Environment, Development and Sustainability
https://doi.org/10.1007/s10668-022-02219-4

Challenges and opportunities of water quality monitoring and multi-stakeholder management in small islands: the case of Santa Cruz, Galápagos (Ecuador)

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Received: 15 October 2020 / Accepted: 13 February 2022

Abstract
Sustainable water resources management roots in monitoring data reliability and a full engagement of all institutions involved in the water sector. When competences and interests are overlapping, however, coordination may be difficult, thus hampering cooperative actions. This is the case of Santa Cruz Island (Galápagos, Ecuador). A comprehensive assessment on water quality data (physico-chemical parameters, major elements, trace elements and coliforms) collected since 1985 revealed the need of optimizing monitoring efforts to fill knowledge gaps and to better target decision-making processes. A Water Committee (*Comité de la gestión del Agua*) was established to foster the coordinated action among stakeholders and to pave the way for joint monitoring in the island that can optimize the efforts for water quality assessment and protection. Shared procedures for data collection, sample analysis, evaluation and data assessment by an open-access geodatabase were proposed and implemented for the first time as a prototype in order to improve accountability and outreach towards civil society and water users. The overall results reveal the high potential of a well-structured and effective joint monitoring approach within a complex, multi-stakeholder framework.

Keywords Water management · Water monitoring · Socio-hydrogeology · Geographic information systems · Database · Water committee

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Resumen
La gestión sostenible de los recursos hídricos se ensuncia en el seguimiento de la fiabilidad de los datos y en la plena participación de todas las instituciones involucradas en el sector del agua. Sin embargo, cuando las competencias y los intereses se superponen, la coordinación puede ser difícil, lo que dificulta las acciones de cooperación. Es el caso de la Isla Santa Cruz (Galápagos, Ecuador). Una evaluación completa de los datos de calidad del agua (parámetros fisicoquímicos, elementos principales, oligoelementos y coliformes) recopilada desde 1985 reveló la necesidad de optimizar los esfuerzos de monitoreo para llenar las lagunas de conocimiento y orientar mejor los procesos de toma de decisiones. Se creó un Comité de la Gestión del Agua para fomentar la acción coordinada entre las partes interesadas y allanar el camino para el monitoreo conjunto en la isla que pueda optimizar los esfuerzos para la evaluación y protección de la calidad del agua. también se propuso e implementó como prototipo como una forma de mejorar la rendición de cuentas y la divulgación hacia la sociedad civil y los usuarios del agua. Los resultados revelan el alto potencial de un enfoque de supervisión conjunto y bien estructurado en un marco complejo y de múltiples partes interesadas.

Palabras clave Gestión del agua · Monitoreo del agua · Socio-Hidrogeología · Sistemas de Información Geográfica · Base de Datos · Comité del Agua

1 Introduction

Sound water resources management is a fundamental component for any sustainable development plan. As such, it must take into account both the environmental features and the socio-economic drivers that can exert pressures on, or be affected by, water use and quality (Re, 2015). Additionally, it also requires a full stakeholder consultation and engagement of local communities, as advocated by the Integrated Water Resources Management (IWRM) approach (UNESCO et al., 2009). Over the last decades, due to the global decrease of water quality (WWAP, 2015), the scientific and political communities started recognizing the need to perform more holistic investigations to tackle water issues (Giordano & Shah, 2014; McDonnell, 2008; Shiklomanov, 1998) that were resulting from its often inadequate or unsustainable management and usage (e.g. uncontrolled wastewater discharge, widespread use of fertilizers and pesticides, lack of adequate sanitation facilities; WWAP, 2009). These issues are particularly relevant in regions characterized by scarce or unevenly distributed water sources, such as arid and semi-arid regions and in Small Islands Developing States (SIDS; Bouchet et al., 2019; Re & Zuppi, 2011; UNEP, 2012; Van Der Velde et al., 2007; White & Falkland, 2010).

The Galápagos Archipelago (Ecuador), a UNESCO world heritage since 1978, considered a living museum and showcase of evolution (UNESCO WHC, 2017) due to its high biodiversity and distinctive environment, is a perfect example of the aforementioned challenges. Given the importance of its natural ecosystems, the archipelago has been extensively studied to examine and preserve its ecological biodiversity (Adsersen, 1989; Alava et al., 2011; Bataille et al., 2011; Castrejón & Charles, 2013; Denkinger et al., 2010; Glynn, 1994; Grant et al., 2005; MacFarland et al., 1974; Richards & Davison, 2010; Silberglied, 1978; Szuwalski et al., 2016; Trueman et al., 2014; Walsh et al., 2008). However, only a few works (e.g. d'Ozouville and Merlen, 2007; Benitez-Capistros et al., 2014; Reyes Perez et al., 2015; Cecchin, 2017; Reyes Perez, 2017; Gerhard et al., 2017; Adelinet et al., 2018, Mateus et al., 2019) targeted the understanding of the water cycle and the recent anthropogenic impacts on water resources from multiple factors (which include the local population activities, the increasing number of tourists visiting the islands, and the shift from "floating-hotel" to "land-based tourism"). At present, one of the main issues affecting the archipelago is the contamination of the local freshwater resources which are not suitable for drinking or domestic consumption, and have been identified as the main cause of water-related diseases (mainly driven by *Escherichia Coli* (*E. Coli*) and *Entamoeba histolica*) among the population (Consejo de Gobierno de Galápagos, 2010; Liu & d'Ozouville, 2013; Grube et al., 2020). Most of the activities targeted to water quality assessment and protection conducted in the past years are characterized by a lack of coordination among the different water institutions in the island, with data often unpublished and, especially in the case of international cooperation projects, long-term sustainability often underestimated. Effective information and data sharing has been advocated for years, together with a wider dissemination of environmental and health issues to the civil society (Ospina and Falconi, 2007). However, despite a relative abundance of water quality monitoring activities (and consequently data), there is a limited knowledge on the status of the water resources in the archipelago and even less on freshwater availability. This situation can be also ascribed to the multiplicity of institutions and stakeholders with overlapping competences on water management and protection. Therefore, a better coordination among them would clearly lead to the definition of more effective plans, programmes and policies for the long-term protection of local water resources (Reyes et al., 2015). These issues have been highlighted by several authors (e.g. Celata & Sanna, 2012; González et al., 2008; Ospina, 2006; Walsh & Mena, 2013) and have been attributed to the difficult relations among the different stakeholders that do not share common objectives and cannot rely on a sound legislative framework clearly defining their competences.

