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Multi-actor approach and engagement strategy to promote the adoption of best management practices and a sustainable use of pesticides for groundwater quality improvement in hilly vineyards

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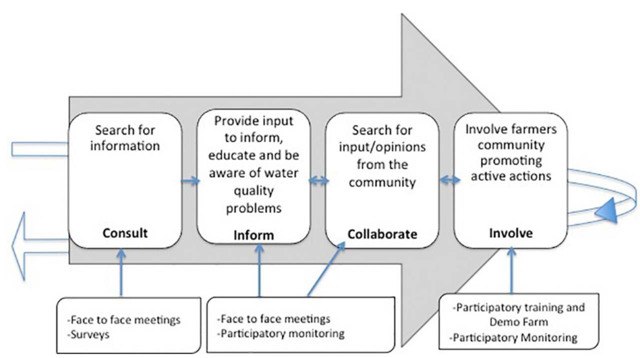
HIGHLIGHTS

- An engagement strategy to prevent groundwater contamination by PPPs was developed.
- All actors with a role in water governance and use were involved.
- Surveys campaigns were developed for the evaluation of BMPs and MMs adoption by farmers.
- Farmers are not completely aware of the water benefits given by adoption of BMPs and MMs.
- Proactive information about challenges in water quality are essential for BMPs adoption.

GRAPHICAL ABSTRACT



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ABSTRACT

The adoption of pesticide mitigation measures and innovation at farm level, are seen as a drivers to reach the sustainable water policy objectives. With the aim to prevent the pesticide pressure of hilly vineyards on groundwater contamination, a stepwise approach in Tidone Valley was applied using different consultation mechanisms and involvement strategies throughout the overall process. Face to face meetings, direct surveys, participatory monitoring and planning of several activities aiming to inform, educate, improve skills, change of individual behaviour or raise awareness, or even initiatives to build institutional trust or support for new investment in innovation are some examples. These activities allowed us to involve key actors of water use and governance (such as farmers, advisors, representatives of drinking water management, farmer's associations, Winemaking cooperatives, local Health Authority), and to have a deeper knowledge of the context agricultural practices, of farmer's knowledge and skills concerning factors influencing water contamination and also to promote the most suitable Best Management Practices aimed at limiting the pesticide occurrence in groundwater. Indeed, the surveys results highlighted that the majority of the farms are small (64% of vineyards <10 ha), that most of the farmers (62%) are not aware of the current legislation on water, even if 64% of them declare to participate regularly to training courses for the prevention of water contamination and that there is a low to moderate level of adoption

Abbreviations: SUD, Directive on Sustainable pesticide Use; WFD, Water Framework Directive; BMPs, Best Management Practices; MM, Mitigation Measure; PPPs, Plant Protection Products; EQS_{gw}, Environmental Quality Standards groundwater.

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of Best Practices able to prevent contamination by pesticides. At the end of the overall process, it can be stated that the multi-actor approach and engagement strategy adopted were successful in improving attitudes to more sustainable practices. This is supported also by the monitoring data that show in 2019 a decrease by 44% of pesticides occurrences and a fall by 68% of values above EQS_{gw} if compared with the period 2017–2018.

1. Introduction

Sustainable agriculture is a key objective of the European Union and a focus of its sustainable development policies. In this framework, adequate solutions are considered necessary to contrast negative impacts to human health and the environment, connected with the use of chemicals as pesticides. (COM, 2003).

At present, approaches are mainly based on regulatory interventions including the approval for placing on the market, after a very comprehensive risk assessment, each active substance as well as the products containing that substance, with Regulation 1107/2009/EC, (EU, 2009) and for the use phase of pesticides in agriculture with the Directive on Sustainable pesticide Use (SUD), (EU, 2009), and the required National Action Plans, adopted by Member States that should contain quantitative objectives, targets, measurements and timetables to reduce the risks and impacts of pesticide use.

This legal framework gives the possibility of implementing risk-mitigation measures to supplement the product approval conditions, with the aim to set specific practices of application of the products that will further limit human and environmental exposure. Awareness and understanding of the implication of labelling instructions is a critical factor, to ensure that products are applied according to the conditions designed in the risk evaluation process, so that to ensure that safety rules and protection goals are met (Alix and Capri, 2018). In parallel, the Water Framework Directive (WFD) is the principal legislative instrument for protecting water resources and to endorse sustainable water resource management at European level. Main challenges addressed by WFD are also found in other of the policy-oriented sustainability assessment approaches such as those promoted to achieve the sustainable use of pesticides (Water Framework Directive (WFD), 2000).

The implementation of such legislation influences the production in the agricultural sector, but the effectiveness of these laws can be reduced or slowed by several factors. As stated in the latest report of Commission (COM 587/2017) the National Action Plans set in conformity the SUD “suffer from delays, are developed mechanically to strictly comply with a pre-set list of measures, resulting in minimal changes in practices and with not sufficient impact to preserve or restore water quality”.

Member States are currently working on reviewing their first plans although there has been substantial progress, the report identifies that there are significant gaps in many areas of the plans, for example in relation to [..] “information to the public, the gathering of information regarding poisoning cases, measures to protect the aquatic environment” (COM 587/2017). In Italy, despite the various measures taken to prevent or to minimize the impact of agricultural activity on water contamination, the results of pesticides water monitoring reveal, in several cases, an inadequate quality of the aquifers and surface water, limiting the achievement of national WFD objectives. Some compulsory measures like training, storage, equipment inspections or respect of nonspray zones are in place at national level, but their effectiveness cannot really be assessed since it is not possible to understand if they have been implemented properly by all farmers. UC Davis Agricultural Sustainability Institute states that “*making the transition to sustainable agriculture is a process. For farmers, the transition to sustainable agriculture normally requires a series of small, realistic steps. Family economics and personal goals influence how fast or how far participants can go in the transition*” (Calliera and Lastorina, 2018). Recent review on factors influencing farmer's adoption of Best Management Practices suggest to focus on study scale, including micro (farms) scale, on measuring and modelling of adoption as a continuous process, and on incorporation of social norms and uncertainty into decision-making (Liu et al., 2018).

