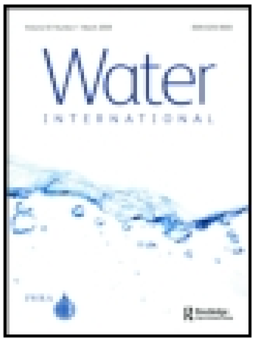

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RESEARCH ARTICLE

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Participatory rural appraisal to assess groundwater resources in Al-Mujaylis, Tihama Coastal Plain, Yemen

Wahib Al-Qubatee[a], Henk Ritzema[a], Adel Al-Weshali[b], Frank van Steenbergen[c] and Petra J. G. J. Hellegers[a]

[a]Water Resources Management, Wageningen UR, Wageningen, the Netherlands; [b]Water and Environment Centre, Sana'a University, Sana'a, Yemen; [c]MetaMeta Research, Hertogenbosch, the Netherlands

ABSTRACT

A participatory rural appraisal (PRA) conducted in the Al-Mujaylis area, Tihama Coastal Plain, Yemen provided a contribution, as a bottom-up approach, to the assessment of the needs of communities and their views on how to avoid groundwater degradation. It was found that PRA tools could be applied usefully in an area with data scarcity and a culturally different context. It is concluded that adopting a research approach between top down and bottom up is most valuable and effective.

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participatory rural appraisal; groundwater resources; Al-Mujaylis; Tihama; Yemen

Introduction

Tihama plain, located along Yemen's Red Sea coast and also known as Yemen's breadbasket, represents a fertile agricultural area of great importance for the food security of Yemen. In the 1970s, a large proportion of Yemen's population (nearly 90%) relied on agriculture and animal husbandry as a source of income. The dominant crop cultivated along the coast was date palm, and more inland date palm, cotton, cereal (sorghum, millet, maize and sesame), fodder, citrus, vegetable crops (onion, tomato and okra), mango and banana were cultivated (Irrigation Improvement Project, 2002). Because of the low prices of imported products compared with domestically produced products, the economic profitability was low (Cohen & Lewis, 1979). As a result, emigration to Saudi Arabia attracted a large segment of the labour force and led to a decline in agricultural production compared with the population growth. By 2010, the percentage of the population who relied economically on agriculture as a source of income was reduced to 54% (Ministry of Agriculture and Irrigation, 2012). Agriculture in the midstream areas mainly depends on the conjunctive use of spate and groundwater for irrigation, while in the downstream areas it depends only on groundwater in addition to scarce rainfall (Al-Qubatee, Ibrahim, From Dalseng, Al-Weshali, & van Steenbergen, 2013).

To improve agricultural production, the Food and Agricultural Organization (FAO) of the United Nations recommended improving irrigation systems in the Tihama region (Tipton & Kalmbach, 1974). The government initiated irrigation-improvement projects through the construction of reservoirs and water-harvesting

CONTACT Wahib Al-Qubatee wahib.alqubatee@wur.nl

structures. It also supported the agricultural sector by banning fruit imports to enhance the profitability of locally produced fruits, subsidizing diesel fuel, and easing the import of drilling and pumping equipment (Ward, 2009). A study in the area of Wadi Zabid (*wadi* in Arabic means a valley) concluded that the best way forward was to build 10 diversion weirs (five were actually built) along the wadi to divert spate water into the existing canals and to build structures in the irrigation system to facilitate the control and distribution of water (Tipton & Kalmbach, 1974). This type of spate irrigation requires the strong control and participation of the users in the water distribution, thus a participatory approach is required. Other Middle Eastern governments also tried to overcome high water demand by building similar diversion structures in combination with desalination plants and deepening groundwater wells, but these water supply solutions are costly and often do not reduce the increasing water demands (Zeitoun, Allan, Al Aulaqi, Jabarin, & Laamrani, 2012).

As a result of these investment programmes, agricultural production has increased considerably, e.g., the banana cultivation areas in the midstream of Wadi Zabid increased from 20 ha in 1980 to 3500 ha in 2000 (Van Steenbergen et al., 2010). This, however, happened at the expense of the sustainable use of groundwater resources as the number of drilling wells in Wadi Zabid and Wadi Rima increased by more than five times between 1987 and 2008, from about 2421 to 12,339 wells (National Water Resources Authority (NWRA), 2008). The groundwater degradation is a result of the change in the balance between abstraction and recharge. Negative impacts of the construction of upstream dams on the downstream areas include reduced surface flow/runoff, dried-up wells and water being lost from the dams' reservoirs through evaporation (Al-Qubatee, 2009). In addition, in some areas where people invested in small dam construction, they consider it to be their own property, which resulted in giving themselves priority water rights and restricting others from becoming shareholders (Vermillion & Al-Shaybani, 2004). Groundwater degradation is also a result of the combined effects of (1) the intensification of agriculture activities (El Ayni, Cherif, Jrad, & Trabelsi-Ayadi, 2012); (2) the decrease of the recharge because of the decrease in precipitation and the reduction in river flows caused by the construction of dams in the upstream parts of the catchment (El Ayni, Manoli, et al., 2012); and (3) economic incentives such as the diesel subsidies, which encourage groundwater abstraction instead of groundwater conservation (Burke, Moench, & Sauveplane, 1999; Hellegers, Perry, & Al-Aulaqi, 2011). The declining access to groundwater affects not only food production but also the socio-economic situation of the population, e.g., an degeneration of the health conditions caused by reduced access to drinking water and a reduction in the cultivation and use of medicinal plants (Sharma, 2009). Along the Red Sea coast, the drop in groundwater levels has also resulted in seawater intrusion (NWRA, 2009).