Under these context conditions, a technical cooperation project, "Health protection and prevention of anthropic pollution risks" in the Island of Santa Cruz (Veneto Region, Italy CS2012A19; Rizzi et al., 2014) was undertaken, with the goal of fostering participatory water monitoring practices in the island. Overall, the project objective was to contribute improving the wellbeing and livelihood of the local population.

As scarce scientific and technical coordination and lack of institutional framing of water monitoring activities were recognized as the main causes of scattered knowledge and improper water management in the island (Lopez and Rueda, 2010), the first action undertaken during the project was to support the creation of a local Water Committee (*Comité de la gestión del Agua*) bringing together all the institutions involved in the control and management of water resources in the island of Santa Cruz, (Rizzi et al., 2014). This permitted to create the basis for improved coordination among all local institutions involved in the conservation and protection of water resources, and to plan long-term monitoring activities Additionally, the presence of a Water Committee is fundamental to ensure that all activities carried out by institutions or organizations external to Galápagos refer to local ones to: (i) guarantee the effectiveness and usefulness of any research project, (ii) focus studies and actions on the real priorities for the islands sustainable development, and (iii) avoid activities replication.

Subsequently, collection and homogenization of all previously available data permitted to gain a better understanding of the *status quo* and get insights into anthropogenic pressure on local water resources. Capacity building and participatory monitoring assessments were also performed involving all the stakeholders participating in the Water Committee. Results of this multi-stakeholder monitoring approach are presented in the manuscript, with emphasis on the importance of data driven management for the achievement of SDG6

Fig. 1 Localization of the Galápagos archipelago and its main islands, including Santa Cruz and the city of Puerto Ayora

(Ensure availability and sustainable management of water and sanitation for all), and for supporting the 2030 Agenda for Sustainable Development (United Nations, 2018). Given the large number of studies and its international interest as a unique reservoir for ecological diversity, Galápagos has the potential to become a "world laboratory for the evaluation of sustainability", in which to promote the so-called political ecology (Ospina, 2007). For this to happen, a solid analysis of the relationship between the society and the ecosystems is required. In this context, the approach presented in the manuscript can be an important basis for decision-making processes that lead Galápagos to become truly sustainable.

Therefore, the main objectives of the paper are to: (i) Frame the current water issues in the socio-economic context of the island of Santa Cruz island (Galápagos); (ii) suggest a procedure for the design and implementation of a shared water quality monitoring plan in the case study on al long-term timeframe; (iii) present the results obtained by testing the suggested practices and establish new organizational models (i.e. a water committee involving multiple stakeholders).

Results are currently used to provide recommendations for new water management strategies in the island, and the approach may be applied in other similar contexts, such as Small Island Developing States, where climate change, population growth and tourism expansion will continue exerting pressures on water quality and quantity. By presenting an application of an approach aiming at integrating water quality monitoring and assessment with stakeholder engagement and public participation, this paper also aims at contributing to the development of the emerging field of Socio-Hydrogeology (Re, 2015).

2 Case study

2.1 Santa Cruz Island

The volcanic archipelago of Galápagos is located approximately 1000 km off the Ecuador mainland and consists of more than 250 islands. The island of Santa Cruz (Fig. 1), having a surface of 986 km^2, is the most populated among the four inhabited islands (others are San Cristobal, Isabela and Floreana;1). According to the last census, Santa Cruz had approximately 15,700 inhabitants in 2015 (INEC, 2016), concentrated in Puerto Ayora, the capital city, Bellavista and Santa Rosa, and more than 270,000 visitors per year in 2019 (PNG, 2020). Being the unique habitat of many endemic species, about 70% of the island belongs to the Galápagos National Park (Parque Nacional Galápagos, PNG).

From a geological point of view, Santa Cruz is a low relief volcanic island, with a maximum height of 855 m a.s.l., made up of impermeable but highly fractured basaltic lava flows (Bow, 1979).

The climate of the region can be divided into two major seasons. The cold season (or *garúa* season), from June to December, when the moisture-laden air from the cool southeast trade winds condenses in contact with the vegetation originating humid conditions, due to an inversion layer set above 300 m a.s.l. (Auken et al., 2009). As a result, this season is characterized by a high hydrogeological potential on the windward mountainside, where rainfall can infiltrate recharging the perched or basal aquifers. On the other hand, the warm season, from January to May, is characterized by heavy rain storms, with annual rainfall ranging from 500 mm in the coastal zone to 1500 in the central higher part of the island (Huttel, 1995).

The island is characterized by the absence of permanent rivers or creeks, because of the high fracturing degree favouring infiltration and preventing the formation of surface watercourses. However, the presence of micro-catchments (*micro cuencas*) facilitates the local accumulation (and storage) of rainwater. As a general feature, the micro-catchments of Santa Cruz island have the following characteristics (Dominguez, 2011): (i) in the upper zone (600–800 m a.s.l.) the clayey soils, with relatively lower permeability, allow for temporary water accumulation and surface runoff, (ii) in the middle zone (200–600 m a.s.l.) the less pronounced slopes with discontinuities and fractures in rocks, favours rainwater infiltration, and (iii) in the lower part (0–200 m a.s.l.) surface runoff is almost null, as the clay component is low, while the fracturing is very high and the presence of open coastal fractures, crevices (*grietas*) and lava tunnel increases the flow towards the ocean.

Several studies contributed to improve the knowledge of the island's hydrogeology using remote sensing analysis (Auken et al., 2009; d'Ozouville, 2007; d'Ozouville et al., 2008a, 2008b, 2010). These researches focused on the drainage network, watersheds and flow characteristics of the island and permitted both the identification and characterization of a previously unknown perched aquifer (50 km^2) located on the southern mountain side and of the geometry of the salt-water wedge in the basal aquifer (Auken et al, 2009; d'Ozouville et al., 2008a). This shows that the island is not as "waterless" as generally thought. However, due to the high permeability of fractured shield series forming coastal aprons (d'Ozouville et al., 2010), groundwater quality is threatened by sea water intrusion that contributes to increase the groundwater salt content, potentially reducing its suitability for domestic and agricultural purposes. In addition, groundwater suffers from human induced contamination due to the lack of adequate sewages and wastewater treatment facilities. In particular, the leaking septic tanks in Puerto Ayora is a well-known phenomenon

