Syst Pract Action Res
DOI 10.1007/s11213-014-9325-0

ORIGINAL PAPER

Methodology to Support Participative Decision-Making with Vulnerable Communities. Case Study: Engineers Without Borders Colombia/Ingenieros Sin Fronteras Colombia—ISFCOL

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Abstract The decision-making process to select the best alternative for solving a social problem in a project, which involves vulnerable communities, must be carried out in a structured way. It is important to take into consideration the preferences and perceptions of all the beneficiaries and stakeholders with their many different competences and interests as this may increase the probability of successful solutions. Thus, this paper answers the following question: How to design a methodology that incorporates different points of view in order to reach solutions with vulnerable communities? Starting from this question, this paper presents a decision-making model for social systems incorporating conventional decision-making methodologies such as the Analytic hierarchy process to systemic methodologies like syntegration through the Conceive, Design, Implement and Operate project framework (CDIO). It also presents a case study developed by the organization Ingenieros Sin Fronteras Colombia (ISFCOL) -Engineers without Borders Colombia- where this model has been applied for solving problems related to the contamination of water sources in vulnerable communities.

Keywords Decision-making · Systemic methodologies · Participative model · Vulnerable community problems · Analytic hierarchy process

Introduction

Developing projects with vulnerable communities can be understood as a task that seeks to provide solutions to social issues affecting communities with a low quality of life.

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Published online: 17 July 2014

Given this context and the aim towards developing long term sustainability, the solution chosen to be implemented must be selected taking into account a range of aspects that go from resource availability to the consideration of the community's interests and characteristics. Therefore, the decision-making exercise, to identify a possible solution within a project, must be made in a structured manner, analyzing the criteria of each party involved and giving priority to the beneficiaries' concerns. Consequently, the adaptation of systemic tools (syntegration) and the decision-making theory analytic hierarchical process (AHP) were integrated into a new structured instrument to further allow selecting the alternative solutions agreed on by all participants. (Stowell and Allen 1988).

The model proposed is framed in the O+CDIO framework (Hernández and Ramírez 2010) [observe, conceive, design, implement, and operate]. Special attention is placed on the Conceive phase is since it is the stage where the solution to be implemented is chosen. In order to make this type of decisions, it is necessary to consider technical, economic, historical, environmental aspects, and give more weight to social criteria, since it's the community which will ensure the implementation of the decisions made.

The first section of this paper approaches the decision-making process this paper is based on. The decision-making process proposed in this paper has seven steps: (1) Firstly, the alternative solution must be defined by the community; so a preliminary extensive diagnosis of the problem and community as a system must be made. (2) Secondly, the information-gathering workshops must be structured, which are the environment in which the organization will be able to obtain the main aspects of the community's perception and which will determine the social criteria to be taken into account for the final decision. (3) Thirdly, the execution of the participative workshops, which will seek to encourage the communication (Knowles and Espinosa 2009) of perceptions through the adaptation of systemic procedure *syntegration* proposed by Stafford Beer (1994). (4) Subsequently, the information gathered is scrutinized and there is a meticulous analysis of the different messages and perceptions presented by the community. (5) The information is then organized and structured in a model. It is proposed to use AHP as the tool for measuring the performances of the different solution alternatives proposed by the community in order to find the one which will maximize the satisfaction of the different criteria. (6) (7) The final two steps are the analysis of the results and the community's feedback and validation.

In the second and following section, this paper explains the integration of the different systemic concepts and the decision-making theory in a model, based on an integration approach. This model structures in a coherent, participative and suitable manner the selection process between alternatives to solve problem into a specific community system.

The third and final section describes the application of the proposed methodology, integrating and adapting the studied methodologies. The case study is based on the project "Quality of Water in Santa Isabel de Potosí" made by Ingenieros Sin Fronteras Colombia—ISFCOL (Engineers without Borders Colombia), an inter-university group that develops projects with vulnerable communities in order to improve their quality of life. Based on the results obtained in the case study, both from the theoretical and practical point of view, this paper finishes with some conclusions and perspectives on future research.

Theoretical Foundation for Participative Decision-Making in Vulnerable Communities

Definition of Vulnerable Communities

Set of characteristics of a group or individual in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (Carba 2003) or social problem (i.e. forced displacement). It involves a combination of factors that determine the degree to which someone's life and livelihood is at risk by a discrete event and identifiable in nature (Ibrahim and Alex 2009) or society (Ramirez et al. 2011).

Projects with Vulnerable Communities

Projects with vulnerable communities are defined as innovative initiatives with a defined goal, which must be undertaken in a geographically specific zone, during a period of time, for a group of beneficiaries with aims to improve an explicit situation (GTZ 1998) related to a vulnerable community. These projects are established in this manner because their goal is aimed at changing a problematic situation that affects a population making it feel insecure and unprotected due to its living conditions and to socioeconomic experiences of a traumatic nature (CEPAL 2001). These projects have special characteristics because their development and results are centered on a collective entity. The decisions made take into account history, experience, knowledge and specific objectives (González De la Fuente 2011).

In this sense, a social system requires a decision-making backbone if decisions made by its actors allow modifying the system's attributes because of interaction processes. Therefore, the decision-making processes in a social system are related to the expected attributes, those that emerge from the interaction of these decisions and their participants. Therefore, the decision-making must fully contemplate the perspectives of the different participants involved since it is their interactions, which will provide the feasibility and attainment to the decisions made (Ramírez et al. 2010).

A primary aspect in the development of projects with communities is the diversity of interests or disciplines of the different actors participating in the decision-making process, because this allows seeing different perspectives of the problem, as well as several standpoints for its solution. The sum of information, tools, and experiences from different fields and branches of knowledge of the community allows for the creation of integral solutions.

Decision-making can be defined as a cognitive process that leads to selecting amongst a set of alternatives a course of action in order to achieve goals or objectives. The process begins when there is the need to find a solution, but it is still unknown which solution will be chosen or when will the decision be made (Clarke and Lehaney 1997).

The organizations that develop projects with communities frequently face decisions of an operational, tactic and strategic nature. Regardless of the type of the organization concerned, these decisions have shared characteristics such as irreversibility, low replicable, they involve some sort of risk, and they have, after a while, an important impact in the future of the organization or of the project (Castillo 2006). Keeping in mind the previous, two approaches have been used to solve problems in vulnerable communities (see Appendix 1).

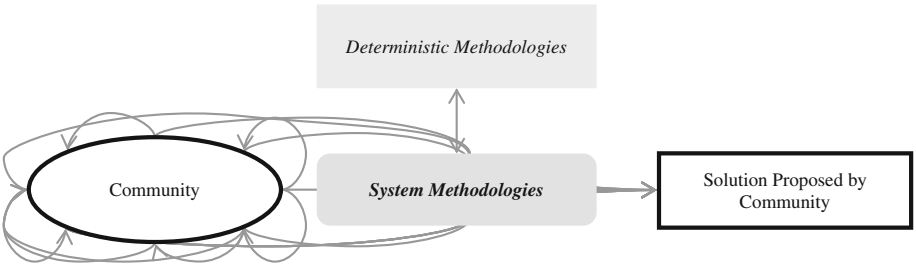


Fig. 1 Deterministic and Systemic methodologies relation

Analysis of Strengths and Weaknesses of the Methodologies

Usually, the decision-making in communities (Brugha 2001) is based in deterministic methodologies, methods that use random variables (Schwaninger 2008) which allow the modeling and optimizing of a solution for a problem situation of the real life based in-assumptions and heuristics that model problems that allow only for approximate solutions or decisions by consensus, which are made according to the positions of a group of experts. The use of these methodologies implies that the decision alternatives are thoroughly and accurately known, hence there is no need to analyze them from the multiple angles in which they can be affected. (Fincowsky and Benjamín 2011).

The decision-making in social systems, from a deterministic standpoint, often leads to solutions that do not prosper and that may even have effects opposed to the desired ones (Aldana Valdés and Reyes Alvarado 2004). Normally, in a decision-making process all the related variables induce a non-deterministic behavior, adding a risk component to the process. Consequently, the related variables must be thoroughly characterized, given the probability of error connected to the decision-making in social systems, such as those that arise in the communities of people. So, it is necessary to use methodologies that increase the probability of success of the decisions that are made based on the participation of every party interested. (Fincowsky and Benjamín 2011).

Considering reviewing of AHP related literature, it is observed that this method is: (i) Systematic approach to decision-making, (ii) Structured and (iii) Rigorous in selecting a solution alternative. Value added that is derived from this tool is subjective interpretation of all participants, the quantitative comparison of these variables and the selection of an alternative defined by them and variables evaluation. AHP allows to handling the derivative complexity from the system interactions and decision-making process. However, it is not evidence how decisions take into account the needs, experiences and the consensus among different stakeholder for decision-making. Above, it can probably guarantee a technically correct solution but hardly to appropriate by community (Carr 1996).

Given this, it is required to integrate this type of deterministic processes with a systemic and participative component to strengthen the process of decision-making, integrating the dynamics of the system and looking for a process more akin to the characteristics of its needs. Foregoing, it is remarkable the importance to address these two approaches together.

Thus in order to increase the probability of success of the decisions regarding social systems, the systemic theory provides tools that allow to participation of every actor involved through the analysis of the system, its components, interactions and effects,

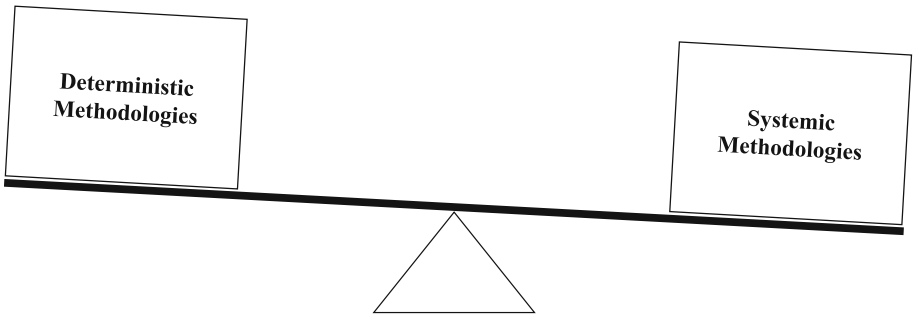


Fig. 2 Methodological balance

allowing thus the construction of a more complete, real and logic outlook (Ackoff 1962; Haftor 2011) (Fig. 1).