The adoption of mitigation measures and innovation at farm level, is seen as a strategy or driver to reach the sustainable policy objectives. But different problems in addressing the challenges are present, especially at farm level. It is supported by a recent growing body of literature, that sustainable agriculture is not the result of a simple linear, one-way process that goes from the scientific production of technics or knowledge to its application, but the result of complex “systemic interactions” between different subjects involved in various ways (GCSA, 2014). The community involved in pesticide risk analysis and pesticide use is highly diverse, including all interested and affected parties such as regulatory risk assessors, risk managers and risk communicators as well as applicants for product authorization, the wider scientific community, consultants and farmers. Several EU research projects (e.g. BROWSE, HEROIC), given the enormous variability and uncertainty associated with the behavioural component that characterizes the pesticide use activity, agreed that there is a need for improvement in measuring different stakeholders risk perception to increase trust in the pesticide risk evaluation process, and then the pesticide use according to the conditions designed in the risk evaluation process and in the labels. Research in HEROIC project highlight that socio-behavioural aspects are not generally addressed except for very few cases, and commonly, it is argued that engagement in unsafe pesticide use and disposal practices is the result of a lack of knowledge and misperceptions of the risks associated with pesticides amongst operators and workers (Calliera et al., 2016). Research in EU Browse project regarding Operators, revealed several short-comings in terms of appropriate behaviour (mainly concerning wearing appropriate PPE, use of the recommended spray volume, compliance with wind speed limits and applying of measures to avoid and address unintended events during application, variable linked to climate condition) (Sacchettini et al., 2015). Recent works analyse farmer's risk perceptions regarding pesticide use (Remoundou et al., 2014) to stimulate their sustainable behaviour and compliance to Good Agriculture Practice (GAP) as written in the pesticide labels. In all these projects and research, a participative and inclusive approach is considered as necessary in all phases of the relationship with stakeholders, in a bottom up perspective starting from a deep understanding of the farmers realities and behaviour of the various actors, to more interactive communication and demonstration strategies, up to training activities that overcome the traditional top-down (from expert to farmers) approach and consider local knowledge as an important key for the transition towards sustainability (Calliera and Lastorina, 2018).

This paper complements this stream of works by evaluating the farmers intentions to adopt sustainable agricultural practices to limit or prevent water contamination and by analysing the bottlenecks in their implementation. The study is part of a broader project on water governance, funded under the EC program H2020, WATERPROTECT, which aims to contribute to a better knowledge and understanding of how water governance is organized at catchment level and how the agricultural activities can be improved in order to limit their impact on drinking water. The Italian case study considers three catchments in Tidone Valley, northern Italy, characterized by an intensive viticulture production.

In particular, the present study aims to develop a communication and engagement strategy effective in providing good agriculture practices and a comprehensive and acceptable list of pesticide mitigation measures able to prevent or limit the pressure of hilly vineyard cultivation on groundwater contamination in Tidone Valley. In the following paragraph will be described the engagement methodologies, the strategies, the analysis of point source and diffuse source of water contamination at context level and also the strategies adopted to reduce the water contamination.

2. Materials and methods

2.1. Area of study: Tidone Valley

The study area is Tidone Valley, located in the north-west of Italy in Emilia Romagna region, in the province of Piacenza (Fig. 1). The landscape variety of the province influences its agricultural productions, particularly extensive in the plain; viticulture has been properly focused and established in the hilly area. Indeed, Tidone Valley represents a hilly zone characterized by an elevation level between 100 and 350 m above sea level and it is known for the deeply rooted tradition and vocation to viticulture. As described by Zambito Marsala et al. (2020) the area is characterized by a mix of urban, peri-urban and rural areas and covers five municipalities for a total of 28.548 inhabitants (10% of total province inhabitants). The main culture is vines, with 2.941 hectares in 2016 (75% of total ha of the province) and the inhabitants of the rural villages are mainly involved in grape and wine production, organized as private farms or as wine cooperatives. The peculiar orographic features of the territory have determined the development and adoption of agricultural/hydraulic plumbing systems that represent a sort of mitigation measure applied in order to limit the erosion and control the water speed, slowing down the water flow that shapes hills, turning them into an orderly sequence of longitudinal lines.

In total 455 farms were present in 2017 in the study area (CCIAA, 2017, https://www.pc.camcom.it/, data available on request). Two types of farms structures are present:

1. Vineyard with a cellar. In this case, grape transformation into wine and wine retail is independent. This is the case for 25% of the total vineyards present on the investigated area.
2. Vineyard without a cellar. In this case, grape growers deliver their grapes to wine cooperatives. This is the case for 75% of the total vineyard surface present on the investigated area. The situation is characterized by many farms with small/medium vineyard area and few farms with a very large vineyard area.

The groundwater in the area is rather susceptible to this production, as demonstrated by Zambito Marsala et al. (2020) that shows the occurrence of pesticides used for grape cultivation in 80% of a total of twenty-six groundwater wells monitored in the period November 2017 – September 2018. In addition, 30% of the twenty-six groundwater wells have values for seven pesticides above the Environmental Quality Standard (EQS) for groundwater. Suciu et al. (2020) highlighted that these occurrences and concentrations are related to both diffuse and point source contamination, with the point source having an important contribution for the wells located in low slope soil, where the water drainage and its lateral movement are low.

2.2. Community engagement and stakeholders participation at the scale of study area

A complex socio-ecological issue such as water quality related to agriculture cannot be solved by just one actor but rather from a multi-actor approach perspective (Els Belmans, 2018). As stated in the introduction, sustainable agriculture is the results of complex “systemic interactions” between different subjects involved in various ways, such as researchers, farmers, entrepreneurs, regional and national organizations etc. All of them have different forms of knowledge (practical, scientific, policy based, etc.) and there is the need to create conditions for interaction between them and combine their knowledge, perspectives, resources, and experiences, to identify and discuss solutions and new ideas. Therefore, in the present study, all actors considered to have an influence on, or that are influenced by, the water and the farming systems were engaged in the study activities.