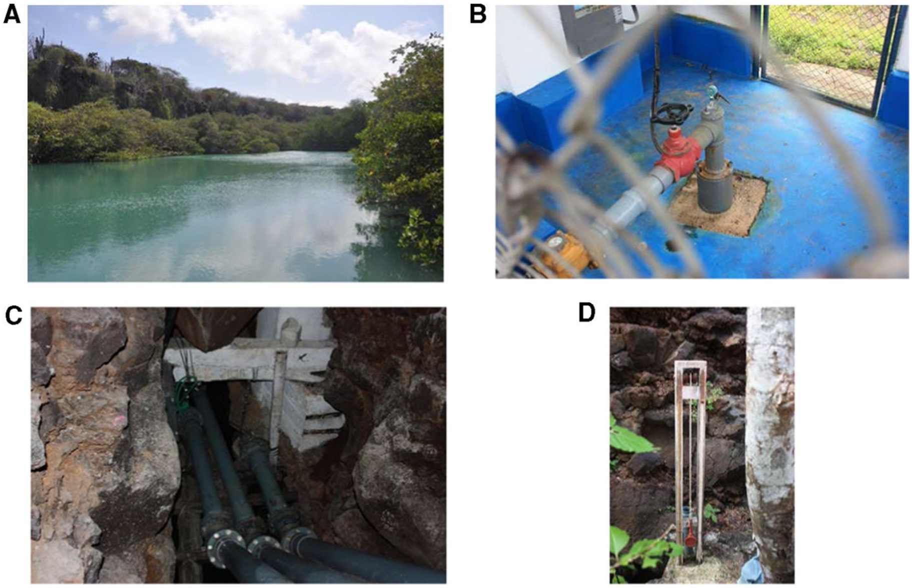

Fig. 2 Images of the sampling sites: Lagunas de las Ninfas **a**, Pozo Profundo **b**, Grieta la Camiseta **c**–**d** (Pictures Tringali, 2012 and Re 2013)

(d'Ozouville et al., 2008b; INGALA et al., 1987) and has worsened over the years due to population growth and the increase of tourists visiting the island (with a rate of 6%; PNG, 2013).

In addition, the Las Ninfas Lagoon, a coastal lagoon, is present in the city of Puerto Ayora (Fig. 2A). This is a shallow saline lagoon (Surface ~ 0.5 ha), used by the local population as a recreational site, but often affected by domestic wastewater contamination, resulting in periodic Escherichia Coli pollution (Stumpf et al., 2013).

As concerns water supply, at present the sources of natural water for domestic use are (i) groundwater, withdrawn from the only borehole of the island (*Pozo Profundo*, located 5 km inland at 160 m a.s.l and 160 m deep, Fig. 2b) tapping the brackish basal aquifer, providing water for Bellavista households, and (ii) water stored in three crevices connected to the municipal network of Puerto Ayora (*Grieta colegio San Francisco*, *Grieta INGALA*, and *Grieta la Camiseta*, Fig. 2c–d; Sarango, 2010). As a common characteristic, these waters, distributed through the municipal supply system, are brackish, hence not adequate for human consumption, and consequently used for different activities but drinking and cooking (Rayes et al., 2015). To cope with this issue, in 2018 the Municipality built two desalination plants. Illegal and uncontrolled pumping from other crevices is also occurring in the island, supplying water for both private and commercial use. In addition, rainwater harvesting is a widespread practice especially in the upper part of the island, where agricultural and farming activities are dominant. For drinking purposes, most of the inhabitants resort to purified water coming from different springs present in the island and sold in reusable containers of 20L, 4L, 1L, and 1/2L (Liu, 2011).

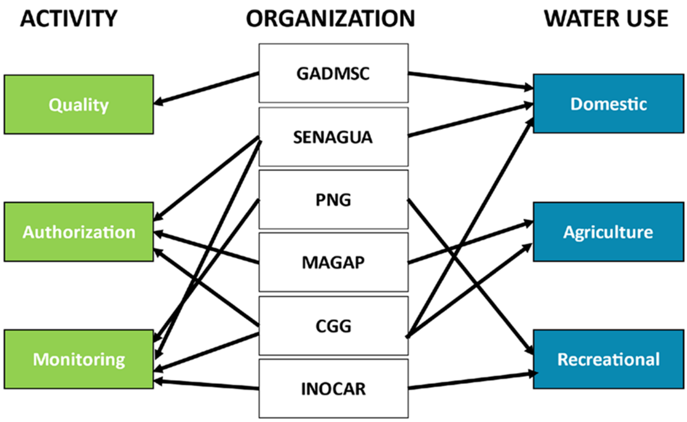

Fig. 3 Water-related organizations and relationships with control activities and water uses in the island of Santa Cruz

2.2 Water-related stakeholders in Santa Cruz Island

From the previous description of the island of Santa Cruz and of its water-related issues, it emerges why it is essential to promote activities and investigation focused on water control, protection and management. In recent years, many projects have been developed in this direction, also involving different local and international authorities, research institutes and NGOs (d'Ozouville & Merlen, 2007). It must be stressed that the uniqueness of Galápagos Archipelago requires specific actions targeted to environmental protection, which result in the presence of different actors involved in planning and decision-making processes. With specific reference to the Santa Cruz Island, several stakeholders are in charge of water control, management and protection (Fig. 3), with responsibilities and legal powers sometimes overlapping. Furthermore, the definition of competencies and responsibilities for the management of the water sector is complex due to the subsequent legal reform in Ecuador (LOREG, 1998; Asamblea Constituyente, 2011).

At the time of the project, the following local stakeholders were identified:

- National Water Secretariat (*Secretaría Nacional del Agua*, SENAGUA[1]), responsible for water resources management. Its specific functions are: (i) awarding licenses and permits for water use, (ii) managing water sources and restoring the quality of the water cycle, (iii) decentralized management to generate efficient administration and use of water resources. Currently SENAGUA has also taken the responsibility for the characterization of the water potential at national level and of the implementation, by 2017, of mega-projects aimed at the expansion of irrigation areas, the implementation of water, sanitation, and hygiene initiatives (i.e. water and wastewater treatment plans) and improving flood control measures.
- Governing Council of the Special Regime Galápagos (*Consejo de Gobierno de Régimen Especial Galápagos, CGREG*), in charge of inter-islands rural water management and coordination, especially focusing on water used for irrigation, agriculture, and

[1] In 2020, SENAGUA was fully integrated into the Ministry of the Environment.

domestic use. CGREG also has the responsibility of defining the guidelines for water management in the Archipelago.