Likewise, the participation is granted by the interactions achieved between the different parts of a system, allowing the development of knowledge and the collective making of a solution. Thus the collective making of a solution allows to developing of autonomy, self-organization, independence, and enhancement of the knowledge of the actors involved; which are essential factors for the development, analysis and implementation of the decisions (Ramírez et al. 2010).

Finally, regarding the decision on the alternative solution to be chosen for a project with vulnerable communities, it is proposed the use of a participative analysis mechanism that employs the AHP and the concept of syntegration. The integration of these two theory concepts allows to structuring and analyzing the inclusion of the interest and perceptions of every participant in the project during the decision-making process, giving priority to those that concern to community.

The methodological proposal provides a solution proposed by communities that otherwise would not be able to access these types of technologies yet using the participative aspect in almost every step of the process.

Problems of this sort could be approached in several ways. On one hand, an engineering team could simply limit themselves to taking water samples, analyzing them in a laboratory, choosing the filter which best improves the water's quality, installing it and leaving. But this approach would not make the community reflect on the fact that the filter is just a technological answer, that the water remains polluted and that fundamentally, it is their problem, in addition to leaving a solution that requires constant intervention and permanent maintenance. The solution is built between all team members involved in the project. The third and actual approach used tried to balance both (see Fig. 2) of the aforementioned alternatives suggesting possible alternatives to filter the water, but giving the community a prime role within the decision-making process through the use of their participation and not just through, for example votes, which would represent a simple democratic system but through a methodology to support decision-making with vulnerable communities.

As it seem in Fig. 2, the deterministic methods provide support to participatory systemic methodologies proposed for decision-making in vulnerable communities and the overall process.

Methodological Proposal

The present decision-making proposal uses as a frame of reference for the development of projects the O+CDIO methodology, Observation–Conception–Design–Implementation–Operation. This referent is aimed towards the development of social skills such as communication and cooperation, and of cognitive skills such as systemic thinking, problems resolution, self-learning, among others, through the development of engineering initiatives (Guoke and Huijuan 2012).

The initial stage, defined by the 'O', has been added by a group of researchers upon realizing the need to analyze and diagnose the communities before conceiving a proposal (Hernández and Ramírez 2010). According to this conceptual framework, the elaboration process of this type of projects comes by initially through the observation of the situation and the system that will be intervened; secondly, by the conception of the solution proposal; followed by the definition of a design which will be afterwards implemented; and, finally, by an operation stage which, in the case of vulnerable communities, is to be carried out by the community itself, implementing taken decisions. The decision-making regarding the form in which the project will achieve its objective and which will be the solution proposal that will be carried out. It takes place during the conception stage. The model presented in this paper is therefore centered on this stage.

Observe

First, the authors must point out that the development or the making of any decision have an objective, something that must be changed or transformed. In this sense, what prompts the need for the project is the presence of a problem issue. A problem situation must not be seen as the absence of a solution, rather a negative situation for a certain social group.

Taking the problem issue as the starting point, the team responsible for the decision, the intervention, or the development of the project must know, as in any similar situation, the context regarding the situation, its participants, how are they affected?, why?, how often?, among other inquiries. It is fundamental in this sense to gather as much information as it is possible.

It is important to remark that the development of the project and the decision-making will generate a transformation in the implementation environment. Since issue is the development of projects in communities, it is clear that the intervention of external agents will alter the current state of the system. Consequently it is imperative to understand the dynamics of the community and comes close to it in order to become part of the system. In this stage it is necessary to make a definition of: the system, the project and the possible alternatives solutions.

Defining the System

There are two actions belonging to the *Observe* stage, which the work team must carry out before they apply the O+CDIO methodology; these actions are explained in the Fig. 3.

In accordance with what is described above, the decision-making team may be in the capacity to describe the organizational system, in a way that compiles the main components of the project and generates a more centered and precise idea of the process being developed. To achieve more active participants linked to project, it is proposed the application of TASCOI (Espejo and Reyes 2011) (Watts 2009) tool, mnemonic of: Transformation, Actors, Suppliers, Costumers, Owners and Interveners.

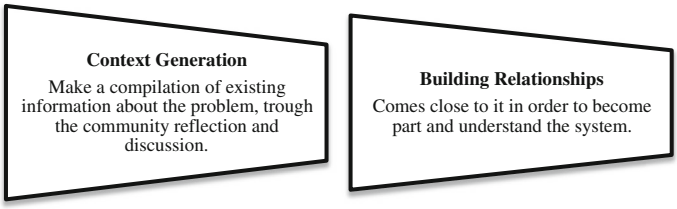


Fig. 3 Observing actions in the O+CDIO methodology

Observer and Conceive

In this stage of the methodology the decision regarding the solution to be eventually designed and implemented is taken. Consequently, it is necessary to execute a process that leads to an objective conclusion that supports to corresponding environment. From the theory and the experience of the authors in projects with vulnerable communities, the following steps are proposed:

Figure 4 presents the tools and activities proposed in *Observe* and *Conceive* stages, as well as the relations between them. Between each step it is necessary a feedback. From the *Observation* stage, the key subsystems for the decision-making must be identified, such as: the system of actors that directly or indirectly affect the decision, the resources associated to the decision-making, the nature of the relationships with the different types of systems that are part of the context (politic, social, environmental, economic, etc.). Next, the needs and perceptions related to the general context are identified. The latter represents the outputs that allow help the stages of *Conception* to reach the most suitable alternative given the preliminary observation. In *Conception* stage the integration of AHP and of social participation alternatives are required in order to evidence aspects such as the cooperation, solidarity, and general adaptability that the groups of actors (Fig. 5).

From theory revision, the necessity to take into account the different interested parties that are involved in the decision-making process of a social system was understood. In the case study, the evidences and results are presented in order to replicate the proposed methodology in similar contexts. In the proposed O+CDIO context, the decision-making is based upon activities that take place in the Observation, Conception, and Design stages of the alternative. Throughout various cycles, the community along with the intervenient team observes the situation. What is observed is then analyzed and redefined (in various cycles) allowing for the proposed solution to be the one with the highest probability of success to be conceived and designed (Fig. 6).

Defining the Alternatives Solutions

The term alternative solution refers to the options available for an organization or community to accomplish its envisaged goals. These alternatives are usually exclusive, that is to say that they cannot be undertaken simultaneously due to their human and economic requirements or to their divergent nature (think of a sale alternative of a resource versus the use of the resource). It is important to identify and analyze the alternatives available for the system in this specific context, those alternatives are selected from a wide spectrum that emerges from all participants (community and all project participants).The range of options comes from both the different interests and arguments of the involved actors. Also there is

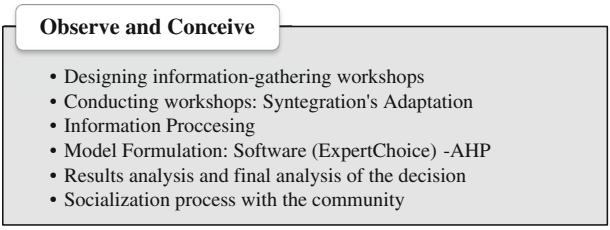


Fig. 4 Structure of the conceive stages. Information Processing: refers to the enlistment of data in accordance with the decision-making process (AHP). This process does not violate the integrity of the data, in order to avoid bias or manipulation of data by the team.

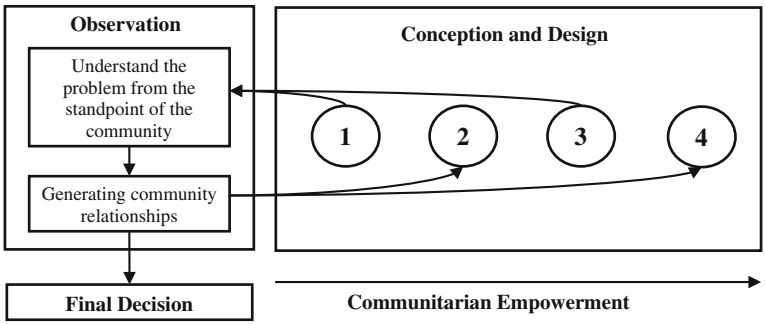


Fig. 5 Observation and conception outline

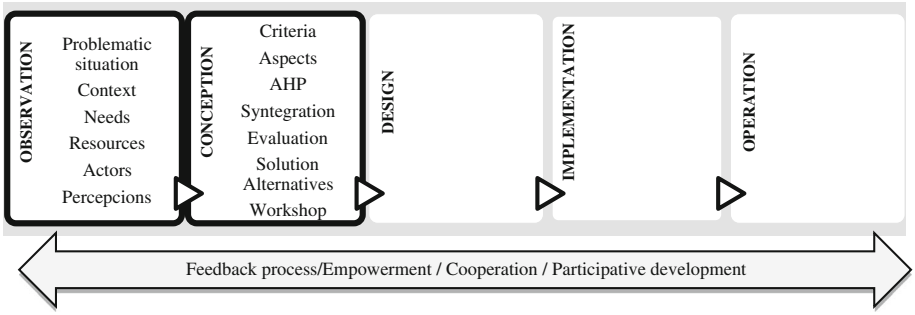


Fig. 6 Tools and actions proposed in the methodology

an uncertainty component regarding the manner in which the alternatives influence the planned goal and particularly the multiple aspects that compose it. Once the proposal alternatives solutions are defined, additional information is required to check if these proposals are feasible or not within the community, for example: Are there are sufficient resources? Is there enough capacity? Is the intervention of an external agent is required? Who evaluates the variables?

Structuring of the Information Gathering and Participative-Workshops

As it was explained in the theory section of the paper, in order to make a decision through the analytic hierarchy process it is necessary to obtain the importance and performance matrixes. These matrixes compare by pairs the performance of the alternatives in relation to defined criteria. The definition of these criteria must be made in a way that it allows them to evaluate the alternatives according to the main aspects of the project.

For the case exposed in this paper, problem issues based in social systems like the communities, it is a priority that the decision-making team takes into account that the criteria must seek to include not only the specific requirements of the solution supplied by the project, but also the autonomy components which will concern the community.

The current exercise proposes, as means for obtaining information to define the criteria, workshops with the community and work team.

The work team must carry out the analysis of the situation, and the design and structuring of the workshops. These activities are based on adaptation sketches from syntegration and in the adaptation already explained in the theory section from this paper (Hühn 2012). The researching team must perform a preliminary definition of: the general objective, the hierarchies, the criteria, and the possible alternatives for the AHP model, based on the information gathered with the community. Proposals are validated and refined with community stakeholders.