Since it is recognized that at context level an “ideal approach do not exist”, in our study the engagement design was conceptualised as an

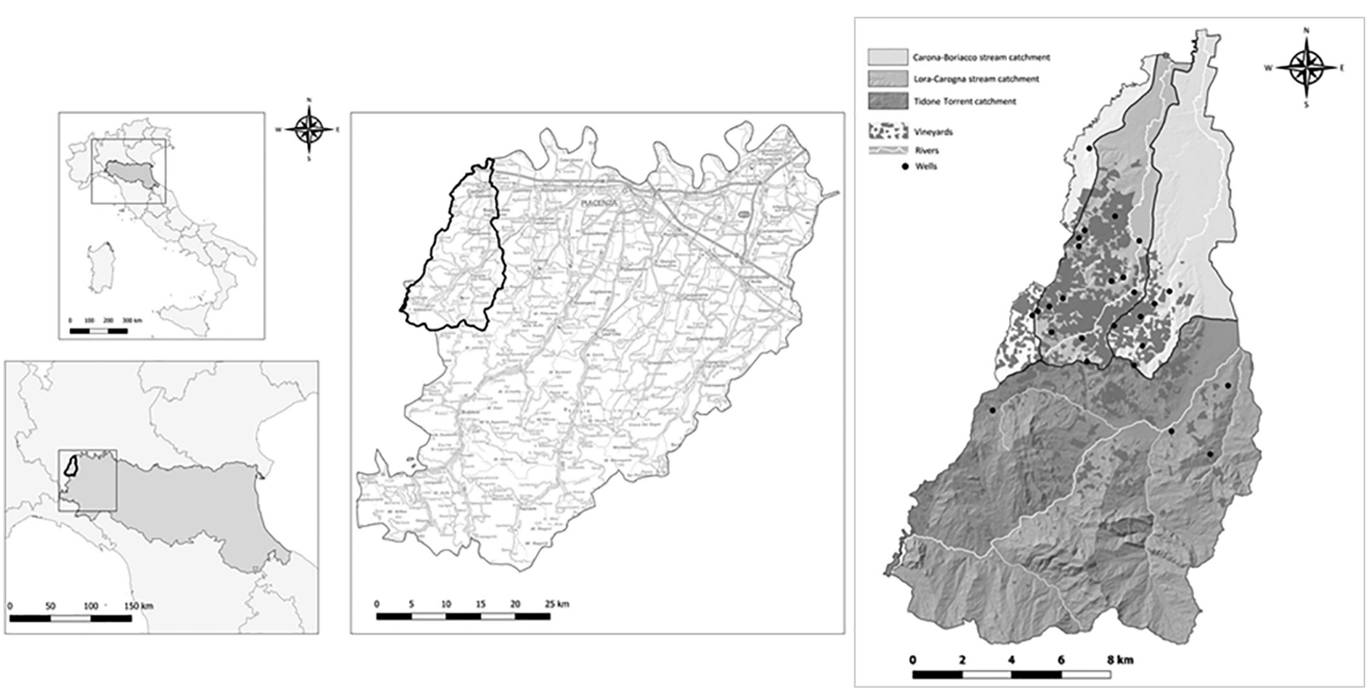

Fig. 1. Area of study: Tidone Valley.

"active engagement". All stakeholders that adequately represent the views of the broader community were engaged, interviewed, involved in the process of collecting data and spreading the information. The bilateral conversation and multi-actor conversation were fundamental in establishing effective and productive relationships to enable a shared understanding of goals or a shared commitment to change and to ensure that public and farmers concerns and aspirations are understood and considered. To be as efficient as possible, and with the purposes to (i) increase the knowledge concerning the level of pollution, (ii) increase the awareness concerning the pollution prevention (iii) facilitate the access BMPs and training and increase the interactions with the experts, it was decided to adopt a stepwise approach that included both water quality analysis and stakeholders analysis, with different levels of participation that range from the consultation to the active involvement, as described in Fig. 2.

This approach led to a range of different strategies throughout the overall process, such as face to face meetings, direct survey, participatory monitoring and the planning of several activities aiming to inform, educate, improve skills, change of individual behaviour or raise awareness, or initiatives to build institutional trust or support for new investment in innovation and synthetized below.

- The *face-to-face meetings* (such as seminars, workshops, community events, or site tours) are a qualitative "dialogue-based method". The advantage is that it allows greater spontaneity and interaction between the researcher and participant, who has the opportunity to respond more elaborately and in greater detail. In turn, researchers have the opportunity to respond immediately to what participants say by tailoring subsequent questions to information the participant has provided (Calliera et al., 2016). This method was adopted throughout the project to obtain information, provide information and knowledge, give adequate and accessible information on the project and on the course of the process, and also to exchange opinions.

- *Surveys* are questionnaire-based quantitative tools, where stakeholders are requested to individually answer questions by choosing from a limited number of provided answers. Because there are only multiple-choice questions, it represents an efficient way to obtain sufficient data in a short time. However, as a passive consultation method, it doesn't allow a deeper discussion (Calliera et al., 2016).

The surveys in the study were conducted by trained survey operators, to ensure the 'consistency' of the responses. This methodology was adopted in the first phase of the project in order to obtain information on the existence in the study area of groundwater wells, on best management practices and pesticide mitigation measures already implemented to avoid diffuse and point sources water contamination and on the willingness to implement new proposals, but also on the interest of farmers to participate in the project.

- *Participatory monitoring*. In Italy monitoring is usually conducted by environmental agencies (in our case ARPAE) and designed for the status evaluation and trend assessment of water bodies in respect to WFD and are not planned to assess the effectiveness of the measures introduced to prevent or limit the inputs of pollutants. The engagement of farmers in the design and the setup of water monitoring, as well as in the results of the monitoring through the appropriate ICT tools and monitoring apps available in the project website (https://water-protect.eu/en), are fundamental to increase the credibility of the monitoring data and help to reduce the information gap between farmers and monitoring agencies (Els Belmans, 2018)

- *Participatory training approach and demonstration farm*. In Italy a system of compulsory certified trainings for professional users, distributors and advisors is established by the National Action Plan as requested by the Directive on Sustainable pesticide Use 2009/128/EC (EC, 2009). The competent Regional or Provincial authorities shall assess the knowledge acquired by course participants by means of an examination. However, as reported in the Standing Committee on Agricultural Research (SCAR, 2015) report, this method of teaching does not necessarily imply a change of behaviour or adoption of innovation, especially in agriculture. Indeed, traditionally, for farmers the changing of farming management practices is full of risks (e.g. economic) that have to be managed. To be effective, a context specific training should understand how farmers make up their decisions and link knowledge to actions to identify the so-called training need that is "the gap between what is and what should be in terms of incumbents' knowledge, skills, attitudes, and behaviour for a particular situation at one point in time" (FarmPath project, 2014, https://farmpath.hutton.ac.uk/). These activities have also been associated with recreational events such as dinners, concerts, scientific coffees; this is to encourage the aggregation and sharing of different experience (students, professionals, citizens, etc.) and to increase the awareness of the community about the efforts and commitment necessary to achieve a more equitable and sustainable future, where at the centre there is the figure of a responsible farmer.