- Galápagos National Park (*Parque Nacional Galápagos*, PNG), responsible for 97% of the total land area of the Galápagos Archipelago (i.e. the national park protected area) and of its maritime area. Therefore, PNG has competences on water in both the terrestrial and marine area. Being a decentralized institution of the Ecuadorian Ministry of Environment (MAE), in Galápagos, PNG has the responsibility of controlling the impact of production activities (particularly infrastructure and tourist boats) on water quality. This is done through the approval of Environmental Impact Assessments and of Environmental Management Plans. In addition, PNG assumed the powers of maintaining an active water quality monitoring programme and of releasing the authorization for sampling activities to other institutions.
- Santa Cruz Municipality (*Gobierno Autónomo Descentralizado de Santa Cruz, GADMSC*), whose functions, among the others, are (i) water quality monitoring, (ii) legislation for water pollution control, (iii) water supply for management and control, (iv) construction and management of the treatment systems for sewages and drinking water, (v) maintenance of the water management structures (excluding coastal waters) in the island of Santa Cruz.
- Ecuador Naval Oceanographic Institute (*Instituto Oceanográfico de la Armada-Ecuador*, INOCAR), in charge of the administrative management of coastal waters, and sea water quality control in collaboration with PNG.
- Ministry of Agriculture, Livestock, Aquaculture and Fisheries (*Ministerio de Agricultura, Ganadería, Acuacultura y Pesca, MAGAP*[2]), managing and authorizing water for agricultural use.
- Biosafety Regulatory Agency for Galápagos (*Agencia de Regulación dela Bioseguridad para Galápagos*, BIOSEGURIDAD), responsible for the preservation of the ecological integrity of the islands and the marine ecosystems. It protects the natural biodiversity of each of the islands of the archipelago by controlling the import (and export) of each product or material (to protect the natural ecosystem from new invasive species and contaminants).
- Charles Darwin Foundation (CDF), conducting scientific research and promoting environmental education in the water sector.
- Santa Cruz Households, including citizens, farmers, fishermen, tourist sector employees, as concerned water users.
- Bottled water companies, 12 local companies using, bottling and selling Santa Cruz's island water (including *Agua Luz*, *Agua Galápagos*, *Agua Gallardo*, *Agua Pelikan Bay*, *Martín Schreyer*, *Miconia* and *Espín*).

3 Methods

In the framework of the technical cooperation project for "Health protection and prevention of anthropic pollution risks" in the Island of Santa Cruz (*Tutela della salute e prevenzione dai rischi di inquinamento antropico*-Veneto Region, Italy CS2012A19; Rizzi et al., 2014),

[2] Since 2019, MAGAP was divided into two different Ministries: a Ministry of Agriculture and Livestock and a Ministry of Aquaculture and Fisheries.

a three-step approach for water quality assessment was developed and tested: (i) creation of a committee grouping all the water stakeholders in the island, (ii) collection and homogenization of all available data on water quality, (iii) joint design and implementation of a shared long-term water quality monitoring plan. In the following paragraphs, all the phases are described in detail.

3.1 Establishment of the Santa Cruz water committee

Given the complexity of the issues at stake, in the year 2012 the Santa Cruz Municipality (GADMSC), with the support of Ca' Foscari University of Venice (UNIVE), proposed the creation of a Water Committee. The latter, locally called *Comité de la gestión del Agua* (hereafter *Comité del Agua*), groups all the stakeholders involved in water control, distribution, monitoring, and safeguard in the Santa Cruz Island and has the main function of promoting joint and coordinated actions for local water management. For this reason, the *Comité del Agua* was identified as the main local institutional partner for freshwater quality protection activities in the island.

The first phase for the establishment of the *Comité del Agua* was the identification of its members (Table 1). Only public stakeholders having legal obligations in water issues were included to provide shared policy resolutions and management principles (hence, at least in the initial phase, excluding water bottling companies and civil society representatives).

Subsequently, delegates and technicians from each institution met regularly to identify target areas and prioritize activities. These meetings were organized and facilitated by GADAMSC and UNIVE, with the main objective of preparing the action plan for the committee, defining the role of each member, and getting feedback on their issues and expectations. In addition, all the meetings had the purpose of creating the basis for mutual trust and collaboration among the institutions, and to pave the way for a more transparent and coordinated water management plan in the island.

3.2 Historical data collection and homogenization in a geodatabase

As previously mentioned, the island of Santa Cruz (and, in general, the whole Galápagos archipelago) has been object of several national and international studies focused, among the others, on water quality protection and management (INGALA et al., 1987; PNG and JICA, 2005, 2006, 2007, 2008, 2009; PNG and MAE, 2010, 2011; Liu, 2011; ESPOL, 2011; Stumpf et al., 2013, Liu and d'Ouzeville, 2013). The uniqueness of the Galápagos archipelago makes it an ideal place to study, constantly attracting researchers from all over the world. However, despite the good amount of information available, data are scattered and seldom adequately disseminated or shared with other institutions (both at scientific and institutional level), as a result of the scarce coordination among the different projects. The main consequence is therefore that scientific outcomes are often not effectively used to support improved environmental management strategies, as proven by the poor sanitation supply and water tanks disinfection, and lack of coordinated strategies for water quality protection.

As for water management, the first attempt to merge all the existing data in a unique database highlighted the presence of several methodological discrepancies and dataset gaps. In fact, the effort of comparing historical data was complicated by the lack of homogeneity among the information available (e.g. chemical results often not accompanied by units of measurements, lack of coordinates for the sampling points, use of

Table 1 Institutions involved in the *Comité del Agua* of the Santa Cruz Island

Institutions	Role in the Comité *del Agua*	Description of its duties in the Comité *del Agua*
GADMSC, PNG/DPNG, SENAGUA, MAGAP, BIOSEGURIDAD, CGG, INOCAR	Members	Proposing revisions of environmental guidelines and regulations Organization and management of water quality assessment activities
FCD, ESPOL, UNIVE	Advisors for technical support	Scientific consultancy Water quality monitoring and data interpretation support

different standards for the names of measured parameters and the not univocal representation of decimal marks). Consequently, despite the high quantity of available data, most of it cannot be used for comparative studies or for supporting decisional and management processes targeted to water resources protection (and eventually the environment and human health in the island).

For this reason, a new standardized coding procedure was defined to improve data collection and management processes, and to homogenize existing data to make historical information available for further analysis. The proposed coding system aims at fostering an easier data comparison, and it favours a quick identification of both the monitoring network sites and the samples. In practice, the new codes ensure that each water point in Santa Cruz Island is properly defined not only by its name, but also by a progressive code embedding information on its location (i.e. in the upper, wet area of the island or in the coastal, driest one) and of its features (i.e. well, crevice, cistern/tank, lagoon etc.). A serial number is assigned to each point so as to ensure the inclusion of new sites in the monitoring network and for the unique identification of each site (Table 2).