It is important to note that the model AHP it is not presented directly to the work community, rather it is through tools proposed by the researchers, which allow the gathering of the information concerning the opinions of the relevant actors. The design of these tools must take into account the social context and the competences of the members of the group. However, the activities and exercises developed with them improve their skills, for example: integration, participation, problem solving and teamwork.

This workshop must congregate the community, preferably in an environment suitable for diverse integration activities. The workshop must be designed after a rigorous analysis of the participants, looking to create mechanisms that allow for the retrieving of the knowledge and experience of the actors involved and, afterwards, for the establishment of goals, criteria and collective alternatives solutions (group members and research team). The workshop must not be biased in favor, or against, any of the participants.

As a product of the workshop, the research team must be able to build an AHP model, its hierarchies, the first level criteria -as well as those of the other levels-, and the alternatives solutions. There is an information refinement process to be taken into consideration; nevertheless, it must not alter the will expressed by the actors. To verify the above, a validation process with the community is done; if changes are required the respective adjustments are made.

Execution of Workshops–Syntegration Adaptation

It is desirable to have in the workshops a group of participants with heterogeneous characteristics, so a participants group that is diverse in terms of gender, age, profession, education, among others, is preferred. This aims at having different points of view and opinions that enrich the decision-making process. The workshops must be designed in such a way that it allows the dialogue and exchange of ideas among the participants.

In consequence, the workshop must allow participants to know what is being developed. The syntegration process allows that each member interacts with all topics of discussion, because information flows from vertex through the edges (participants). Therefore,

participants' proposals will include all the information discuss previously and become more robust as time goes. Thus, the syntegration concept is fundamental for the process of designing the workshop environments.

The syntegration adaptation guidelines establish that the groups assembled must not be fixed during the entire workshop; on the contrary they must interact between them and periodically exchange their members in order to make the information flow through all the participants.

Is required a joint and structured participation and no hierarchies to have an effective adapting syntegration process in those cases that requires decision-making, such as it was presented in this paper. However, it aims to providing effective and efficient communication among all participants. Although, it is usual that syntegration process take several days, but this case study had to add intermediate periods between syntegration sessions. Those modifications were subject to availability of participants, because their state of vulnerability does not allow them to devote three or four days for this exercise. However, in the interim, active tasks are assigned to feed the different reverberations.

Information Processing and Model Formulation in ExpertChoice®

As it was mentioned above, in order make a decision through the AHP it is necessary to obtain relevant information to be able to establish:

- The first and second level criteria that allows the evaluation of the alternatives.
- The importance and performance matrix.

The workshop produces a significant amount of information that should be refined. To this end, the researching team must refine the information gathered from the workshop participants through categorization methods in order to define the criteria and the matrixes. The community participates actively, but doing validation exercises of the obtained results.

ExpertChoice® is a resource that allows the information generated through the information gathering workshops to be incorporated, and to determine the alternative solution. The program allows the execution of the analytic hierarchy process AHP through an easy-to-use interface.

Results and Final Analysis of the Decision

The results provided by the ExpertChoice® software must be analyzed and understood from the perspective of the information that was at its source; it is also important to perform a sensitivity analysis and to fully understand the nature of the results. The added value of generating a solution starting from this procedure is the comprehension of the needs of community, the multidisciplinary input, and the incorporation of a formal qualitative and/or quantitative method; all these factors help reduce the risk of an erroneous decision.

Feedback

It is necessary that no stage of the process is detached from the community, and the multidisciplinary approach is not discarded. It is indispensable to acknowledge publicly the importance of the participation and the contribution from the community. It is also important to not only present the results to the community, but also to evaluate them; it must be kept in mind that the solution to be implemented will be operated by the

community, hence there must exist a high empowering and appropriation level that can only be achieved with the total satisfaction and willingness of the community regarding the choice made.

In conclusion, the methodology proposal allows project participants: (i) To participate actively in O+CDIO framework stages, (ii) To communicate their necessities and expectations and (iii) To formulate in a participatory process solution proposals. The AHP is used exclusively as a tool to support the Observe and Conceive stages and solution design process.

Case Study: "Water Quality in the Santa Isabel Rural Settlement - Guasca, Colombia"

It is necessary to notice that ISFCOL is involved in social projects, in which the 'social' component means any state of vulnerability in a community. The project has to seek the vulnerability mitigation. The social component implies taking into account the systemic approach, it is related to the decisions that may be taken by the whole structure and/or by the parts of participant community. This is conceived as a set of aspects diversely related, capable of self-organization and capable of evidencing properties that could not be explained through understanding of its components.

It was evidenced in the presentation of the methodology that, the impact of the present research is focused on the making of decisions in projects with social communities. In this sense, just the observation and conception stages are presented, since these are the ones in which the decision is made. Design, implementation and operation (O+CDIO stages) are not within the reach of this paper.

Ingenieros Sin Fronteras Colombia (ISFCOL) -Engineers without Borders Colombia-

Having already defined in the precedent sections the characteristics of the social systems, wherein equally problem issues arise and the decisions are made collectively bringing together organizations, unions, communities, among others, this section presents the ISFCOL organization and its model of participation and decision-making concerning social systems.

ISFCOL is an organization constituted by students, professors and alumni of the Universidad de los Andes and the Corporación Universitaria Minuto de Dios, whose purpose is to improve the quality of life of marginal communities in Colombia, to work with multidisciplinary teams and to achieve a two-way learning between the communities an ISFCOL.

Similarly, through a holistic vision of the projects carried out by the ISF in Colombia, integral solutions are proposed, reuniting the technological transfers and the strategies for working with the community. In this way, the contribution of this organization is made in a context of scientific research that aims for an appropriation of the knowledge by these communities, promoting the improving of the economic and social conditions of the deprived population in the country, and fostering the social and environmental responsibility.

The projects of ISFCOL are characterized by having several actors that come from the community, the government and the academic sector, each one presenting diverse interests and methodological proposals which are discussed in the light of the problem issues to be solved or ameliorated. Therefore, this paper presents ISFCOL as a leader and participant in the making of decisions concerning the solution of social problems regarding the management of water resources (Ramírez et al. 2011).

Water Quality in the Santa Isabel, Guasca Rural Settlement

Given the characteristics of vulnerable communities, the case study problematic are related to meet basic needs such as lack of water quality. Since it is a situation with multiple possible solutions, the decision-making process have to take into account different viewpoints of the stakeholders.

Context

Given the characteristics of vulnerable communities, their problematic situations are related to meet basic needs such as lack of water quality. Since it is a situation with multiple possible solutions, the decision- making process has to take into account the stakeholders' different viewpoints.

The project "*Water Quality in the Santa Isabel rural settlement - Guasca, Colombia*" it is being developed with the Santa Isabel rural settlement in Guasca, Cundinamarca since the second semester of 2011. The project began when a group of ISFCOL students identified through the dialogue with the community an environmental problem issue concerning the main water source of the zone, the creek El Asilo. This creek, which is a water source for the daily use and consumption of the community, has been affected after some time; its flow has diminished, there are foul smells, and the people that live near it or that use its water for domestic consumption has been affected with gastrointestinal diseases.

The work team and community identified that the management of the water resources in the municipality of Guasca—Cundinamarca at "Santa Isabel de Potosí" rural settlement (case study) is a situation characterized as a social problem. In it, the ISFCOL staff apply the model proposed in this paper and present the process with the community. The community repeatedly expressed the difficulty to ISFCOL staff to organize all the participants in order to address the problems associated with water management.

In this sense, the principal objective of the project was established, namely, to improve the quality of life of community members, involving all families, that live in the rural settlement through the implementation of technologies or methodologies aimed to improve the quality of the water resource. The initial diagnose based in information gathering methodologies allowed the identification of possible causes of the current situation of the creek: inadequate management of the solid resources, lack of septic tanks in some households, absence of environmental regulation entities, inadequate thrash management, lack of community organization, formation of artificial dams in the high of the mountain, potato plantings and increase of urban building in the rural settlement.

The diversity of actors involved in the problem and the lack of community auto-organization require the alternative solutions not to be limited to the technical engineering components, but rather be the result of a systemic work with ISFCOL with the community.

The main source of interest in this issue for ISFCOL resides in the zone where the community is located, which is one of the most important in Colombia in terms of moorland: an ecosystem that generates and regulates water par excellence. The development of a project that appropriately and successfully leads to a diagnose and to the implementing of a solution that has a positive impact not only in the families but also on the perception of the water resource as a non-renewable good is a meaningful step towards the amelioration of the most relevant issue for Colombia and the world nowadays: the high possibility of a general shortage of water in the future.

Observe

The project started in 2011 when some community members of "Santa Isabel de Potosí" rural settlement expressed to ISFCOL a problematic related to potable water access for consumption and pollution of the creek, named "El Asilo". It is important to notice that every project must initiate from a need or a problem, in this case it was the community itself that communicated the presence of a social and environmental problem. Assessing the context and the initial information of the situation, the group ISFCOL acknowledged the pertinence and importance of developing a project oriented to the local community's water quality. With the initiative and the existence of the problem issue, the following step –before defining project plan or objectives– was to observe with the community and understand the issue. Is in this moment when it is crucial to develop what was named "*creation of links with the community*". Considering the space and time of the project for the first stage, if one wants to gain access to a problem situation in order to fully understand it is indispensable that access is granted by the persons affected by or involved in it. Consequently, the first approach was to community leaders in the zone.

Based on the relationship already established, the group focused in the "*context generation"*. This stage is oriented towards understanding of the problem situation as a system and, consequently, the analysis of the points of view of the actors, a task that aims to the definition of the project itself and its objectives. For the generation of the context, around 20 field visits were made, in which the creek was inspected, noticing the environmental impacts in the area, as well as focus groups and workshops with members of the community in order to get a better comprehension of the community's perception. Based on these activities, the context of the issue was defined as follows:

- Lack of organization from the community population. No community board.
- There is no garbage collection system or collection or recycling culture.
- High profit margin for the potato plantations and deforestation of the creek due to the potato plantations.
- There are no septic tanks. The wastewater goes straight to the creek.
- The suburbs and the community throw solid wastes into the creek.
- Pollution caused by the poor management of solid waste (farmers and cattle raisers).
- Possible disease outbreaks due to the consumption of polluted water.
- Pollution due to the agro-industry: they throw chemical waste and fertilizers.
- Lack of attention by the city hall and loss of community's integration.
- Pollution due to thrash burning.
- The water is more turbid or polluted when it rains and droughts caused by the appropriation and diminishing of the water flow.
- No respect by the farmers of the creek's cycle.
- The households do not have septic tanks, resulting in the dumping of the wastewaters directly in the creeks.