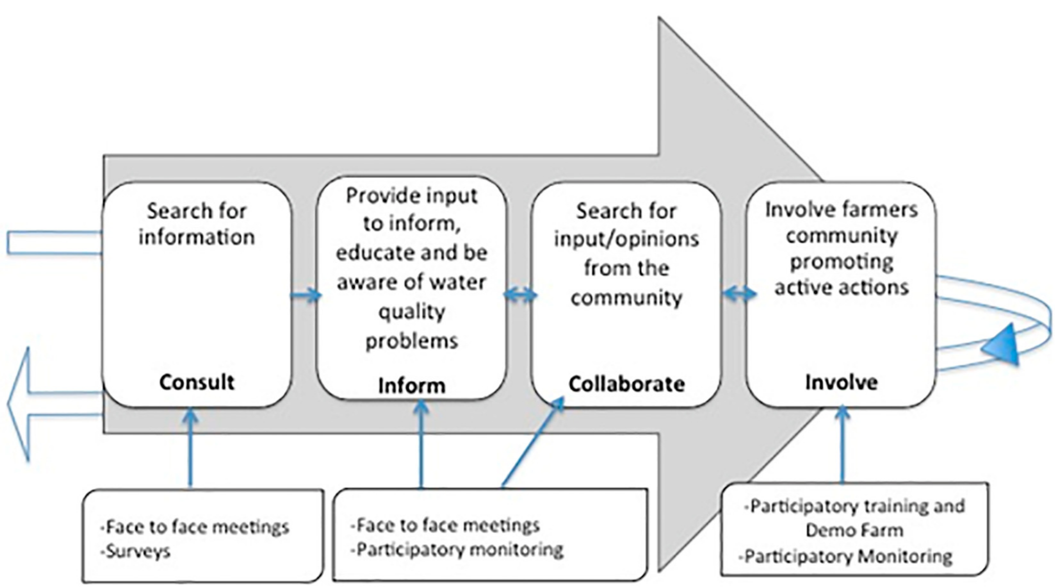

Fig. 2. Stepwise approach and levels (in bold) of participation.

2.2.1. Stakeholders involved

The stakeholders involved as key actors were met individually during the first phase. This occurred thanks to the presence in the working group of individuals operating in the area who have a good reputation and credibility from previous work carried out in the territory, like the regional environmental Agency - *ARPAE-ER*, the consumer Association PiaceCiboSano – *APCS* and the Catholic University - *UCSC*.

The key actors engaged were: the regional drinking water management company – *IRETI*, the provincial plant health farmers consultancy - *Consorzio Fitosanitario Provinciale*, the three farmers' associations present on the territory - *Confagricoltura*, *Coldiretti* and *CIA*, the local manager of irrigation water in Val Tidone catchment - *Consorzio di Bonifica*, one of the two Wine cooperatives present in the territory - *Vicobarone*, the farmers' organisation *Consorzio Vini Doc Colli Piacentini* and the local Health Authority - *AUSL*. All were contacted by phone or by email, interviewed and involved in the process of collecting data, of contacting and engaging grape growers, spreading both the information and the work progress as well as the outputs. Finally, with their contribution were involved 175 grapegrowers, coming from: Ziano Piacentino, 50.3%, Alta Val Tidone, 16%, Castel San Giovanni,9.7%, Pianello Val Tidone, 6.9%, Borgonovo Val Tidone, 4.6%, and other areas and municipalities, 12.5%. However the selection of strategic places and time periods was fundamental for farmers engagement. Indeed, in the first phase 97 farmers were met during the grape delivery at the Wine cooperative Vicobarone, in the structures of the social cellar, while 40 farmers were met in the offices of farmers unions Coldiretti, Confagricoltura and CIA, during the declaration of the quantity of grapes produced. Finally, the remaining 38 were met directly in the estates or by phone. Also newsletters and media campaigns, with articles in local newspapers were used as instruments for information purposes on the initiatives.

In a second step, the regional and catchment leaders of water governance, Emilia-Romagna Region and catchment Authority of Po River, ADPO, were involved. For their involvement, the use of preliminary data from groundwater monitoring and surveys about farmer's practices was fundamental.

2.2.2. Strategies adopted for farmer engagement and the analysis related to sustainable use of pesticide

2.2.2.1. Surveys - conceptual framework. Sustainable water management shall ensure the achievement and maintenance of the good water status, meeting legal and/or agreed quality standards in all affected river basins, as requested by WFD (EC, 2000). Water pollution is a global challenge and agriculture represents in many cases a pressure on water quality, mainly due to the use of pesticides. Water contamination by pesticides used in agriculture could be caused by both diffuse and point sources contamination, the latter should to be considered mostly accidental.

Good Agriculture Practices and Mitigation Measures are key components in defining the conditions of use of pesticides in crop protection strategies. They are specific to the type of risk they intend to mitigate, for example, they may consist in a recommendation for special protection for users while handling the product, or to adjust the conditions of use to minimize transfers to groundwater.

Based on the conceptual framework, in the project several hypotheses are put forward to be tested. The list of the hypotheses is as follows:

- viticulture could be a source of water quality pressure the study area;
- farmers are not aware of the current and local legislation on water
- farmers are not aware of local monitoring data for pesticides and nitrates in surface and groundwater;
- farmers are not aware of good practices and mitigation measures efficacy in limiting or preventing water contamination;
- compulsory training courses on sustainable pesticide use needs to be improved

In detail, water contamination by pesticides could be caused by both diffuse and point sources contamination, the latter should to be considered mostly accidental. In order to understand the contribution that the farming system of our study area can have on water quality, two survey campaigns were carried out.