As concerns the samples, the proposed alphanumeric code aims at providing all the relevant information regarding the sample characteristics (e.g. soil, water), the period of collection (i.e. year and month) and the institution or group responsible for the monitoring campaign (Table 2). All this information will ensure transparency and data traceability, thus promoting comparative studies and making all available data more easily accessible. Also, in this case a serial number is included to facilitate the distinction between the samples.

Between September 2013 and April 2014, existing information (Table 3) on water quality was updated using the proposed codification, and incorporated in a new geodatabase, the SantaCruzWDB (Santa Cruz Water DataBase). The latter contains more than 7000 measurements collected through almost 1000 samplings related to 54 chemical, physicochemical and biochemical water parameters. The SantaCruzWDB includes information on samples that were taken in 68 sites during 14 sampling campaigns performed in 1985, and between 2005 and 2014. All 68 sites were visited in August 2012 in order to verify and update the coordinates and to integrate the archive with some pictures of each sampling point (Mancin, 2013). The SantaCruzWDB was designed to optimize data storage and information exchange and was implemented using the open-source RDBMS PostgreSQL (http://www.postgresql.org/) with its spatial extension PostGIS (PostGIS, 2014).

The conceptual scheme of the SantaCruzWDB is reported in Fig. 4, and it shows all the tables contained in the database and their connections. The proposed structure avoids data redundancy and optimizes the connection between tables using the previously described standardized codes (Table 1) or progressive numerical codes. The most important tables of the SantaCruzWDB are:

- *Sample*: containing the values of the parameters measured in the field or in laboratory,
- *Sampling*: including the information about the sampling campaign, i.e. when and where the values were measured,
- *Site*: for the spatial location and characteristics of the sampling sites.

The SantaCruzWDB also contains tables storing additional information that are useful for data analysis, such as:

Table 2 Description of the standardized codes for the Santa Cruz Island

Information	Code	Description
Sampling sites	XY000	**X**–S = *Zona Seca* (dry zone); H = *Zona Húmeda* (wet zone) **Y**–D = *Descarga* (discharge); G = *Grieta* (crevice); *T* = *Tanque* (tank/cistern); *M* = *Mar* (sea) **000**—progressive number from 001 to n
Example:	HG001	Pozo profundo, is a *grieta* (G) located in the wet zone (H)
Samples	YEAR00RT000	**YEAR**—sampling's year **00**—sampling's month **R**—responsible of the sampling: M = GADMSC; P = PNG; C = CGG; S = SENAGUA; F = FCD; U = university **T**—sample's type: Ag = water; S = soil; Ai = air **000** = progressive number from 001 to n
Example	201404MAg001	Sample of water (Ag) collected in April 2014 (201,404) by the GADMSC (M); sample number 1 for that month in that location (001)

Table 3 List of the existing datasets used to implement SantaCruzWDB

Source	Period of reference	Parameters' number	Parameters' list	References
INGALA	May, June, August and December 1985	16	Air temperature, precipitation, pH, turbidity, conductibility, total hardness, NO_2^-, NO_3^-, TDS, SO_4^{2-}, Ca, Cl^-, Mg, Na, PO_4^{3-}, K	INGALA et al, 1987
PNG	Every month or every three months from 2005 to 2011	36	Air temperature, precipitation, water temperature, pH, DO, salinity, turbidity, conductibility, total hardness, oils and greases, NO_2^-, NO_3^-, SO_4^{2-}, Ca, Cl^-, Na, PO_4^{3-}, Cd, phenols, total P, Hg, Pb, NH_3, tensioactifs, Ni, Cu, Cr, Zn, Se, Ag, CN^-, B, Ba, Al, faecal coliforms, total coliforms	PNG and JICA, 2005, 2006, 2007, 2008, 2009 PNG and MAE, 2010, 2011
FCD	June 2009	3	Air temperature, precipitation, conductibility	FCD, 2012
FCD	December 2010, February, March and April 2011	5	Air temperature, precipitation, total coliforms, Escherichia Coli, Pseudomonas	Liu, 2011
ESPOL	August 2011	26	Air temperature, precipitation, water temperature, pH, DO, salinity, turbidity, conductibility, total hardness, OM, BOD, COD, oils and greases, NO_2^-, NO_3^-, TDS, SO_4^{2-}, Ca, Cl^-, Mg, Na, PO_4^{3-}, TPH, PAH, faecal coliforms, total coliforms	ESPOL, 2011

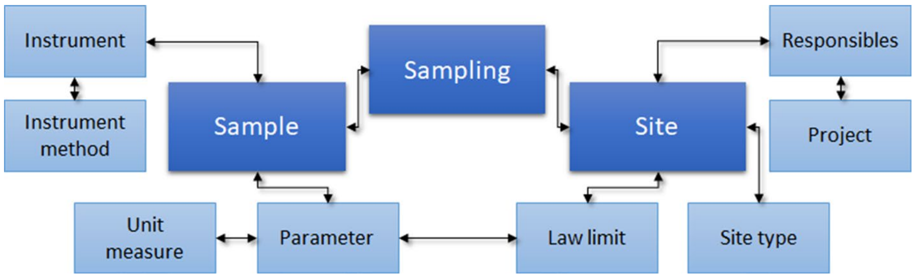

Fig. 4 Conceptual model of SantaCruzWDB

- Statutory limits set by the Ecuadorian legislation (Texto Unificado de Legislación Ambiental Secundaria del Ministerio de Ambiente; TULAS, 2003) that each parameter should respect in order to identify non-compliant values,
- The instruments and the analytical procedures used for the analysis,
- The organization or the group responsible for the sampling campaign.

To foster information sharing and inter-institutional collaborations, the SantaCruzWDB was integrated within a local web platform accessible to registered users of the different institutions and organizations working in Galápagos. The web portal also permits the visualization of all available data over a map together with some basic statistical calculations (e.g. minimum, average, maximum value for each parameter).

3.3 Capacity building and participatory water quality monitoring

In order to test and promote the standard codification and to set a long-term monitoring network, two sampling campaigns were performed in May 2013 and April 2014. These field works were planned as a joint activity with all the institutions involved in water monitoring assessment in the Santa Cruz Island (PNG, GADMSC, SENAGUA, MAGAP, CDF, BIOSEGURIDAD, CGREG, FEIG and INOCAR), coordinated by a team of researchers from UNIVE and the Escuela Superior Politécnica del Litoral of Guayaquil (ESPOL).