Also, the main actors and their roles within the community were identified with the community leaders. Some of those issues were used in the first workshop, implementing syntegration process (Table 1).

Based on the evidence, understanding of the context, and the establishment of relationships with community leaders and habitants, the project's TASCOI was defined:

Table 1 Actors and roles in the project

Actor	Role
Community of the rural settlement	The Santa Isabel rural settlement, according to the Guasca town hall, is formed by 100 families (60 % men and 40 % women). Most of its inhabitants practice the agriculture or the raise of cattle, whether on their own land or on someone else's. It is important to remark that there is no aqueduct that provides drinking water for the settlement and that the El Asilo creek is located in the border between the municipalities of Guasca and La Calera. The latter has caused that neither of the town halls recognize this zone as their responsibility, resulting in a serious neglecting of the needs of the community
Potato farmers	In the upper region of the settlement, there are large extensions of potato plantations. These plantations exceed the legally permitted height above sea level, which is established to protect the moorland endemic ecosystem and its water cycles, which are damaged with the plantations. The Resolution 1197 of 2004 from the Colombian Ministry of the Environment, Habitat, and Territorial Development contains all the laws and papers concerning the regulation of settling and cultivation in the moor zones
Guasca and La Calera Town Halls	The town halls are the main regulating entities in the zone. However, the long distance between the rural settlement and the municipalities' urban centers and the halfway location of the El Asilo creek result in a meaningless and inconsequential presence of both these governmental entities
Suburbs	As a result of the presence of urban residential sets at Sopo Valley (near the creek, approx. 50 mt), the settlement has seen several high income housing developments, which benefit from the creek but have a private water treatment plant; nonetheless, some of their wastewaters end up in the creek. They are one of the actors who pollute the creek
CORPOGUAVIO	The Guavio Regional Autonomous Corporation (CORPOGUAVIO) is the main environmental entity of the province in which Guasca is located: El Guavio. CORPOGUAVIO has presented some reports concerning the environmental problem issues of the rural settlement, however apart from the formal documents presented, these denunciations have not had any repercussions and no measures have been taken by the Governmental regulating entities
ISFCOL	The organization seeks to improve the water quality for the community through an engineering project, thus involving professors, students, and alumni with the needs of the community

- *Transformation*: The project Quality of Water Santa Isabel, Potosí will implement some technology with the objective of improving the quality of water for the community consumption.
- *Actors*: ISFCOL and the community of Santa Isabel, Potosí.
- *Suppliers*: Santa Isabel de Potosí community, Universidad de los Andes and Corporación Universitaria Minuto de Dios.
- *Costumers*: Santa Isabel de Potosí community and ISFCOL.
- *Owners*: Santa Isabel de Potosí community.
- *Interveners*: The environmental corporations of the zone (CORPOGUAVIO), the town halls of the Guasca and La Calera municipalities.

Defining the Project

After defining a context and the relations with the community, it was possible to establish the basic guidelines for the project. Below we will present the objective but we will not go any deeper in the other aspects of the planning, since the relevance of the present research

is the decision-making: "To improve the quality of life of some families in the Santa Isabel rural settlement through the implementation of technologies to improve the water quality".

Defining the Alternatives Solutions

Based on the problems identified, community and ISFCOL did some research on possible solutions, based on previous experiences of all participants. It is important to remark in this stage, that the alternatives solutions are only proposed once there is a clear context, relationships and a project proposed. The definition of the list of solutions was made through a joint work with the community and ISFCOL; this aspect is completely indispensable since the community must have a high level of appropriation, and therefore of appreciation, of the solution proposal. In addition, it must be kept in mind that there are several iterations to be made regarding the definition of the alternatives solutions, in order to increase the probabilities of success for the succeeding stages:

Implementation of Sand Filter in the Family Households The filter is based on a process, in which the untreated water passes, by effect of gravity, through a porous sand layer (The National Environmental Services Center 2009) leading to the formation of the organic layer above the sand known as "schmutzdecke", which entraps and degrades the organic matter. Afterwards, the filtered water goes through the gravel layer, which supports the sand, and arrives to the draining system for being collected and expulsed (Weber 2003).

One of the advantages of this type of filters is the simplicity of the design and the operation, as well as the lack of chemical compounds and energy. This kind of filter can remove organic and inorganic suspended matter, as well as pathogen organisms. The filter may reach up to 90 and 99 % for removal of viruses and bacteria (The National Environmental Services Center 2009). ISFCOL has had previous successful experiences using this filter, which guarantees the knowhow *for the* implementation and the operation.

This filter is limited when filtering water with a high turbidity level because this type of water may clog the fine sand, as well as with waters with low level of nutrients which difficult the filtering because they don't promote the creation of the organic layer. In addition, this type of filter does not remove in their entirety the organic chemicals and the heavy metals. (The National Environmental Services Center 2009).

Implementation of the Semi-Anthracite Carbon in the Households In this type of filters the water passes through the tank, containing activated carbon, retaining through adsorption, smells, flavors, organic pollutants and residual chlorine, afterwards, there is a process of backwash through the insertion of water in the opposite sense, removing the carbon and providing new contact surfaces which eliminate the carbon fines (Awwa Research Foundation 2003). This type of filter is installed in the households that lack a water purification system and have reported gastrointestinal diseases.

In order to use this filter for water purification the following materials are required: activated carbon (semi-anthracite carbon, similar in the chemical structure to the artificial carbon or coke), flocculants (which facilitates the sedimentation of the solid particles), caustic soda (neutralizes the water), sodium hypochlorite (disinfects the water), gravel and sand (filters solid particles of different sizes (Speight 2013).

According to Speight (2013) the water to be treated must be mixed in a dose of flocculants and caustic soda, this dose varies according to the amount of water to be treated, afterwards sodium hypochlorite is added to the solution and it is transferred to the

filter build on different layers, the first ones are made by gravel and sand and the final ones by activated carbon or anthracite.

Implementation of the Ozone Filter in Family Households The ozone applications in the treatment of water come from its particularly energetic oxidizing characteristics, which are used for degrading or eliminating certain organic substances or unwanted minerals, as well as from its powerful bactericide effect. The oxidizing effects of the ozone act in three different ways: direct oxidation by loss of an oxygen atom, direct oxidation by addition of an ozone molecule in the oxidized body, or oxidation through catalytic effect that favors the oxidizing function of the oxygen present in the ozonized air (Rakness 2005).

According to Rakness (2005) this system allows for the filtering of water without affecting the natural qualities of the water such as salts and minerals, the only momentary addition to the water made by the ozone filters is ozone (O_3), a natural bactericide, that in a matter of seconds after purifying is transformed into oxygen (O_2) without leaving any trace, making it more healthy, digestive and good-tasting.

Conception

This stage evidences the need for including the Observation stage to the CDIO conceptual framework. In this type of projects it is impossible to conceive proposals if there is not yet a full understanding of actors, relations, and dynamics that allows to develop these type of projects.

Is in this stage when the work team, along with the community, will make the decision of which alternative solution will be chosen.

Structuring of the Information Gathering Workshops–Syntegration Adaptation

The information gathering workshops (at least three) are the means to obtain the constitutive factors for making a decision through the AHP:

- First and second level criteria that allow the evaluation of the alternatives.
- Importance and performance matrices.

For the current case, the two actors involved are the ISFCOL and the community of the Santa Isabel de Potosí rural settlement. The first one has a more technical perspective of the possible solution, whereas the second one is more oriented to the role that the community will play in the possible solution. In this sense, the need to take into account in the decision-making process the criteria of both these parties, defining both the technical and social hierarchies, is evident, the former with regards to the technical aspects (ISFCOL) and the latter concerning the social aspects (community).

The information sources for the technical hierarchy were the bibliographic review of similar projects and the opinion of experts and professionals close to the ISFCOL. In the present paper, due to the relevance in terms of the subject treated, we will present only the structuring process for the social hierarchy.

As it was mentioned in the theoretical framework of the present paper, in order to make any decision it is indispensable to remember that the criteria or aspects which will be used to choose the best alternative solution must include in their entirety the point of view and needs of everyone involved, which for the current case are the Santa Isabel de Potosí community and ISFCOL. For ISFCOL the aspects used for classifying and evaluating the

performance of the different alternatives solutions are evident. However, the criteria of the community is not evident and, therefore, it is required to carry out a workshop that through a creative structuration leads to defining the criteria of the community for evaluating the alternatives.

One of the main characteristics of the workshop to be made with the community is that it must not be completely explicit, that is to say, it must not ask directly: Which would be your criteria for evaluating the alternatives solutions? Such a direct question could result in a biased answer and the use if technical terminology could not be intelligible for the participants. In this sense, for the workshop designed for the case study at hand the participants were presented with a situation in which they should assume a similar role to the one they would eventually play in the project, but in another context.

In this similar role all participants have the same power of decision, have benefits as obligations too, trying to imitate those identified by work team: (Improve of the quality of the water for consumption and Build and operate the alternative solution). It is noticeable that there is a simile between the situation proposed in the workshop and the project Quality of Water in the Santa Isabel de Potosí Rural Settlement. This facilitated understanding the criteria or relevant aspects that the community considers important regarding the decision-making for something that will get them some benefits but also some obligations.

Workshops

In developed workshops all community members was involved, both children and adults, if it is required. These workshops sought to identify the views of the participants through interviews, surveys and games that encouraged participation and open dialogue about issues of community and those related to the creek, in this case.

One of the characteristic of syntegration process is that have to be developed in consecutive days. As it is explained above, in this exercise, this condition is not fulfilled. Given the poverty, needs and the context of participants, they cannot spend long times out of their jobs (their only source of money). For this reason, the methodology was adapted to a three intensive workshops and spaces of one or two weeks for reflection and consistently reverberation between it. Above it is presented each of the objectives and activities developed in the workshops:

Workshop 1 Objective To recognize, along with the community, focal points concerning problematic situations that affect the source of the water which they consume. In the first meetings, the community identified and exposed their needs and issues. The authors presented the main issues discussed in Workshop 1, see Fig. 7. The participants involved in this workshop was those that were described in TASCOI definition, however most of the people were members of the Santa Isabel de Potosí community.