The first was undertaken between August–November 2017, and the second - in the period of March–May 2018. The dates on which the surveys were carried out are directly connected to the starting time of WaterProtect project and to the availability of the farmers, who were more available in that period as the work in the vineyards is less pressing. Questions related to the type of grape cultivation (following the integrated pest management), number of PPP applications and type of PPPs (insecticides, fungicides and herbicides) and the management of point sources contamination were included in the questionnaire submitted in the first survey while the second survey focused mainly on mitigation measures and good agricultural practices for limiting or preventing drift and runoff for hilly vineyards (with a slope > 2%).

2.2.2.1.1. Survey 1. Data collection took place through face-to-face interviews conducted by trained survey operators and involving 175 farmers, 38.5% of the total farms acting in the study area. The respondents were informed about the survey goals before the interview and farmers were interviewed on the basis of their willingness to participate in the project. To reach a higher number of respondents, a mixed tools and approach were adopted (such as direct interviews in farms, in the Cellars, indirect interviews by phone call, one line questionnaire…). Indeed, 97 farmers were interviewed during the grape delivery to the Wine cooperative Vicobarone, in the structures of the social cellar, while 40 farmers were interviewed in the offices of farmers unions Coldiretti, Confagricoltura and CIA, during the declaration of the quantity of grapes produced. Finally, the remaining 38 were interviewed directly in the estates, by phone and for farmers whose familiarity with IT tools was known, an on-line questionnaire was submitted.

The questionnaire was composed by 24 multiple-choice questions and was divided in the following four different parts:

- presence of wells, depth, use of well water;
- fertilization and phytosanitary treatments: use and frequency;
- sustainable pesticide use and prevention - respect of good practices and mitigation measures;
- knowledge and awareness of the problem (possible pressure of viticulture on ground water quality)

The frequencies of the observations for homogeneous groups was analysed using Microsoft Excel.

Observation of BMPs, correct behaviours in the pesticide management at farm level and adoption of innovative technologies as bioremediation systems were selected as measures with high level of efficacy to limit or prevent point source contamination.

Some measures, such as sprayer technical inspection, were not taken into account in the survey, as mandatory under Directive 128/2009/EU and subject to official inspections and sanctions. Indeed, regular technical inspection of pesticide application equipment is compulsory by Article 12 of Legislative Decree 150/2012, and shall be performed by dedicated Test Centres. In addition to that, professional users shall conduct adjustments and calibrations of equipment used, in order to ensure pesticide mixtures spraying in correct amounts and equipment's proper working conditions, thus guaranteeing high level of safety and protection for both human health and environment. For this reasons questions on these topics were not included in the questionnaire.

2.2.2.1.2. Survey 2. Out of the 175 farmers involved in the first survey, fifty farmers were selected and involved in the second survey, based on the interest showed for the present research and the size of their vineyards, possibly adjacent to the monitoring wells. In particular, 30 farmers have vineyards with less than 10 ha surface area (62% of total farmers), 18 in between 11 and 40 ha (36% of total farmers) and only 1 farmer has a vineyard with a surface area higher than 40 ha. The total acreage of land whose owners responded to the questionnaire was 599 ha. The frequencies of the observations for homogeneous groups was analysed using Microsoft Excel.

MMs selection was carried out using as reference the MagPie toolbox (MAGPIE SETAC, 2017) and the latest available version of the Italian Ministry of Health Guidance Document on the topic (Azimonti et al., 2017) and following four main criteria: (i) applicability at our landscape conditions, (ii) availability for implementation, (iii) sufficient knowledge/level of confidence and strength of scientific evidence, and (iv) possibility to demonstrate or measure the efficacy of the GAPs and MMs to support their implementation.

The MMs and BMPs selected and suggested in the survey to limit or prevent diffuse contamination in vineyard with slope > 2% are listed in the Table 1. The runoff MMs selected and monitored in the survey have a high level of efficacy as they are located near the runoff source or where runoff/erosion starts (as for Vegetated Filter Strip), and/or may provide additional benefits for soil conservation and erosion prevention and for reduction of nitrate leaching. For drift two type of drift reduction strategies were identified: no spray zones and use of spray drift reduction technology. As stated in literature, the selected and monitored mitigation measure allow high percentage of drift reduction (MAGPIE SETAC, 2017).

Therefore, the survey's aim was to select the measures most fitting to our vineyard conditions and to obtain information for:

- farmers knowledge about factors influencing run off and drift and skills or ability to identify specific risk situations. The knowledge of the factors involved in the contamination processes allow to adopt behaviours or structural changes aimed at limiting and controlling the occurrence.
- existence in loco of selected MMs and farmers knowledge and skills for MMs implementation and management, acquired through experience or education, and MMs efficacy in limiting the contamination;
- farmers motivation and availability to implement the MMs suggested and, if not, their motivations and barriers.

Table 1
MMs and GAPs selected and suggested to farmers reduce water contamination due to run off and drift at catchment level.

Run off	Knowledge	MMs for reduction run off and erosion
	Proximity of field to the water bodies (adjacent, not adjacent)	Vegetated filter strip (VFS) at edge-of-field In field vegetative filter strips (VFS) as grassed talwegs at landscape level
	Presence or observed concentrated runoff or moderately concentrated run off in the field	Artificial wetland or retention pond
	Knowledge on slope and soil texture influence on run off	Vegetated ditches
		Inter-row processing and weeding on the row Permanent grassing in the row and weeding on the row Optimize irrigation timing and rate using Decision Supporting System
Drift	**Direct**	**Indirect**
	Adoption of several technical devices for drift reduction and special equipment to reduce spray drift as Air Injection Drift Reducing Nozzles (DRN), and other machinery equipment	Buffer strip of size (width) not less than 5 m and not more than 15 m depending on the type of spraying material
	Last row sprayed from the outside towards the inside	Adoption of vertical barriers able to intercept the drift (hedges, trees, artificial windbreak) in addition of the buffer zone Anti-hail net

2.2.2.2. Monitoring activities within the study area in the framework of participative engagement. The focus of the monitoring campaigns was the occurrence of pesticides in groundwater, resulted relatively exposed to pesticides used for grape production, as demonstrated by Zambito Marsala et al. (2020). Therefore, in our strategy, in order to achieve a change, farmers must first of all, be aware of the problem of water quality, independently of the social pressure. Indeed “risk is what matters to people” (Renn, 1998). Typically an individual is willing to accept a higher risk if it is associated with a personal benefit (e.g. pharmaceuticals). Vice versa people are much more risk averse when they do not expect a direct personal benefit (e.g. concerns about pesticide application) (Wilks et al., 2015). Being themselves users of groundwater for drinking purposes or personal care, farmers perceive drinking water quality as an important issue. Therefore, if data presented to them is related to drinking water in a communication context aimed at raising awareness and risk-benefit considerations, farmers could be more motivated in adopting technical practices or behavioural change improving their environmental performance.