Prior to the field activities, six trainings were organized (three in 2012 and three in 2013) with technicians of the institutions involved in the *Comité del Agua*. The meetings were held at GADMSC in Santa Cruz, and they were focused on the following topics: (i) creation of a water quality monitoring plan, (ii) in situ measurements (water level (in Pozo Profundo), water temperature, pH, electrical conductivity, total dissolved solids, salinity, dissolved oxygen and redox potential) and procedures for sample collections and storage, (iii) data collection and reporting, (iv) basic concepts of analytical procedures for chemical analysis of water samples, (v) basic concepts for data interpretation and report writing; (vi) GIS techniques and database creation and maintenance.

During the first campaign, a group of monitoring water points was selected, representing the basis for a long-term water quality assessment in Santa Cruz Island. These 8 water points represent the main sources of fresh water for urban/domestic consumption in the island (Table 4) and must therefore be monitored and protected to avoid water-borne diseases for the local population. In addition, some sea and lagoon water samples were collected to assess the interaction between saline and fresh water.

Table 4 Sites monitored during the sampling campaigns of 2013 and 2014

Sampling site	Code	Site typology	Water typology	Uses
Vertiente Santa Rosa	(HG002)	Natural source	Surface water	Not in use at the time of the project
Pozo profundo	(HG001)	Well	Groundwater	Municipal Water Supply for Bellavista
Grieta la Camiseta	(SG006)	Crevice	Surface water	Municipal Water Supply for Santa Cruz
Grieta INGALA	(SG005)	Crevice	Surface water	Municipal Water Supply for Santa Cruz
Grieta el Barranco	(SG001)	Crevice	Surface water	Not in use at the time of the project
Grieta Tortuga Bay	(SG010)	Crevice	Surface water	Not in use at the time of the project
Grieta colegio San Francisco	(SG007)	Crevice	Surface water	Municipal Water Supply for Santa Cruz
Grieta de la Estación	(SG003)	Crevice	Surface water	Not in use at the time of the project
Las Ninfas Lagoon	(SM012)	Sea	Surface water	Recreational
Sea Water	(SM010, SM011, SM012, SM013)	Sea	Surface water	Recreational

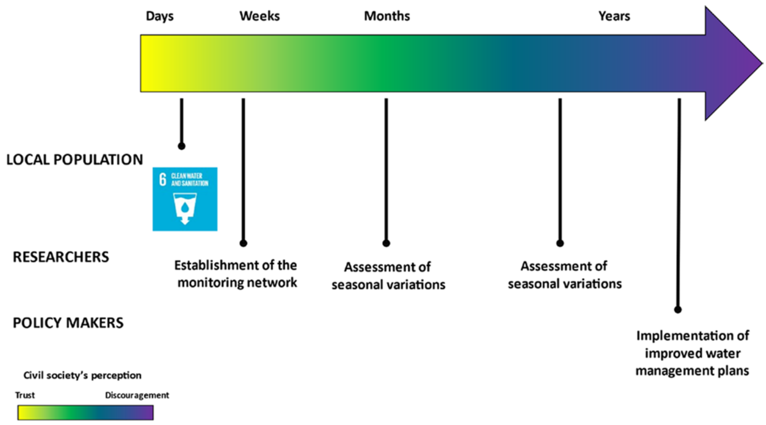

Fig. 5 Short- to long-term activities, roles and expectations related to the implementation of a water monitoring plan

To ensure the project sustainability and continuation of the monitoring assessment, all the topics of the training activities were summarized in a sampling manual (*Direciones Oficiales para el monitoreo de la calidad del agua en la isla Santa Cruz—Galápagos, Ecuador*), which also includes the sample forms for data collection in the field. The manual was presented and delivered during the project final meeting held in Santa Cruz in 2014, and both hard and soft copies were distributed to the local stakeholders and deposited into the GADMSC archives.

4 Results and discussion

4.1 Challenges and opportunities of establishing the water committee

The creation of the *Comité del Agua* was welcomed by all the stakeholders, sharing the common goal of maximizing the efforts of improving the water quality in the island. The overlapping of competences did not pose a strong constraint, even though matters arose on the possible chairing duties within the committee. The frequent meetings with both managers and technicians from each institution paved the way for the definition of a shared vision on the monitoring actions in the Island, facilitated by the uniformed sampling procedures and the joint database. However, one of the main obstacles was represented by the perceived discrepancy between the effort (in time and money) required for long-term monitoring and the need to provide the local populations clear answers about the quality of local water resources for domestic and recreational uses (Fig. 5). In particular, the authorities more closely related to the local population (e.g. those in charge for quality and authorization related to domestic and recreational water resources; Fig. 3) are the more exposed to the pressure for the general public and thus generally blamed of inefficiency in case of persistent water quality issues. This issue is not uncommon when dealing with water resources management (Re et al., 2018), and it is one of the challenges to overcome to promote data driven management policies and gain water user's trust on scientific outcomes. For this reason, public conferences were organized on a yearly base to share the outcomes of the project and to promote outreach initiatives related to the water quality monitoring programme.

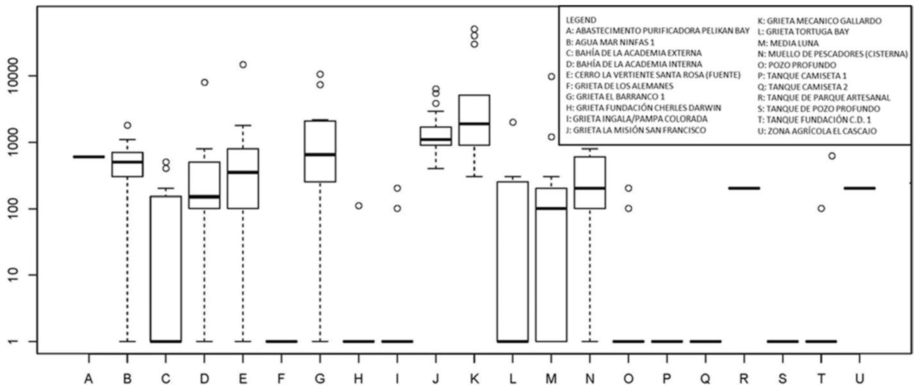

Fig. 6 Boxplot showing the values of faecal coliforms resulting from all the historical data collected in the SantaCruzWDB

In the long run, the *Comité del Agua* may play a leading role in (a) managing conflict possibly arising either among the different institutions or with the civil society and (b) public engagement with the civil society to foster the direct confrontation with local water users.