At this stage, the community was particularly active and ISFCOL only played coordinator's role of these early discussions. Obviously, it was necessary the participation of all community members, they had not done so far. This was very valuable, because an open space for discussion among themselves was necessary for project development (Fig. 8).

Workshop 2 Objective To determine through a group decision-taking simulation, the criteria they would consider as most important to take into account. A special emphasis was made on the need to define how the relationship, between the actors that take decision,

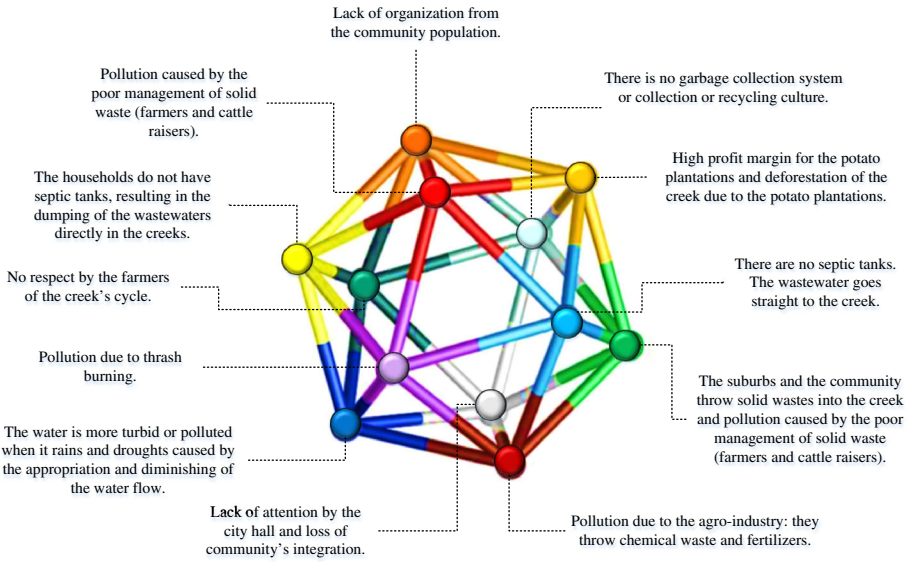


Fig. 7 Syntegration exercise at Workshop 1

Fig. 8 Members of the community and Ingenieros Sin Fronteras Colombia sharing, throw an environmental recognition, the perspectives about the water condition

would be and the role they would play after the decision was made. The authors proposed another syntegration exercise to establish the aspects that were necessary to evaluate the proposed solution alternatives, see Fig. 9.

Workshop 3 Objective To analyze through a grading scheme, certain problematic situations that affect their community. Three aspects mainly: understand if the community perceives the zone's environmental degradation as a problem; understand each member of the group's work dynamic and their abilities to generate proposals.

Workshop 4 Objective To detect the different dynamics developed by the community towards the work team through games such as letter soup and obstacle races.

The autonomy and sustainability of the implemented proposal is not guarantee, it depends on the active participation and validation of the results with the community. This

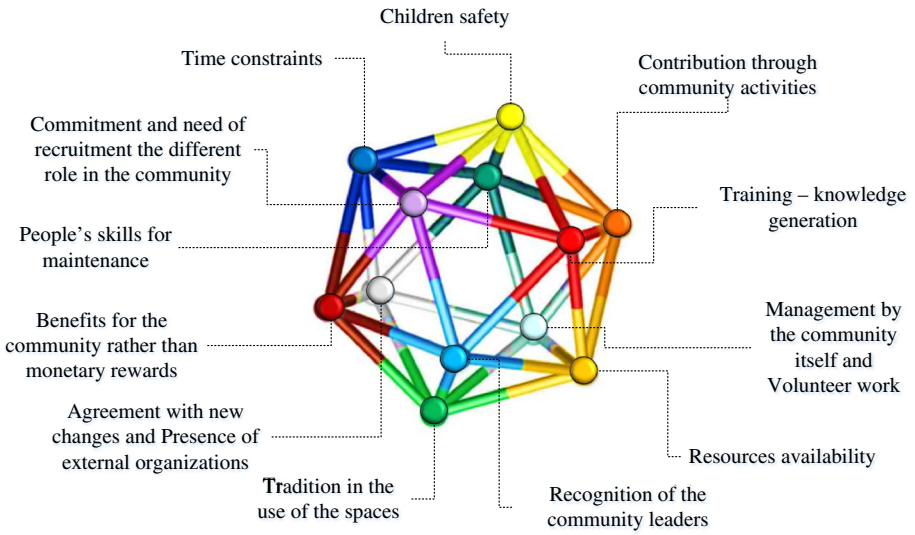


Fig. 9 Syntegration exercise at Workshop 2

is a possible way to ensure these aspects, because it is something that they built themselves. It is important to notice that those exercise stimulates the active participation of the community members. It could see in the Figs. 10, 11 and 12 that community are the relevant actors in workshops, assuming the role of process' owners. It develops community's autonomy. The activities developed in workshops with community improve their skills in aspects like: integration, participation, problem solving and teamwork, so it contributes with the empowerment skills development in the community too (Fig. 13).

Information Processing

For gathering of the information during the workshop, ISFCOL researchers were in charge of noting down all that was discussed concerning the questions asked and the situation proposed. Even though, as it was explained, the workshop was not explicit regarding the problem issue of the Santa Isabel de Potosí community, through an analysis of the recurring aspects emerging in the answers it was possible to understand the standpoints, thus the criteria, relevant for the community in the moment of making a decision.

Keeping in mind the objective devised for the workshop, it is important to take into account that the case study presented to the community, was a hypothetic parallel case and was used as an excuse for understanding the perspectives and criteria of the Santa Isabel de Potosí community when confronted to situations in which they obtain benefits, but in turn they must commit and assume roles and responsibilities. For the analysis of the results the following steps were followed:

Filtering of the Information, Assembling in Categories and Naming of the Categories

Each of the workshops reports were examined thoroughly and the relevant aspects evidenced by the participants were identified. Many of the aspects pointed out in a group reappeared in the other groups. In accordance to this, a matrix indicating if the aspect had

Fig. 10 The community defining the aspects consider important in a general making decision process

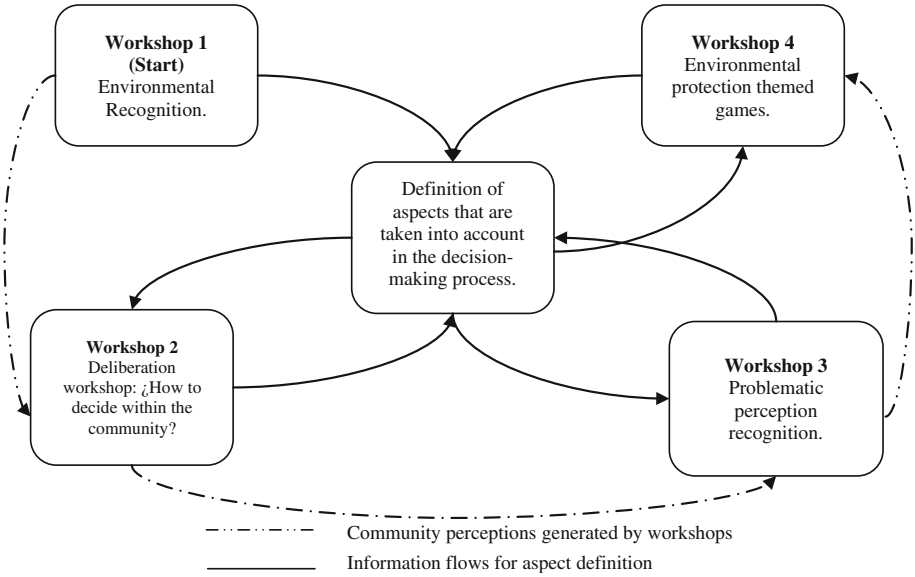


Fig. 11 Workshops structure

been mentioned was created for each group. At the end, there was a total of the number of times that the aspect was mentioned. It was perceived that many of the aspects discussed above were deeply connected or could have the same meaning. The aspects were grouped by similarity of meaning.

Even though the aspects were grouped, it was not completely clear how certain categories should be named and if they really represented all the aspects within the category, because there were opposing positions in some of them. Keeping this in mind, an analysis to the interior of each category was carried out. The name of each category was defined from the frequency of usage of the above terms by members of the community and making a verification and validation process of meaning with them.

In accordance to what has been exposed, the aspects or criteria for each of the hierarchies, social and technical, were defined:

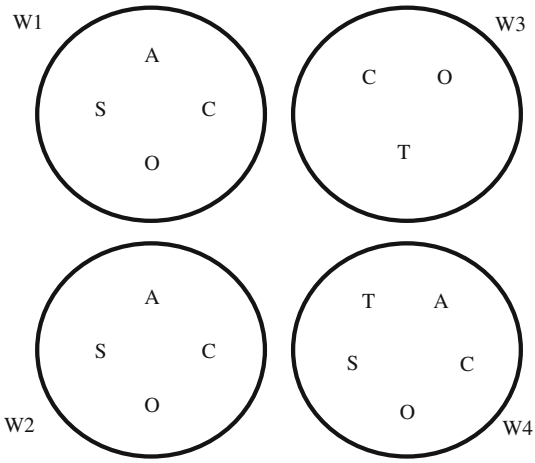


Fig. 12 TASCOI's entities participation distribution

Fig. 13 Community validate the aspects and criteria

Social Aspect Hierarchy

Taking into account, the analysis made of the information gathered the six criteria mentioned above were defined. However, when confronted with the ones established for the technical hierarchy, it was evident that a reclassification was required (Fig. 14). The criteria finally defined for the social hierarchy are the following:

Community Benefits The aspects included in this category refer to the extra benefits, in addition to the main objective of the intervention, which the community would like to obtain. An example of an extra benefit, besides the improvement in the quality of the water, is the formation for the children in water related subjects. All of this revolves around the fact that the community wants to see its efforts rewarded by an integral solution.

Project's Image This criterion concerns to the engagement between ISFCOL and community members. If an alternative promotes participation and interest of the community, the project's image related to this alternative will be greater than others will.