This is why, in order to increase farmers interest on the monitoring campaign and data, they were engaged in the development of wells monitoring network and selection of pesticides to be monitored.

In addition, to collect data on PPPs with the highest use and sale in the study area an expert judgement consultation was conducted. All the obtained information, was then compared with the indications given by the Integrated Pest Management guidelines of Emilia-Romagna Region (http://agricoltura.regione.emiliaromagna.it/produzioni-agroalimentari/temi/bio-agroclimambiente/agricoltura-integrata/disciplinariproduzione-integrata-vegetale/Collezione-dpi/2019/norme-generali-2019) for the active ingredients authorized for grapevine cultivation and the most recent data concerning the active ingredients quantity sold in Emilia Romagna Region. Collection of data about the main diseases affecting the grapevine, through interviews with the technicians of the Provincial Plant Protection Consortium and other local stakeholders, allowed the identification of the pesticides mostly used in the study area. For more details on pesticides selection and monitoring outputs please refer to Zambito Marsala et al. (2020).

However, the list of pesticides monitored, the application frequency and amounts, the occurrences and amounts in groundwater, as above or below the Environmental Quality Standard for groundwater (EQS_{gw}), and the information on their hazardousness for both human health and environment are summarised in Tables 2 and 3. The ISTAT data, elaborated by AAAF (Gruppo di lavoro Fitofarmaci) group, concerning the active ingredients quantity sold in Emilia Romagna Region in 2012 (no other recent data was available) confirm the high use of our monitored PPPs in Emilia-Romagna Region, with values ranging between 16 kg (Cyflufenamid) and 117,069 Kg (Chlorpyrifos).

(http://www.appa.provincia.tn.it/fitofarmaci/programmazione_dei_controlli_ambientali/Criteri_vendita_prodotti_fitosanitari/pagina123.html). The EQS groundwater for the active ingredients correspond to the limit for drinking water and is 0.1 μg/L. The contextualisation of the monitoring results, by giving the information collected and presented in the Tables 2 and 3, should improve the results communication in the process of participatory water governance, towards farmers and citizens.

3. Results

The involvement of all the actors of the study area, having a role in water governance and water use, allowed us to characterise the territory, to have a deeper knowledge about agricultural practices, farmers knowledge and skills concerning pesticides handling and water protection but it also allowed us to promote the most suitable MMs and BMPs.

The main outputs of the two surveys and of the participatory activities are presented in the following sections.

3.1. Survey 1

The total acreage of farms, of which owners responded to the questionnaire, was 1088.2 ha. In particular, 64% of vineyards are less than 10 ha surface area, 25% of vineyards are between 11 and 39 ha surface area, 7,5% of vineyards are more than 40 ha surface area and 3,5% didn't give an answer. 44% of the farmers follow the integrated pest management guidelines for grape cultivation and in 107 farms there is a groundwater well, used for drinking (8%), irrigation (18%) and for treatments mixtures (80%) and only small percentage is not used (4%). For 88% of the respondents the PPPs treatments carried out within a year are less than 10, mainly fungicides and insecticides, while 95% of them haven't been involved before in projects or actions that concern the prevention of water contamination. Furthermore, 62% and 90% of farmers are not aware of the current legislation on water and of monitoring data for pesticides and nitrates in surface and groundwater in Val Tidone, respectively, even if 64% of them declare to participate regularly/have participated in training courses concerning the prevention of water contamination.

Lack of information exchange between farmers in Val Tidone on water contamination as well as the existence of geographical information systems (GIS) that allow to visualize the vulnerability of water to pesticides, was highlighted by 80% of famers. However, 50% of them are not interested in using such tools and 66% do not perform farm analysis to identify built-up areas, areas frequented by the population and protected natural areas. A regional resolution has recently been approved (Resolution of the Regional Council n.2051 of 03 December 2018, which replaces the previous Resolution n.541 of 18 April 2016) which, as required by the PAN, incorporates specific obligations regarding these issues at local level. This information has become part of the compulsory course program. Finally, 54% of farmers expressed interest for participation to information and training courses and 40% allow the use of their well for monitoring PPPs and nitrates occurrences in groundwater.

Regarding the answers to questions related to point source contamination, the results pointed out that:

- Sprayers washing in dedicated areas equipped with waste water recovery or disposal systems are present in 39% of farms;
- Dedicated areas for mixing and filling sprayers are present in 44% of the farms. Of these, 19% are used for both sprayer washing and waste management at the end of the treatment while 28% are used just for external sprayer washing;
- Storage of pesticides in appropriate places and proper disposal of containers are applied by 90% of respondents. Correct handling and appropriate storage of plant protection products and for treatment of their packaging and remnants is compulsory. By 1 January 2015 all professional users have to comply with provisions of Annex VI of the Italian National Action Plan; these obligations are easily controllable and linked to sanctions for non-compliance
- 40% of farmers are interested in the adoption of bio purification system to treat the wastewater collected after sprayer washing. It is significant that almost half of farmers are willing to do more to protect the environment going beyond existing rules.

Table 2
List of pesticides monitored, their frequency and quantity of use and occurrences in groundwater.

Category: pesticide	Frequency (max)	Amount	Detected in water monitored[d] (yes/no)	Over the legal limits (yes/no)
Chlorpiriphos	1 per year[a]	360 g/ha[a]	Yes	Yes
Chlorpiriphos-methyl	1 per year[b]	230 g/ha[b]	Yes	No
Chlorantraniliprole	1 per year[a]	54 g/ha[a]	Yes	Yes
Cyflufenamid	2 per year[a]	25 g/ha[a]	Yes	No
Cyprodinil	2 per year[b]	300 g/ha[b]	No	No
Dimetomorph	3 per year[b]	250 g/ha[b]	Yes	Yes
Flufenacet	4 per year[a]	1.350 g/ha[a]	Yes	No
Fluopicolide	3 per year[a]	133 g/ha[a]	Yes	Yes
Isopropalin[c]			No	No
Metalaxyl-M	3 per year[a]	97 g/ha[a]	Yes	Yes
Metsulfuron-methyl	3 per year[a]	6 g/ha[a]	Yes	No
Penconazole	3 per year[a]	40 g/ha[a]	Yes	Yes
S-metolachlor	1 per year[a]	1920 g/ha[a]	Yes	Yes
Tetraconazole	3 per year[a]	30 g/ha[a]	Yes	Yes
Tribenuron-methyl	3 per year[a]	30 g/ha[a]	No	No

[a] The frequency and amount values derive from EFSA peer reviews.
[b] The frequency and amount values derive from label.
[c] Revoked.
[d] Sampling campaigns were made from November 2017 to September 2019.

