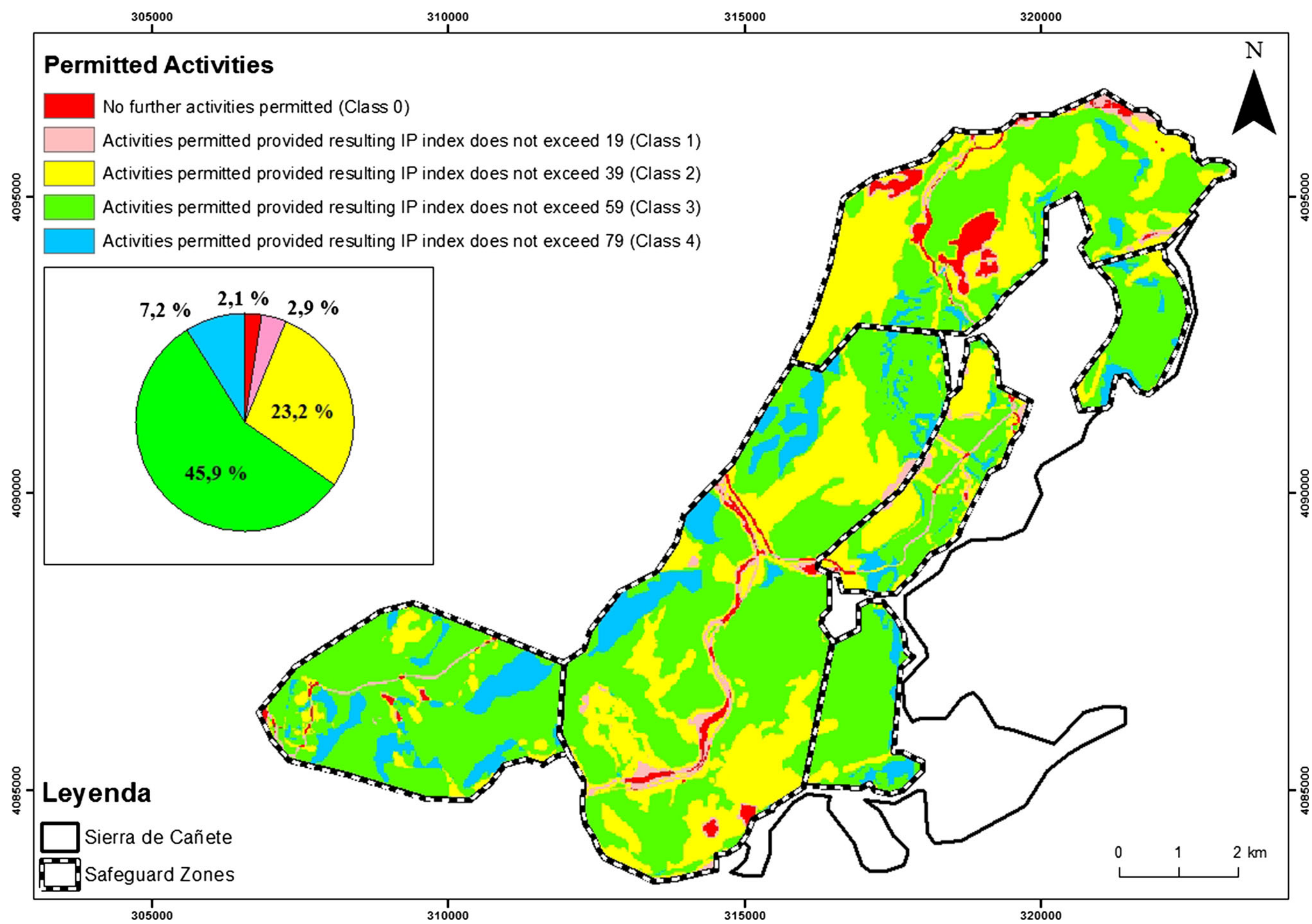

Fig. 3 Mapping of permitted activities in Sierra de Cañete (Malaga, Spain)

activities with a pressure intensity exceeding 79, is not represented in the Sierra de Cañete.

This study demonstrates the need to include an inventory of groundwater protection zones in reports on land-use planning, as is done with other landscape units, such as existing flora and fauna or geomorphological features. Once safeguard zones are defined and a corresponding map of permitted activities created, it would also be appropriate to ensure the region in question is monitored and controlled, as well as putting punitive measures in place. This way, any work or activity, whether temporary or permanent, that invades any protected zone will be subject to fines by the competent authorities, provided that the limitations imposed prohibit that activity.

Active cooperation among all stakeholders involved in groundwater protection, through public participation processes, is essential to the definition of measures and restrictions to be established. Although the relevant criteria and objectives are defined at the national level, the implementation of established measures requires the participation of local bodies, namely, autonomous communities and municipalities. This is where the role of the aforementioned Committee of Competent Authorities is extremely important.