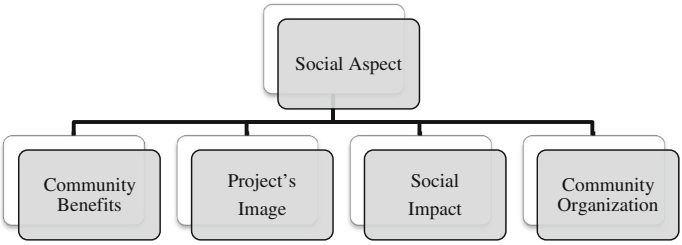


Fig. 14 Social aspect hierarchy

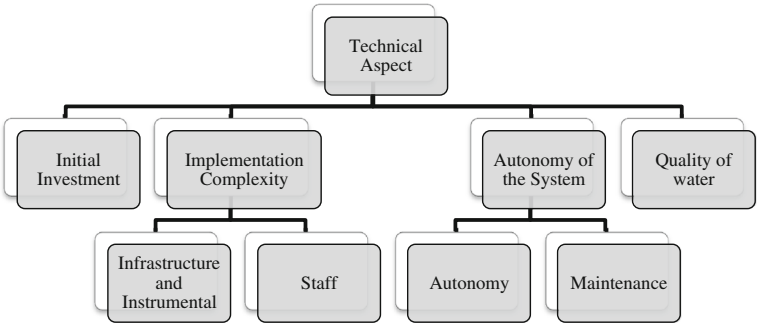


Fig. 15 Technical aspect hierarchy

Community Organization This criterion is related to the auto-organization skills of community necessary to develop a specific alternative.

Social-Impact Even if the community agrees with the change, it considers essential that its traditions and life styles are not drastically altered.

Technical Aspect Hierarchy

Initial Investment The amount of capital required for carrying out each of the alternatives, it includes the cost of the materials, the labor cost, the prototypes and other costs required for developing a determined alternative (Fig. 15).

Implementation Complexity It includes the physical or instrumental component (tools, machines, etc.) as well as the human talent required for implementing an alternative. It has two sub-criteria:

Infrastructure and Instrumental It concerns the effort put into the obtaining installations, structures, tools, machinery and instruments required for constructing or implementing an alternative.

Staff It concerns the complexity of the tasks to be performed and the skills required for the persons who will assume them.

Autonomy of the System As it has been explained, an alternative solution may be considered successful only if, after the intervention of ISFCOL, the proposal is supported thanks to the appropriation of the community. This criterion evaluates the level of independence achievable by the alternative owing to the low level of complexity and the low time demanded of the activities to be carried out by the community:

Autonomy Evaluates temporarily the autonomy of the system, that is to say the frequency in which the development must be intervened in order to guarantee its optimal functioning.

Maintenance This aspect represents the complexity of the sustainability that assures the preparation, feedback, inspection and other tasks required for keeping the alternative operational.

Quality of Water It concerns the impact on the improvement of the quality of water. It comprises different metrics that allow determining the water drinkability. This aspects are regulated through legal normativity that establish the permitted limits for each of the previous parameters; given these tolerance levels, the water drinkability, or the lack of, can be established taking into account certain resolutions that governs the process.

Model Formulation

Determinations for the Performance and Importance Matrices Based on the information gathered in workshops, by surveys, interviews, dialogues and group activities about communitarian organization and community's welfare was developed with 80 % of the community, including community leaders. The qualifications and opinions of the workshops were synthesized through a work session between owners of the process (Community and ISCOL), to construct the pairwise performance matrices for the *Social Hierarchy* adjusted to the Saaty scale (see tables at Appendix 2). The whole process can be found in the Appendix 2.

Results Analysis

The aspects and comparison matrix were introduced in the ExpertChoice® software. These graphs should be interpreted as follows: First the comparison is peer of alternatives, second comparison is performed for each criterion defined in hierarchies (social and technical) considering the AHP model presented, and finally it is presented an "overall" result of the comparison of the two alternatives, which allows to establishing which of these is best.

After the comparison between the alternatives (see Appendix section) *Carbon Filter* was defined as best alternative solution for the community to access to safe water for consumption.

Feedback

A preliminary report of the results of the workshop was already presented. The decision was communicated through a participation plenary in which each of the results was be thoroughly debated and analyzed. The participatory plenary is just to inform the community about the decision. This mechanism encourages participation because each actor could explore the selected alternative solutions by the proposed methodology. As

participation is the core of the methodological proposal, it is important to evaluate and validate the expectations of all participants with respect to the selected alternative.

Main Results

First, it was possible to understand the emerging community need to access to safe water for consumption, from dialogue, activities and conducting technical tests. Given this problem was necessary to integrate the community by reviewing and understanding each point of view and their setting of particular and general perceptions of the identified problem.

To support decision-making at community, ISFCOL provided a methodology to support this process, based on the case study experience. This case study demanded that ISFCOL team evaluate between different approaches, the best that would support the community in the decision-making process. It was decided to make a review and analysis of previous literature and experience to present a proposal. The above analysis allowed to ISFCOL to infer that was required the integration of two approaches that aims the problem of decision-making around issues that affect vulnerable communities. The proposal to integrate Systemic process with Analytic Hierarchy process to support solving vulnerable communities' problems is derived from the value added to the decision-making process resulting from the synergy of advantages and disadvantages of each approach, the systemic and the deterministic one.

ISFCOL accompanied the community to structure and making the decision on which of the alternatives was the most appropriate to meet the collective need to access to safe drinking water. In this process was incorporated the vision of all stakeholders and made a verification and validation process with these about the selected solution, the solution was approved.

Conclusions and Perspectives on Future Research

Decision-making processes with vulnerable communities require a thorough understanding of all parties involved, not just in purely democratic sense, but instead, by building a shared vision between all participants. The methodology used in this research provides a technological solution to communities that otherwise would not be able to access these types of technologies yet using the participative aspect in almost every step of the process.

The approach proposed tried to balance both of the aforementioned alternatives suggesting possible alternatives to filter the water, but giving the community a prime role within the decision-making process through the use of their participation and not just through, for example votes, which would represent a simple democratic system but through a methodology to support decision-making with vulnerable communities.

For the construction and proposal of alternatives, the cultural, social and economic applicability must be taken into account, that is to say, the portfolio of alternatives must consider only those that are feasible and viable from these perspectives; unreachable proposals, that demand resources which are not available or that are not focused on the objectives of the project will hinder the decision-making process. It is fundamental that at every time the participants of the process have at hand the information that is produced,

this guarantees that there are no doubts or suspicions regarding the decision-making process. It is fundamental that the work team keeps in mind that the criteria must include the specific requirements of the solution provided by the project, as well as the components for the autonomy concerning the community.

In the case study, an adaptation of syntegration was necessary because the of the community's context. All workshops are aligned to the dynamic proposed in the syntegration model. Both considerations try to ensure the results of a syntegration process.

With this aim, the research team must create a preliminary definition of: the general objective, the hierarchies, the criteria, and the possible alternatives of the Analytic Hierarchy Process model to be constructed. As seen in the case study, the syntegration process must be adapted to the conditions and context of the participants, because if this recommendation is not taken into account, community participation in the decision-making process and the exercise's result would be affected negatively.

Regarding the O+CDIO framework, in this paper only two stages are developed (observation and conception) as they are the stages in which the decision made concerns the solution or product to implement. Future work is required to develop other tools for the following stages of this framework.

As a product of the workshop, the research team must be able to build an AHP model, its hierarchies, the first level criteria -as well as those of the other levels-, and the alternatives solutions. There is an information refinement process to be taken into consideration; nevertheless, it must not alter the will expressed by the actors. To verify this, a validation process with the community is done; if changes are required, the corresponding adjustments are made.

Finally, Ingenieros Sin Fronteras Colombia is characterized for developing projects with vulnerable communities to solve problems related to quality of life. It is evident throughout the document the relevance of the community's participation in the decision-making process. The system–oriented decision-making exercise and the alternative solutions proposed in the case study are best for the local people but not for the whole environment because the water remains polluted. The exercise was only aimed at improving the families' quality of life; ISFCOL is going to continue to work together with the community towards the mitigation of the creek's overall pollution, taking into consideration not only the population's quality of life, but also a healthy community and environment.

Acknowledgments Ingenieros Sin Fronteras Colombia thank to all the participating members of the community for their participation and dedication in proposed activities of the project. Especially to Don Gustavo and his family, who is one of the residents and community leaders, he was one of the member of community who came to ISFCOL looking for a solution to the problem of lack of access to safe drinking water. We also thank to the local environmental authorities for their support to the process. Finally, we recognize that this project would not have been successful, if community and other participants had not been participated actively in the process.

Appendix

Appendix 1: System Methodologies and Decision-Making Process

Keeping in mind the characteristics of projects in vulnerable communities, this section highlights some of them and relates them with a theory that is going to be the basis of the proposed model for this paper.

Deterministic Methodologies: Analytic Hierarchy Process (AHP)

When researchers deal with systems, several objectives arise in a simultaneous way, especially in social systems. For this reason, one of the recommended methods for approaching these situations is the AHP, because it reduces the complexity of the decision-making process. The AHP is a method that formulates the problem through a hierarchic structure that allows selecting the best option within a set of possible alternatives. In this way, a better structuration of the problem leads to a better hierarchic structure (Castillo 2006).

This process allows the decision makers to model a problem in a hierarchic structure showing the relations among the goal, the objectives or criteria, sub-objectives and decision alternatives. Besides the structuring of a problem, the AHP enables the incorporation of considerations, both objective and subjective (experts' opinions, community inputs, among others), which arise in participation through its pair wise comparison methodology (Forman and Selly 2001).

According to Saaty (1994) the AHP process is based on three basic principles: *decomposition*, *comparison* and *synthesis of priorities*. The decomposition principle consists on structuring in hierarchic aspects a problem; the principle of comparison is used for making a pairwise comparison between aspects of the same level with respect to a superior level in order to establish priorities; finally the principle of synthesis of priorities allows for a global priority to be established which will be used to make decisions regarding the decision alternatives. Given the aforementioned characteristics of the AHP, it can be used for decision-making process in social problems.

The pairwise comparison matrices seek to simplify the decisions made by reducing them to a single aspect of the problem, facing each pair of aspects or alternatives in order to establish their importance or performance regarding to each aspect of a higher level. If the comparison is made between aspects, the criterion is the importance within the hierarchy structure, whereas if the comparison is between alternatives the chosen one must be the more suitable if the problem had only one aspect or objective (Castillo, 2006).