Table 3
Pesticide monitored in the catchment and additional information for communicative program.

Category: pesticide	Classified as hazardous to the Aquatic Environment	Classified as hazardous to human health	Considered as pollutant by the local/national legislation
Chlorpiriphos	H400, H410	H301	No
Chlorpiriphos-methyl	H400, H410	H317	NP
Chlorantraniliprole	H400, H410	H319, H335	No
Cyflufenamid	H400, H410, H411	H332	No
Cyprodinil	H400, H410	H317	No
Dimetomorph	H411		No
Flufenacet	H400, H410	H302, H317, H373	NP
Fluopicolide	H400, H410		No
Isopropalin	H400, H410		No
Metalaxyl-M		H302, H318	NP
Metsulfuron-methyl	H400		No
Penconazole	H400, H410	H302, H361d,	NP
S-metolachlor	H400, H410	H317	No
Tetraconazole	H411	H302, H332	NP
Tribenuron-methyl	H400, H410	H317, H373	No

NP = Considered as pollutant by the local/national legislation, Hazard statement is designated as code, starting with the letter H and followed by three digits. Eg. H4xx refer to aquatic Environment and H400 and H410 means respectively Very toxic to aquatic life and Very toxic to aquatic life with long-lasting effects. H3xx refer to human health and H302 means Harmful if swallowed, H317, H318, H319 respectively May cause an allergic skin reaction, eyes damage, eye irritation, H332 Harmful if inhaled, H373 May cause damage to organs through prolonged or repeated exposure.

3.2. Survey 2

The results of the second survey, in which questions about 14 MM and BMPs able to reduce diffuse sources contamination of groundwater were made, highlighted that:

- 88% of respondents are familiar with factors that affect runoff, eg. slope and soil type and 58% recognize the need for a water body/well to be safeguarded from a runoff. In Italy professional farmers undertake compulsory trainings in these issues by certified training companies; before 2016, the legislation reserved the purchase of pesticide classified and labelled as very toxic, toxic and harmful exclusively to people holding the authorisation to purchase and use them. From that date on, through the compulsory courses (every 5 years) foreseen by National Action Plan and in line with the contents of Directive 2009/128/EC, it was possible to start raising awareness about environmental issues of all professional pesticide users.
- The Vegetated filter strip at edge-of-field is applied in 52% of farms. However, in some cases it is used for passage of vehicles (inaccurate knowledge) while in other cases it was already present as hydraulic arrangements;
- Vegetated ditches are present in 78% of farms and are considered effective in containing runoff. In general respondents are not concerned

about runoff that is perceived of moderate intensity. Respondents believe that measures taken (hydraulic arrangement, drainage channels, good field practice such as Inter-row processing and weeding on the row) are sufficient to contain the phenomenon;

- Barriers are present in 24% of farms and are considered effective in containing drift;
- A buffer strip of size (width) not less than 5 m and not more than 15 m is applied by 97% of respondents. Non spray buffer zone is compulsory in Italy if specifically indicated in the label;
- Air injection drift reducing nozzles are used by 52% of the respondents. In general, technical devices for drift reduction and special equipment to reduce spray drift are considered effective in reducing drift exposure although adoption is not always easy due to the widespread use of pneumatic sprayers in the area;
- Nutrient soils analysis for pH, macro elements, organic matters and C/N are performed by almost 50% of respondents and are used for fertilization planning.
- Weed control is undertaken by 44% of farmers. Of these, 73% apply a good practice of inter-row processing and weeding on the row, while the rest use permanent grassing in the inter row and weeding on the row. Grassing between rows (at least alternate) is increasingly popular and is adopted for quicker and more effective phytoiatric strategy and thus to reduce the number and use of pesticides

3.3. Participatory monitoring, participatory training approach and demonstration farm

Based on the results from Zambito Marsala et al. (2020) and Suciu et al. (2020), that evaluated the presence of the 15 PPPs in groundwater and the possible contamination sources, an impact of end-users behaviour on PPPs concentration in groundwater was highlighted. However, even if after three sampling campaigns, between November 2017 and September 2018, 153 occurrences of PPPs were observed in the 78 collected samples (38 values were above EQS_{gw}), in the last two sampling campaigns, between July and September 2019, just 69 occurrences of PPPs were monitored in the 53 collected samples, with 9 values above EQS_{gw}. Therefore, in 2019 a decrease by 44% of PPPs occurrences and by 68% of values above EQS_{gw} were observed.

In the framework of participatory monitoring strategy, maps, results and graphs are produced and are all available on the project *platform* at the link: (https://water-protect.eu/en),. Indeed, a *GIS Platform* was developed within the project, in which it is possible to consult the results of the monitoring studies. These data, together with the survey outputs, were presented during participatory training events, organized with the scope to facilitate the spread of sustainable practices, to prevent point sources contamination and, at the same time, to promote a coherent and harmonised approach that can facilitate the birth of useful collaborations and tangible synergies.

A high percentage of farmers use well water for pesticide treatments and still a fairly high percentage of farmers of the area under study don't have a dedicated area for mixing and filling the sprayers.

The participatory training events were organized in a “demonstration farm” where an impermeable and mobile platform for filling and washing sprayers was implemented. Here, new technical solutions for correct management of wastewater (spillage or water resulting from the external machine cleaning) were presented and communication material prepared in the form of card games, posters and infographics of BMPGAPs, designed to getting farmers familiar to the problems and relative solutions, including how to use the well water without contamination risk, were prepared and distributed.