To complete the process, administrations with authority over land management and urban areas will have to define clearly the safeguard zones and their restrictions to ensure the quality of groundwater intended for human consumption. The process needs to be reviewed of concession of new licenses for using water—taking into consideration the analyses carried out based on the proposed methodology. For example, it would be quite inappropriate to authorise a new catchment in a safeguard zone with strong to moderate restrictions or in areas where the risk of groundwater contamination is high. Compliance with WFD requirements will depend on effective cooperation among administrators and implementation of measures.

Economic assessments and reflections

This section discusses economic assessments and issues that must be taken into account for an effective implementation of safeguard zones defined with the proposed methodology. The economic impacts of implementations of safeguard areas are perceived quite differently depending on the level of administration that determines this process. At the European or member state level, the need to establish protective measures is not questioned, while, at the autonomous community level, groundwater safeguard zones are seen as necessary but difficult to implement. However, local authorities are unclear about the actual benefits of adopting these measures, in particular, if important economic activities in the area are affected. Finally, at the user level, public awareness campaigns must accompany all protection strategies.

The most notable economic impact arises from changes in land use from productive models (i.e. agriculture, farming and industry) to less productive models with a lower yield due to restrictions on the use of chemicals, changes in the type of industrial activity or limitations on placing energy lines, pipelines or roads. One factor to consider when defining restrictions on new activities is the way in which these economically affect citizens through changes in land use. Administrators need to discuss the possibility of establishing policies that could be based on compensation or credits that facilitate the economic management of the affected territories.

These economic impacts have repercussions and trigger social impacts, which are more difficult to assess. Prohibitions on new activities or movement outside safeguard zones can cause regional and social imbalances that must be analysed.

Safeguard zones also have legal impacts due to the need to adapt regional and local legislation to ensure compliance with the restrictions imposed in these zones. This legislation may conflict with, among other laws, previous legislation related to land use.

However, the definition and implementation of safeguard zones and the mapping of permitted activities also generate many positive economic impacts that are difficult to assess quantitatively. First and most obviously, the zones offer the benefit of having a water supply of enough quality to ensure, among other things, the decrease in illnesses related to different pollutants and, consequently, lower medical expenses. This can also reduce the need to resort to more expensive water sources, usually by lowering the cost of water supply infrastructure. Second, safeguard zones improve, in general, environmental quality, through not only the quality of the protected water but also the soil and associated ecosystems, as required by the WFD. All this triggers an increase in the quality of life that affects all of society, and, therefore, this impact also needs to be assessed and quantified. Moreover, defining safeguard zones as a preventive groundwater strategy intended to protect human water consumption is more desirable in terms of costs than remediation or restoration measures—assuming that they are even possible—after a contamination event.

From a qualitative point of view, it appears that the cost-benefit ratio is clearly in favour of the definition and implementation of safeguard zones. Nonetheless, it is necessary to quantify this balance in economic terms. Regardless, due to the basic need for a water supply and its relationship to the maintenance of public health and environmental quality, ensuring citizens' health through a water supply of adequate quality should be above any economic considerations.

From a quantitative point of view, the importance or relevance of particular indicators depends on the real ways that these elements are likely to condition the safeguard zones established. Bear in mind that, in each case, the protected areas are characterised by factors such as the presence of residents, farms, livestock and forests. In this way, the importance or relevance of impacts on food safety depends on features that include farms and livestock in the area or the volume of population consuming water.

For this reason, in future research estimating the importance of socioeconomic impacts, studies need to include a method of evaluating the relevance of each indicator. This relevance can be assessed based on the level or degree to which, in reality, elements that could be affected are represented, thereby enabling scenarios to be developed for each indicator.

Next steps

The delimitation of safeguard areas can be integrated into spatial land-use planning by mapping the activities permitted—a tool that can be directly applied in the region in question. This process sets a threshold value corresponding to a tolerable water environment value based primarily on the hydrogeological and climate characteristics of the area. An analysis of existing pressures identifies the current groundwater condition.

If the condition exceeds the threshold, current new activities are not allowed. When the condition is less than this threshold, different management scenarios can be created for the activities to be permitted.

This represents a management tool that accommodates different assumptions about the implementation of new zones or changes in existing zones by evaluating the economic impact of decisions. A combination of groundwater protection with the possibility of economic activities makes this methodology an effective tool for sustainable development.

This methodology has been successfully applied to several karst aquifers in Spain and Belgium, but validation for aquifers with intergranular porosity is necessary. In addition, the methodology needs to integrate socioeconomic evaluation tools for different management scenarios and their interrelationship with other protection policies to be implemented in general.

The proposed methodology—compared with traditional methods of groundwater protection—allows the same approach to be applied in different conditions (e.g. karst, intergranular porosity and mixed materials), which can often be present in the same groundwater body, the basic unit of WFD implementation. Similarly, planning policies are effectively integrated with resource protection. This is, therefore, a general methodology applicable across Europe and compatible with sustainable development, allowing economic activities compatible with environmental protection depending on the associated pressures and economic costs.

This tool also allows the integration of diverse aspects on different geographical and socioeconomic scales, making it versatile and promoting coordination between different government and decision-making levels, in order to achieve sustainable development within the spirit of WFD guidelines (see Fig. 4).