Saaty (1994) builds two scales, the first one on comparison by importance between aspects (see Table 1) and the other on comparison by performance between alternatives taking into account the elements A and B (see Table 2). Although it is a technical instrument, it allows to collect the result of the workshops, other activities with stakeholders, participation and interaction of team working with the community (Table 3).

Table 2 Importance criteria saaty scale

Scale Value	Description
9	A is extremely more important than B
7	A is very strongly more important than B
5	A is strongly more important than B
3	A is moderately more important than B
1	A and B are of equal importance
1/3	B is moderately more important than A
1/5	B is strongly more important than A
1/7	B is very strongly more important than A
1/9	B is extremely more important than A

Table 3 Performance criteria saaty scale

Scale Value	Description
9	A is extremely better than B
7	A is very strongly better than B
5	A is strongly better than B
3	A is moderately better than B
1	A and B are of equal
1/3	B is moderately better than A
1/5	B is strongly better than A
1/7	B is very strongly better than A
1/9	B is extremely better than A

In consequence, this is a structured way to deal with a project with multiple objectives; however it does not specify the way to involve different views of stakeholders. For that reason the next sections explains a systemic approach and its strengths in order to establish the basis for a proposed model that integrates deterministic and systemic methodologies.

Systemic Methodologies

Systemic approaches are characterized by proposed solutions that consider the whole context which also that take into account the stakeholder's different views. This approach unifies and concentrates on the interaction between the elements of the system, also leads to action through objectives and multidisciplinary education. Systemic approaches aims to validate facts through comparison and analysis of the behavior of the model with reality and modifies groups of variables simultaneously. These methodologies are oriented towards the coordination of activities between different systems (Olsson and Sjöstedt 2005). Those related to the proposal are presented below:

O+CDIO It is an innovative educational framework which provides projects participants fundamentals set in the context of Conceiving–Designing–Implementing–Operating real-world systems and products (CDIO 2013). CDIO is not a systemic framework; it is a work context. The CDIO framework presents a view of how product or system development moves through four metaphases: conceiving, designing, implementing and operating. Participatory conception aims to identify opportunities through high conceptual level and project management skills. Designing includes aspects of the design process, as well as disciplinary, multidisciplinary, and multi-objective design. Implementing includes test and feedback validation, as well as design and management of the implementation process. Operating covers a wide range of issues from designing and managing operations, through supporting product lifecycle and improvement, to end-of-life planning (Crawley 2001). It was proposed an additional stage to CDIO framework that allows project participants to observe in depth the context in which they will work (O+CDIO) (Hernández and Ramírez 2010). In all stages participants are thinking together in how they can build an inclusive proposal.

Based on previous systemic aspects, the project participants use the- O+CDIO framework as a way to integrate technical knowledge with local knowledge from the community, particularly as a way to focus said integration towards the design and

implementation of solutions. Thereby to design an engineering solution to a problem such as quality water access in rural areas it is necessary to integrate a design framework like O+CDIO with a systemic perspective.

TASCOI To observe systems as a whole and to analyze properties that emerge from the interactions of the parts, implicit characteristics of systemic methodologies are used (Mirijamdotter and Bergvall-Kåreborn 2006). It makes them particularly effective for addressing poorly structured situations with many points of view. Systemic methodologies offer different tools to define precisely the stakeholders in a system. Examples of these tools are: CATWOE by Checkland (Bergvall-Kåreborn et al. 2004) and TASCOI by Espejo (Espejo 2009).

Both the importance and pertinence of the CATWOE and TASCOI tools are recognized by ISFCOL. Nonetheless, TASCOI methodology was preferred as it was a useful tool to identify the project's participants which possess information relevant to the decision-making process.

Relevant to TASCOI tool, it is important to note that this methodology is used exclusively to generate an initial observation process that seeks to solve a problem. Below it is presented the TASCOI tool (Espejo et al. 1999) and the explanation of every one of the mnemonic:

It is a tool to identify the elements of the system and to understand there interactions. The "Transformation" term refers to the desired change of state to be achieved through the project's implementation.

Syntegration

It is a systemic contribution to the decision-making process taking into account the different perspectives. This systemic view makes a necessary a contribution to the different stakeholders in the process. In order to define collectively the decisions to be made from the conception phase until the implementation phase, an adaptation of some procedures of the syntegration of British professor Stafford Beer (1994) is put in place, this adaptation is explained later at case study.

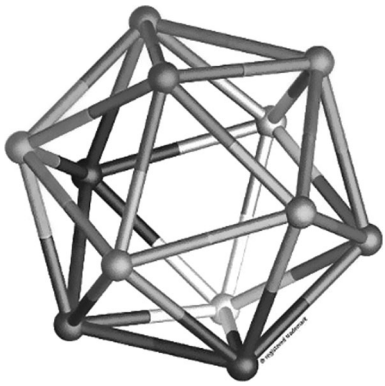
In simple terms, the syntegration protocol (Clusella et al. 2012) is a set of rules that a group of persons accepts to follow in order to approach a collective and participative discussion regarding a subject that concerns everyone, and to which everyone can look from a very different point of view, with the purpose of designing communication mechanisms that facilitate a participative and equitable dialogue between the participants.

The syntegration protocol (Pérez 2012) facilitates the establishment of agreements by encouraging multiple feedback circuits among all the participants. This permits that, even though every participant only can assist to a maximum of six out of twelve topics discussions, everyone will have the possibility to find out the topics discussed in every reunion. This is possible due to the distribution and the sequence in which these reunions are held (Beer 1994). The distribution and sequence of the original syntegration protocol is represented through icosahedron (see Fig. 1), the biggest of the regular polyhedrons (Fig. 16).

In order to use the icosahedron as a model of the participation protocol, the following equivalences are required:

- Each *vertex* represents a discussion topic,
- Each *edge* represents a participant,

Fig. 16 Icosahedron



- Two opposed *vertexes* indicate two topics that may be discussed simultaneously.

Some of the icosahedron's vertexes are constituted by the critical topics and main strategic lines represent a possible solution for the problem situation, those are built collectively by the participants.

The methodology is highly participative, as it can be observed in the interaction of the edges of the icosahedron (or participants), with different roles, which allows the construction and consensus of the topics in which the contribution of each participant is not only important, but fundamental for the process' success.

It is important to notice the *reverberation* phenomenon which occurs with this methodology. The reverberation takes place around the third day of the exercise, in the original protocol, when the interaction of the actors in each of the subjects produces that similar ideas flow from one subject and one group to another, facilitating the agreement on the conclusions. For the case study presented in this paper, this activity lasted for one day.

On the other hand, the mechanics of the group activities facilitate the generation of new ideas by the decision makers. Some of the activities grant a significant ludic nature to the protocol. Among them, it is important the agreement of participants of participate, adopt and respect the different roles assumed by other participants in the different groups.

Likewise, two activities guarantee a feedback process. By the end of each reunion, the ideas, conclusions, and results are documented and are made public through different means (memos, documents, and writing workshop materials) available for every participant. In this way, the conclusions of any group can be consulted by any of the participants at any time (Hernández and Ramírez 2010). The result allows the identification of problem issues—processes—proposals according to the priorities, as well as the strategic proposals to follow.

As it was explained above, syntegration is a systemic process that aims to make the most democratically decisions, the following aspects are highlighted: (i) This proposal considers all points of view and (ii) It is not mandatory, because the reflections that are made at different times, getting different stakeholder points of view involved in decisions.

Nevertheless, the emphasis is on democratic and participatory involvement (Rios Insua et al. 2008) of intervening in discussions, it is not necessarily always additional tools that allow to complement orderly and systematic discussion (not only systemic) when making decisions are made.

Table 4 TASCOI entities, (Espejo et al. 1999)

Entity	Description
Transformation	What input is converted into what output?
Actors	Who is involved in carrying out the activities entailed by the transformation?
Suppliers	Who are the suppliers of the inputs to the transformation?
Customers	Who are the ones receiving the outputs of the transformation?
Owners	Who has in the system an overview of its transformation?
Interveners	Who, from the outside, is defining the context for the system's transformation?

Table 5 Pairwise performance matrix, social hierarchy

	Sand filter	Carbon filter	Ozone filter
Performance matrix–(*Community benefits*)			
Sand filter	1	1/7	2
Carbon filter		1	9
Ozone filter			1
Performance matrix–(*Project's image*)			
Sand filter	1	1	1/7
Carbon filter		1	1/7
Ozone filter			1
Performance matrix–(*Community organization*)			
Sand filter	1	1/3	5
Carbon filter		1	7
Ozone filter			1
Performance matrix–(*Social impact*)			
Sand filter	1	5	7
Carbon filter		1	2
Ozone filter			1

Appendix 2: Pairwise Matrices Definition

In order to define the pairwise matrices of the technical aspect, the work team consulted an expert in the drinkability and the hydric resource management fields. To obtain the information from this expert an interview was held in which –after explaining the functioning of the Saaty scale- the expert was asked to give a Saaty qualification for each of the alternatives given the explanation of the criterion. The results obtained are shown in Table 4.

The importance matrices allow the definition of the relevant order of the criteria for the evaluation of the alternatives. For each hierarchy the determination process was different. For the Social Hierarchy, those criterions and weights were established by the community considering the six criteria initially presented. The relevant order was established based on the frequency that certain aspects were mentioned by the community. From that, the frequency was translated into a percentage and related to each of the criteria. The results of this exercise are shown in Table 5.