The presentation of monitoring data motivated farmers to participate to these events and stimulated them to implement and to adopt the innovative and sustainable measures proposed and change behaviours.

Commonly, the platforms used for washing sprayers and filling are made in concrete, often waterproofed with resin. This solution could have maintenance problems especially if located in geographical areas where temperatures in winter fall below the freezing level, as it is our case. Therefore, it has been decided the use of a mobile platform, available on the market, cheaper and very easy to use, durable (double layer UV resistant PVC) and that can be easily protected during the winter. The collected pesticide polluted water should be stored in a storage tank, transferred with a pump or gravitationally. Storage must ensure double retention, so that any leaks can always be recovered.

Finally, the stored polluted water should be delivered directly to a specialized company, even if the costs are quite high for large volumes. Indeed, several alternatives were taken into account and presented, as for example the re-use of the stored water after a chemical/physical treatment for the external sprayer washing, or the installation of bioremediation systems. These solutions were not implemented in the “demonstration farm” because both are not legally approved (at the time of the project). In fact, legal contradictions restrict the application at national level of the physical/chemical/bio-purification systems, even if it could represent a BMP and a technically viable alternative MM of point source contamination, enabling the treatment of PPPs contaminated liquids directly in the farm.

In this context, the leader for water governance, Emilia - Romagna Region, was directly involved trough sharing of research outputs (monitoring data, survey outputs, hydrological data), which highlighted the possible impact of end-user behaviour on groundwater contamination in the study area. This increased the awareness and sensibility of the Region to find together with the farmers and partners of the project the most suitable solution.

4. Discussion and conclusion

The effectiveness of engagement initiatives may depend more on how the initiative is implemented, rather than the choice of method used (Dean et al., 2016). It is generally assumed that face-to-face methods increase awareness and knowledge in attendees, facilitate the gathering of community opinion and preferences and also provide input for researchers. In our study, different consultation mechanism and strategies throughout the overall project, such as face to face meeting, direct survey, participatory monitoring and the planning of several training activities, were adopted. The low level of trust of the farmers, was the highest barrier at the beginning of the project. The involvement of key people, like representative of farmer's consultancy, of farmer's organizations or of farmer's associations, was fundamental to gain farmers trust and further involvement. Therefore, our perception, supported also by the results of the monitoring campaigns, which show a decrease trend in the contamination of the aquifer examined, is that the level of awareness of farmers, concerning water pollution in the study area, increased but we cannot say that most of them are aware of the problem. An important number of farmers, the ones that follow most the activity of the project and participate to all the face to face meetings, are now showing a high interest and are willing to take actions in order to avoid pollution.

However, some sustainable practices or innovations which could potentially match the incentives of rural development policy are discredited for several reasons because:

- are not always compatible with farmers work organisation and landscape situations;
- their impact is not ensured, farmers need more information;
- are not economically feasible;
- the legislative contradictions as for example for physical/chemical/bio-purification systems, with the result to have CAP measures inapplicable for farmers.

Furthermore, even if training is compulsory and operators need a certificate to use pesticides, and despite the quality level of the regional training system, the training is entirely theoretical and does not include demonstrative activities and sharing of experiences. A very high percentage of interviewed farmers are unaware of the existence of monitoring data on pesticides and nitrates in surface and groundwater even though 64% declare to participate regularly or have participated in training courses concerning the prevention of water contamination. Therefore, to link environment and farmers and increase their awareness, the organisation of demo farming participatory events, as proposed in this work, results as mandatory. The knowledge of the factors involved in the contamination processes and of the context monitoring data allow to adopt behaviours or structural changes aimed at limiting and controlling the contamination. There is a growing interest by farmers and operators in more "modern" communication approaches —experimental, demonstrative, and participatory (Sacchettini and Calliera, 2016). An improvement of the training system is recommended with the use a combination of lessons and group discussions, followed by practical demonstrations, which allow "learning" through practice and promote the understanding of the issues addressed.

To link back the experience we have gathered during this exercise to the effectiveness of the policy implementation in protecting water resources, we can definitely conclude that proactive provision of information on the challenges in water quality and their potential cause are essential to ensure awareness at farm level, and understanding the positive contribution farmers can make. Currently, information is often unclear, scattered or not easily accessible. In many cases farmers rely on informal channels (farmer associations, media, extension consultants, etc.) to obtain such information.

The positive contribution to sustainable water management of agriculture, including through implementing BMPs and MMs should be evaluated, recognized and communicated. Perception on costs vs. benefits of implementation of various BMPs or MMs have an important impact on the willingness of farmers to implement them. Hence, direct information, know-how and as well as support for actual investments needed for implementation of will play a key role in the future uptake of such measures by farmers.

Link environment and farmers and Demo farming participatory events. It is also important to improve the "farmer image and proudness" and restore public confidence in farmer's activities, the sensibility of farmers to social pressure, and their investments and commitments to pro-environmental actions in line with the Sustainable Development Goals (SDGs) n.6 on water. Participatory events fostered the community's understanding of the added value of the commitment of farmers that, with the application of mitigation measures and respect for good practices, contribute to collective well-being by acting on all ecosystem services and common goods.

A set of indicators that highlight the contribution agriculture has into water management (able to capture positive and/or negative trends) will help involvement of farmers and will stimulate ownership of the process.

At the end of the overall process, we can affirm that the multi-actor approach adopted was successful in increasing knowledge and improving attitudes to more sustainable water practices. The different consultation mechanisms and involvement strategies applied throughout the overall process, could be expanded to other areas with similar environmental and agricultural conditions. However, there is no evidence whether these increases in knowledge and positive attitudes can be maintained over time. Therefore, further targeted communication campaigns and actions should be taken into account in order to reach a more sustainable pesticide use, to maintain a good water status and to solve contradictions, both communicative and legislative, which make the recommended rules or MMs inapplicable.

CRediT authorship contribution statement

Maura Calliera - Conceptualization, Methodology, Investigation, Writing-Original Draft, Writing-Review & Editing. Ettore Capri - Supervision, Methodology, Writing - Review. Roberta Zambito Masala - Investigation, Review. Elisabetta Russo - Investigation. Miriam Bisagni - Investigation. Ruggero Colla - Review & Editing. Alexandru Vasile Marchis - Writing - Review & Editing. Nicoleta Suciu - Supervision, Methodology, Project administration, Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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