As previously mentioned, performing collective action on a common resource requires trust and cooperation from every involved stakeholder and the *Comité del Agua* has the potential to be quite effective in this regard, being a multi-stakeholder platform for the promotion of a vision on water management in the island based on informed decision-making processes, and ensuring long-term processes accountability. In addition, the vision to be agreed with the institutional members of the *Comité del Agua* is to achieve water resources sustainability and the optimization of water use boosting local agro-ecological production, both minimizing the introduction of alien species to Galápagos and reducing dependence on the Continental Ecuador.

4.2 Insights from the historical data collection

The observation of local development policies highlights the existence of a gap between the principle of decentralization and the willingness of aid-workers to delegate power to local stakeholders. The resulting initiatives may therefore give rise to dynamic without direction, in which, ignoring the local reality, projects overlap existing (or past) ones, or, in the worst scenario, are strongly dependent on the wishes of the lenders. Sometimes, in fact, the work of international cooperation can be too focused on the project itself, forgetting to interact in a fruitful manner with local stakeholders. The latter, if marginalized, clearly lose interest in contributing in a positive and effective way, and the result is that projects fail in being based on real local needs. Additionally, the lack of coordinated actions for monitoring activities results in a fragmentation of information available and poor reproducibility.

The database created by selecting, standardizing and merging the different available historical datasets (including data from 1985 and then from 2005; Mancin, 2013) highlights that, despite the sampling efforts, most of the data are not robust enough to perform an adequate trend analysis for most parameters. As demonstrated by Mancin (2013), several gaps exist in the data records, with sampling campaigns often not performed in the same period of the year, making the comparison of data and trend analyses more difficult, or even impossible when data collection is too scattered over time.

It also emerged that historical data related to a specific parameter in each site can have large variations, as in the case of faecal and total coliforms concentrations in water (Fig. 6). Coliforms, which are particularly dangerous when present in water as they can threaten human health, are often found in concentrations that are higher than the statutory safety threshold. It is therefore important to have data of good quality to be able to take correct decisions aiming at reducing their concentration below the regulatory threshold. However, while faecal coliforms show low variability in some sampling sites (e.g. *Grieta colegio San Francisco*, *Grieta mecanico Gallardo*), they show very large interquartile ranges and presence of outliers in about half of the sampling sites. The large spreading of values is also confirmed by the standard deviation that measures the dispersion of a set of values. Table 5 shows minimum, maximum, average and standard deviation related to the total coliforms measured in several sites. The fluctuations and dispersions of these values can be explained by several reasons (e.g. different sampling season/time, different analytical method, problem with the calibration of the used tools), but independently on the reason, it makes data

Table 5 Statistics calculated for total coliforms resulting from all the historical data collected in the SantaCruzWDB

Site name	N. of samplings	Minimum	Mean	Maximum	Standard deviation
Abastecimiento purificadora Pelikan bay	2	1100	1100	1100	0
Agua mar ninfas	51	300	1041.18	2700	4794
Vertiente Santa Rosa	2	0	350	700	495
Grieta el barranco	3	1932	1977.33	2000	39
Grieta Fundacion Charles Darwin	12	867	1812.42	3000	788
Grieta ingala/ pampa colorada	56	0	43.27	300	93
Grieta la Camiseta	9	0	88.61	188	57
Grieta colegio San Francisco	57	89	3359.53	45,000	7306
Grieta mecanico Gallardo	1	1600	1600	1600	*
Grieta Tortuga bay	5	346	535.4	712	149
Media luna	2	100	300	500	283
Muelle de pescadores	1	900	900	900	*
Poza sr. Chiess	4	265	612	1072	358
Pozo profundo	57	0	121.82	2923	428
Tanque la Camiseta 1	2	200	200	200	0
Tanque la Camiseta 2	2	0	0	0	0
Tanque de parque artesanal	2	500	500	500	0
Tanque de pozo profundo	6	152	211.5	307	60
Tanque Fundacion Charles Darwin 1	1	1472	1472	1472	*
Tanque Fundacion Charles Darwin 2	1	1320	1320	1320	*
Zona agricola el Cascajo	1	700	700	700	*

*Presence of only one sample, so it is not possible to calculate the standard deviation

Table 6 Summary of the shared benefits and challenges emerged from the joint monitoring approach in Santa Cruz Island (Galápagos)

Opportunities	Challenges
•Data accountability: shared monitoring initiatives can improve transparency among local stakeholders •Creation of a comprehensive dataset •Trust: working in synergy can improve trust among stakeholders •Cost-efficiency: avoid the replication and more effective use of resources •Streamline the procedures for the release of sampling permits and for the potential shipment of samples to Ecuador mainland •Integration: pave the way for the development of joint initiative and shared management plans •Ensure that international cooperation projects target the needs and priorities of local stakeholders and environmental conditions •Produce data that can contribute to the development of global indicators for water resources protection	•Compromise and power sharing among involved stakeholders •Adaptation of institutions' monitoring strategies to the shared decision of the Water Committee •Identification of the monitoring network with points of common interest •Resources allocation to cover monitoring and analytical costs •Assessment of data property •Maintaining the monitoring network at the end of the project •Ensure project sustainability when there are changes in governmental structures

more difficult to use for robust and science-based decisions. It is further possible to see that several sites have been visited only one or two times over the years (Mancin, 2013). The establishment of a water monitoring plan would help avoiding cases where some sites are visited just sporadically, resulting in not relevant and not significant data. All these factors represent an obstacle for the use of the collected data to assess both past and current quality trends, thus making the large amount of information available not fully exploitable.

4.3 Lessons learned from the multi-stakeholder water monitoring approach

Besides the clear advantage of supporting the production of shared data that can be used by all the local institutions, the capacity building and joint monitoring initiative outlined several opportunities (Table 6). The creation of a shared and structured monitoring network is necessary to obtain timely and credible data on water and sanitation. Benefits clearly spans from the environmental sector to other public and private ones. Sound data improve accountability and can support evidence-based decision-making. In addition, integrated strategies permit a more efficient use of monitoring fundings, resulting from both national and international cooperation projects (United Nations, 2018), and the use of a common coding facilitates information sharing. Nonetheless, several challenges also emerged. Among them, it is worth mentioning that institutions already in charge for monitoring assessment may already have well established procedures for water sampling and data reporting. The proposal of a shared monitoring network may therefore pose them a choice between: (a) revisiting the existing approach to the shared one, or (b) duplicating the efforts and applying both methodologies. In the short term, the second option may seem more practical, but eventually, and especially if all institutions would adapt to the shared approach, the first one would be more beneficial. In addition, as concerns the selected sampling sites, each institution may already have its own monitoring network, but it must be stressed that what was proposed in the frame of the research project is not to substitute the existing networks. On the contrary, this selection groups the most relevant water points to be included in any future assessment, especially in international cooperation projects, to ensure continuity and the creation of a robust time series to support decision-making processes for water quality protection.