Table 6 Weight of the criteria–social hierarchy

Criterion	Weight (%)
Community benefit	30
Project's Image	30
Community organization	30
Social impact	10

Table 7 Pairwise performance matrix, technical hierarchy

	Sand filter	Carbon filter	Ozone filter
Performance matrix–(*Initial investment*)			
Sand filter	1	1/5	2
Carbon filter		1	7
Ozone filter			1
Performance matrix–(*Infrastructure and instrumental*)			
Sand filter	1	1/6	3
Carbon filter		1	8
Ozone filter			1
Performance matrix–(*Staff*)			
Sand filter	1	3	1/5
Carbon filter		1	1/7
Ozone filter			1
Performance matrix–(*Autonomy*)			
Sand filter	1	8	1
Carbon filter		1	1/8
Ozone filter			1
Performance matrix–(*Maintenance*)			
Sand filter	1	2	1/6
Carbon filter		1	1/8
Ozone filter			1
Performance matrix–(*Quality of water*)			
Sand filter	1	1/3	7
Carbon filter		1	9
Ozone filter			1

Based on these weights and AHP, the following pairwise importance matrix was constructed with the criteria comprised in the *Social Hierarchy*:

Regarding the importance matrices for the *Technical Hierarchy* criteria, an analysis of the consulted sources was made, the work team consulted an expert in the drinkability and the hydric resource management fields too (Tables 6, 7, 8). According to these weights was assigned to each criterion of the hierarchy and previous discussions, as it is detailed in the following table:

Table 8 Criteria importance matrix–social hierarchy

	Community benefit	Project's Image	Community organization	Social impact
Importance matrix–(*Social aspect*)				
Community benefit	1	1	1	3
Project's image		1	1	3
Community organization			1	3
Social impact				1

Table 9 Weight of the criteria–technical hierarchy

Criterion	Weight (%)
Quality of water	40
Autonomy	32
Initial investment	14
Technical complexity	14

Table 10 Criteria importance matrix–technical hierarchy

Importance matrix–(*Technical aspect*)				
	Initial investment	Technical complexity	Autonomy	Quality of water
Initial investment	1	1	1/(2,5)	1/(2,6)
Technical complexity		1	1/(2,5)	1/(2,6)
Autonomy			1	1/(1,5)
Quality of water				1

Table 11 Pairwise importance matrices–complexity and autonomy

Importance matrix–(*Technical complexity*)		
	Initial investment	Technical complexity
Infrastructure and instrumental	1	2,33
Staff		1
Importance matrix–(*Autonomy*)		
	Independence	Maintenance
Independence	1	1,5
Maintenance		1

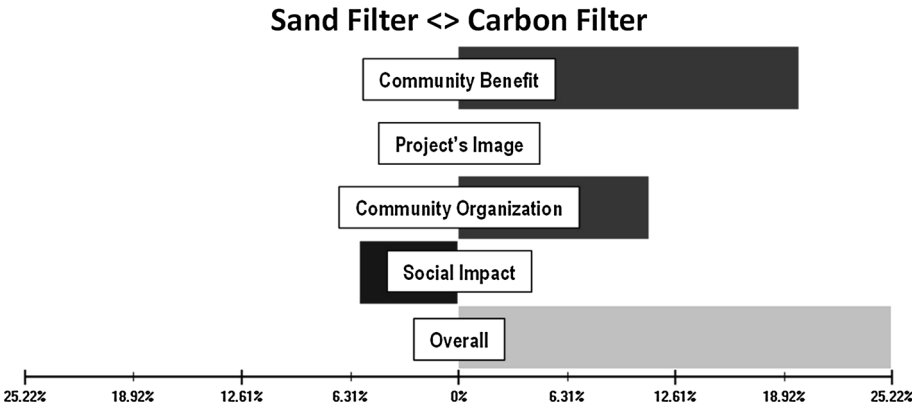


Fig. 17 Head-to-head sensitivity, sand filter versus carbon filter–social hierarchy

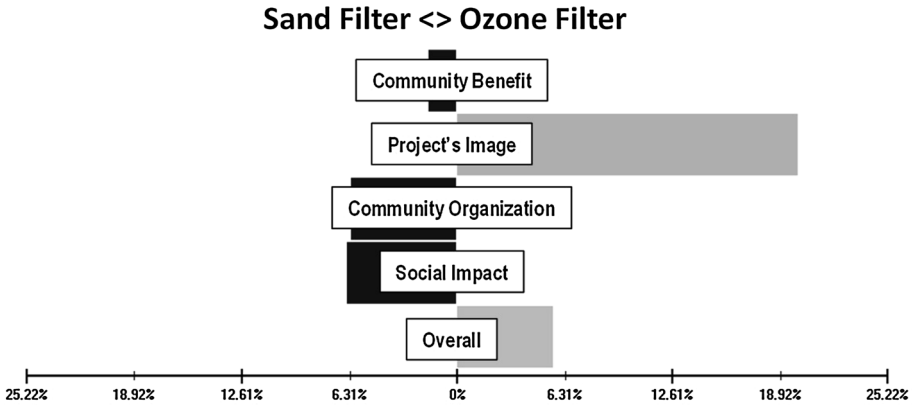


Fig. 18 Head-to-head sensitivity, sand filter versus ozone filter–social hierarchy

Based on these weights the following pairwise importance matrix was constructed with the criteria comprised in the *Technical Hierarchy*, see Tables 9, 10:

Below there are the two importance matrix for the sub-criteria *Technical Complexity* and *Autonomy* (Table 11):

Appendix 3: Results of Comparisons Between Alternatives

Figure 2 shows a comparison between the Sand Filter and the Carbon Filter alternatives. It is apparent that the latter largely surpasses the former in global performance in the *Social Hierarchy*, by approximately 25.22 %, mainly due to its outstanding performance in the *Community Benefit* (19 %) and *Community Organization* (11 %) criteria; it is remarkable that the only aspect in which the Sand Filter stands out in comparison with the Carbon Filter is in the *Social Impact* with a 6 % (Fig. 17).

Figure 3 shows a comparison between the Sand Filter and the Ozone Filter alternatives. It is apparent that the latter surpasses the former in global performance in the *Social*

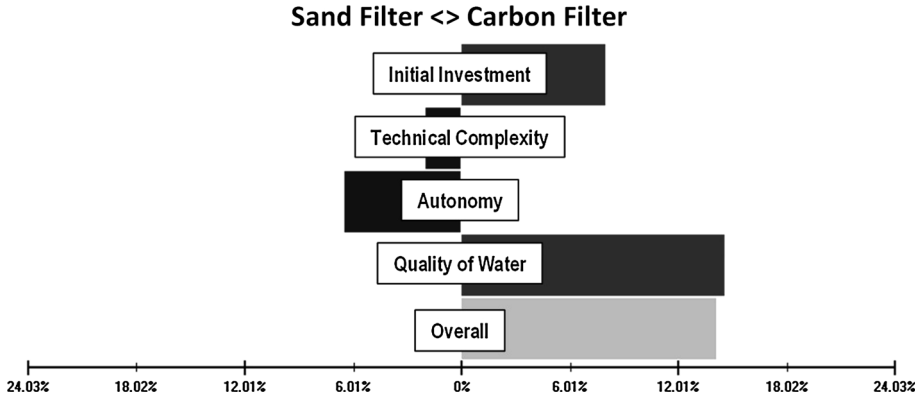


Fig. 19 Head-to-head sensitivity, sand filter versus carbon filter–technical hierarchy

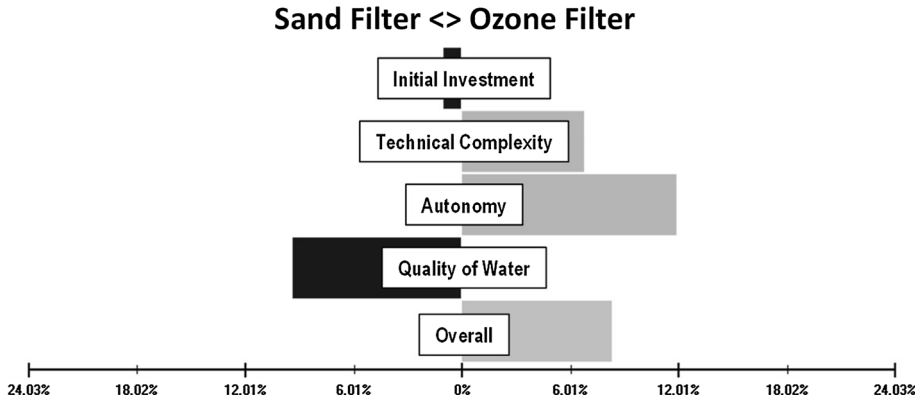


Fig. 20 Head-to-head sensitivity, sand filter versus ozone filter–technical hierarchy

Hierarchy, by approximately 5 %, mainly due to its outstanding performance in the *Project's Image* (19 %) criterion. It is important to notice that, even though the Ozone Filter outperforms the Sand Filter, in three out of the four criteria it is the latter the one with the better performance, in *Community Benefit, Community Organization and Social Impact* (by 1, 6.31 and 6.31 %, respectively) (Fig. 18).

Figure 4 shows a comparison between the Sand Filter and the Carbon Filter alternatives. It is apparent that the latter surpasses the former in global performance in the *Technical Hierarchy*, by approximately 14 %, mainly due to its outstanding performance in the *Initial Investment* (8 %) and *quality of Water* (15 %) criteria. It is important to notice that, even though the Carbon Filter outperforms the Sand Filter, in two out of the four criteria it is the latter the one with the better performance, in *Technical Complexity* and *Autonomy* (2 % and 6 %, respectively) (Fig. 19).

Figure 5 shows a comparison between the Sand Filter and the Ozone Filter alternatives. It is apparent that the latter surpasses the former in global performance in the *Technical Hierarchy*, by approximately 8 %, mainly due to its outstanding performance in the *Technical Complexity* (7 %) and *Autonomy* (12 %) criteria. It is important to notice that,

Table 12 Global performance by alternative

Sand filter	Carbon filter	Ozone filter
0,5437	1,0000	0,6985

even though the Ozone Filter outperforms the Sand Filter, in two out of the four criteria it is the latter the one with the better performance, in *Initial Investment* and *quality of Water* (1 % and 10 %, respectively) (Fig. 20)

The advantage of the Carbon Filter in comparison with the other two options is evident; however, the following section develops the global index, which permits the evaluation of the alternatives in a more general level, since it incorporates the two separate evaluations of the two hierarchies into a single one.

Equation 1 is the index designed for evaluating the global performance of each alternative taking into account their respective performances in each hierarchy and the weight assigned to each of these (Social: 60 % and Technical: 40 %). Consensus of community members and other participants of the workshops assign these weights.

$$IDG_i = SocialStd_i * W_s + TechnicalStd_i * W_t \quad (1)$$

In which: IDG_i represents the general performance of the solution i alternative, $SocialStd_i$ represents the standardized performance of the i alternative in the social hierarchy, $TechnicalStd_i$ represents the standardized performance of the i alternative in the technical hierarchy, W_s represents the weight assigned to the social hierarchy (60 %), W_T represents the weight assigned to the technical hierarchy (40 %)

After the necessary calculations, the results are the following given in Table 12.

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