This tool promotes standardisation, which will enhance the efforts of the various agencies involved in the protection and management of groundwater used for human consumption to achieve sustainable management of water resources. This is an important contribution to the Common Implementation Strategy of the WFD, as well as land and water planning.

Conclusions

Land-use planning seeks to coordinate and harmonise policies that have an impact on regions. Water—as a public good and an essential resource for the development of life and evolution of populations—must become one of the basic pillars of the successful management of regional policies. Therefore, it makes no sense to plan water resources without taking into account land management forecasts.

To fulfil their purpose, protection zones must be incorporated into land-use planning. To this end, this paper proposes a methodology that creates a map of permitted activities. This map can be used by planners to select areas, based on flexible criteria, where pressure-creating activities can be allowed and to determine the characteristics of these activities so that the WFD objective of preserving water used for human consumption continues to be met.

Mapping permitted activities is based on a double-entry matrix that assesses the risk of groundwater contamination. This procedure involves calculating an index of intensity of environmental pressures (IP index) in combination with an index of intrinsic vulnerability to pollution (DRISTPI index) in order to characterise the risk of contamination.

An application of the proposed algorithms, using spatial analysis tools associated with a geographical information system, yielded five classes of permitted activities with varying degrees of restrictions, together with a Class 0 corresponding to areas where no new activities can take place. Each class is illustrated by a list of permitted activities, based on their corresponding IP index.

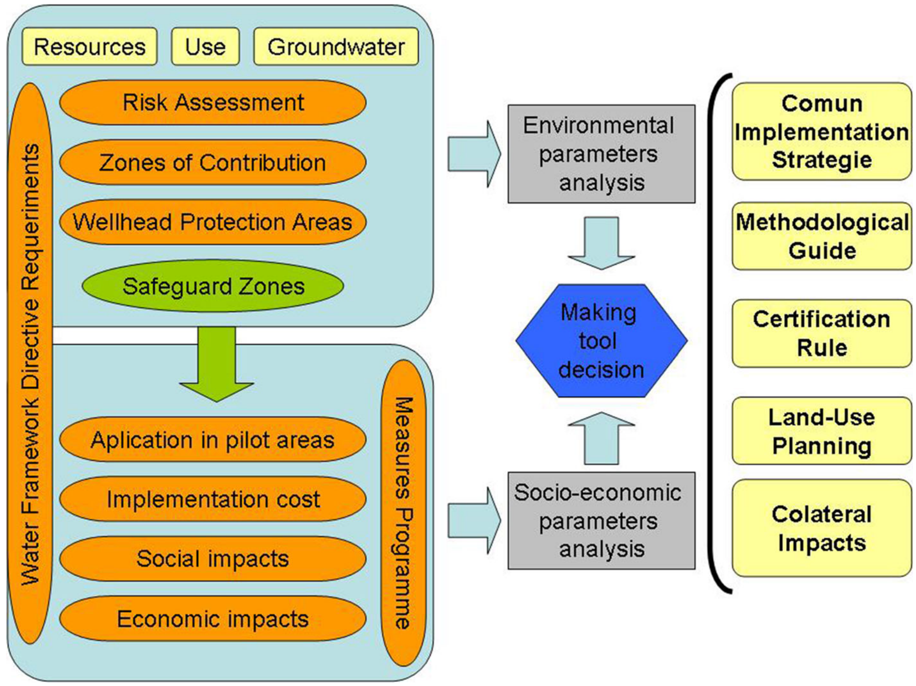

Fig. 4 Methodology for the implementation of the WFD guidelines regarding groundwater for human consumption in regional policies

The proposed method of mapping permitted activities was applied in the Sierra de Cañete. The preliminary results reflect a predominance of Class 2 zones, where activities with a moderate or lower IP index can be introduced. Only 5 % of the region (i.e. Classes 0 and 1) restricts new activities to those with extremely low pressure intensity or allows no new activities.

Zoning to protect groundwater for human consumption together with the use of activities permitted mapping as a preventive strategy constitutes a useful approach to land-use planning. However, this method requires further research to determine the possible economic impacts of its implementation, especially changes in land use that, in turn, may have social impacts and produce regional imbalances. These are factors that need to be taken into consideration and evaluated in future studies.

To ensure the method's effectiveness, safeguard zones and the associated map of permitted activities must be included in land management planning. To do this, these areas must be safeguarded as part of the measures to be considered by the Committee of Competent Authorities for inclusion in new processes of contemporary water planning. The importance of water planning as an integrating factor in land management needs to be emphasised, based on which it could be appropriate to give habitual preference to water planning measures over land-use planning and urbanism tools.

The implementation of these security measures could result in financial impacts mainly related to changing land-use patterns. These impacts and the importance given to them vary according to what each administration considers within the scope of its territorial and management processes. Economic impacts could turn into social impacts that can cause regional imbalances that need to be assessed. Nonetheless, the definition of safeguard zones to protect groundwater intended for human consumption and the use of maps of permitted activities as a preventive strategy are quite useful and valuable tools that offer benefits to regional populations.

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