Another important issue, common to all monitoring and analytical data treatment in SIDS and islands, is the related to the logistics. As concerns the specific case of Santa Cruz, this is represented by the absence of a certified laboratory specialized in water analyses, and even though PNG is equipped with laboratories to perform chemical and biological analyses, the availability of reagents (and therefore their retrieval and shipment to mainland Ecuador) can extend the time normally foreseen for the analytical procedures. Similarly, shipments of samples for analysis that are not carried out on the island are expensive and subject to various bureaucratic procedures which could affect the preservation of the samples themselves. The coordination among all the stakeholders would therefore permit to reduce these procedures, ensuring more timely and effective data acquisition. However, frequent Governmental changes and associated changes in the Ministries structures may hamper the long-term sustainability of local actions. The resulting frequent turnover of local directors and personnel, may, in fact, generate a high instability of public bodies, most of which are members of the *Comité del Agua*. Consequently, every restructuring of the Ministries (and associated redistribution of competencies) has the potential of losing part of the acquired knowledge and competences.

5 Conclusions

Results of the participatory approach permitted to highlight the gaps and potentials of water resources management in a multi-stakeholder framework. In particular, it demonstrated that the criticalities related to data acquisition, sustainability of the monitoring plan and translation of scientific outcomes into shared policies for water protection can be easily overcome by joint and coordinated actions among all institutions and groups sharing water responsibilities. Equitable power balance among the stakeholders ensured the effective functioning of the Committee, although representatives of the civil society and other marginal actors should be engaged to ensure future decisions on water resources protection are effectively to be targeted on both environmental and societal objectives. Indeed, the creation of a water committee can enhance the benefits of a multi-stakeholder decision-making process by: (i) strengthening collaborations and propose solutions that go beyond individual stakeholder interests; (ii) optimizing resources by performing joint activities and monitoring assessments; (iii) permitting to create a common vision on monitoring assessments (thus ensuring the full exploitation of collected information); (iv) achieving common purposes by sharing information and responsibilities.

The creation of the first geodatabase using standardized codes and storing the whole information from all sampling campaigns represents a centralized archive accessible to all the institutions related to the *Comité del Agua*, guarantees a better and larger use of historical data as well as facilitate the collection of new data resulting from ongoing and future cooperation projects without having the risk that results are not accessible after the end of a project.

The presence of the *Comité del Agua* proved to be fundamental, especially when the structure of international cooperation changed in 2018. In fact, the incorporation of the

Technical Secretariat for International Cooperation (*Secretaría Técnica de Cooperación Internacional*, SETECI) into the Ministry of Foreign affairs resulted in a rapid increase of NGO's project with lack of coordination with local actors. The *Comité del Agua* therefore fostered horizontal coordination among local authorities, NGOs and stakeholders. Since its establishment, the Committee has continued its activities and the SantaCruzWDB has been used by GADMSC, coherently with the competencies assigned by the law, to implement the new water distribution system, the creation of the Public Water Enterprise (*Empresa Pública Municipal de Agua Potable y Alcantarillado*; Aguas de Galápagos EP, 2020) in 2016 and the new plan for wastewater management.

Based on the positive outcomes of the project, the same approach could be replicated in other islands of the Galápagos Archipelago, thus favouring a more holistic policy for integrated water resources management at regional level and contributing to national ownership.

To ensure the sustainability of local water resources, future steps may involve the definition of a long-term periodic monitoring network plan of selected sites to be performed by local technicians and to take advantage of international cooperation projects for further training of local technicians in charge for water monitoring and management. The development of a shared procedure for sampling shipment outside Galápagos would also facilitate the process and reduce the risk of sample loss and/or contamination prior reaching the laboratory.

Acknowledgements This research is framed within the technical cooperation project "Tutela della salute e prevenzione dai rischi di inquinamento antropico" realized with the support of the Veneto Region (Italy) during the years 2011–2014 (CS2012A19). The research was also supported and co-funded by the Municipality of Santa Cruz (Gobierno Autónomo Descentralizado de Santa Cruz, GADMSC), Galápagos (Ecuador). Authors would like to thank Emanuele Giordano for the support in the data collection phase and during preliminary evaluations. Moreover, these results were achieved with the supports of the people involved in the Waster Committee, in particular Edwin Naula Gomes and Javier Oscar López Medina (PNG), Tito Guerra Parrale (SENAGUA), Juan Carlos Cuzmán and René Ramirez (MAGAP), Marilyin Cruz Bedón and Fabricio Vásquez (BIOSEGURIDAD), Jeampierre Robayo, Italo Sanmartín and Monica Soria (CGREG), Daniel Orellana, Noemi d'Ozuville and Jaime Ortíz (FCD) José Rivas (INOCAR) Juan Carlo Carrión and Patricio Ruiz (FEIG), Mario Piu Guime and Gabriel Tipán Gabriel (GADMSC). Furthermore, the authors would like to thank the colleagues from ESPOL who supported in the preparation, execution and analysis of the water monitoring Paul Cesar Carrión, Samantha Jimenez, Andrea Vera Loor, Jorge Mendoza, Jhonny Castro. Finally, authors are grateful to the team of the Municipality of Santa Cruz (GADMSC) who supported the project along all its phases, in particular Johny Eduardo Cabrera García, Sheila Gabriela Rosero Perez, Veronica Lorena Andrade Sierra, Jorge Morales, Danny Guardian, Washington Ramos and Pamela Guerrero.

Author contributions Not applicable.

Funding Open access funding provided by Norwegian Institute of Bioeconomy Research. This research is framed within the technical cooperation project "Tutela della salute e prevenzione dai rischi di inquinamento antropico" realized with the support of the Veneto Region (Italy) during the years 2011–2014 (CS2012A19). The research was also supported and co-funded by the Municipality of Santa Cruz (Gobierno Autónomo Descentralizado de Santa Cruz, GADMSC), Galápagos (Ecuador).

Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest Authors declare no conflicts of interest in relation to any aspect of the presented research.

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