Participatory rural appraisal (PRA) is a term used to describe a growing range of approaches and methods that can be used to encourage stakeholders to participate in analysing and assessing measurements in land planning and to bring their own knowledge to the dialogue (Chambers, 1994). This approach was developed in the early 1990s to initiate a paradigm shift from the top-down to a bottom-up approach, and from blueprint planning to an interactive learning process. It is a shift from extractive survey questionnaires to experience sharing with local people (Cavestro, 2003; Sijbesma & Postma, 2008). In the participatory approach it is important to combine the implicit knowledge of the community with the distinct scientific knowledge of the researchers and decision-makers in order to overcome lack of data on the hydrogeological and the often complex societal ecosystems (Ritzema, Quang Anh, & Thi Kim, 2011), to increase understanding of the complexity of problems, to reach solutions that are acceptable for stakeholders and that can be implemented (Burke et al., 1999; Zanetell & Knuth, 2002), and to achieve effective water governance (Barreira, 2003). Moreover, participatory methods have been used successfully to provide sufficient data for participatory groundwater modelling in areas with lack of continuous data recording, and at the same time lead to an agreement between the stakeholders on the water resources management plan (action plan) to sustain both the livelihood and the ecosystem (Ritzema, Froebrich, Raju, Sreenivas, & Kselik, 2010).

The government started to apply an integrated water resources management (IWRM) approach to managing basins that were facing a critical depletion of their groundwater resources. Taher, Ward, Fadl, Saleh, and Sultan (2013) assessed the first phase of such a project in the Sana'a Basin. They concluded that by implementing IWRM in alleviating water degradation, its advantages were being flexible, adaptable, and responsive to local conditions and needs. However, they suggested that for follow-up phases, more emphasis should be placed on the development of a decentralized participatory approach and to improve water legislation. In Tihama plain, numerous groundwater resources studies have been conducted (e.g., Tesco-Viziterv-Vituki, 1971b; Al-Eryani, 1979; DHV, 1988; Al-Kebsi, 2000; Abu-Lohom, 2002; Nasher, Al-Sayyaghi, & Al-Matary, 2013). These, however, focused mainly on technical aspects such as hydrology, hydrogeology, hydrogeochemistry, geophysics, geochemistry and modelling and lack an IWRM approach. Numerous authors have indicated that complex water-management problems require a fully integrated research approach (social, economic, institutional, political and technical) with a focus on engaging the different and sometimes contradictory interests of all stakeholders (Burke et al., 1999; Hussein, 2016; Margerum, 2007; Pahl-Wostl, 2007; Raadgever, Mostert, & Van de Giesen, 2012; Von Korff, Daniell, Moellenkamp, Bots, & Bijlsma, 2012). Participatory approaches are gaining importance to make information available to researchers, environmental managers and decision-makers (Zvoleff & An, 2014), not only to discuss interventions but also through collective simulation and modelling (Bots, Bijlsma, Von Korff, Van der Fluit, & Wolters, 2011; Dionnet et al., 2013). Although participatory research in the field of natural resources and environmental management is increasing, some aspects are not receiving adequate attention (Trimble & Lázaro, 2014). Especially, the extent to which stakeholders are interested in, and capable of, being involved effectively in governance varies widely, and is often not addressed satisfactorily (Smiley, De Loë, & Kreutzwiser, 2010). In this study, we argue that adopting a research approach between top down and bottom up is more valuable and effective, especially in the areas of high illiteracy. The objective of this paper is to evaluate the use of such a mixed approach to PRA in areas with data scarcity and in a cultural context where Islamic religious values encourage people to apply *Shura* (Islamic term for consultation) among themselves, with the experts and specialists, and to be more cooperative and altruistic. The usefulness of PRA as a bottom-up approach in assessing the degradation of groundwater resources in the Al-Mujaylis area is evaluated with the aim to obtain a better understanding of the effects on the livelihoods of the local population and of the local stakeholder's views on the problems and their views on appropriate solutions.

Study area

Yemen has an ancient civilization and historical heritage known as 'Arabia Felix' (Jungfer, 1987). The water harvesting and diverting techniques are the most famous examples (Brunner & Haefner, 1986; Harrower, 2010), i.e., the great and famous dam of Ma'rib with its antique irrigation system that has been in operation for more than two millennia (Brunner & Haefner, 1986). Nowadays, the continuous increase in the construction of harvesting and diversion structures in the upstream/midstream areas without adequate water resources management is resulting in negative externalities such as groundwater resources degradation in downstream areas. The degradation of groundwater resources has both environmental and socio-economic impacts in the affected areas. At the end of 2012, field research was conducted in the downstream (Al-Mujaylis village and surrounding areas) and midstream areas of Wadi Zabid and Wadi Rima (Figure 1) to study the cause–effect relationship between land-use changes and groundwater degradation and the socio-economic impacts.

Wadi Zabid and Wadi Rima, with catchment areas of 4450 km^2 (Qaid, 2007) and 2900 km^2 (Land Resources Division, 1977) respectively, originate from the Yemen Highlands (Western slopes). The mean annual precipitation varies from 100 mm at the coast to 350 mm in the foothills and to more than 550 mm in the Eastern mountains, with temperatures ranging between 18 and 40°C (NWRA, 2009). The mean annual runoff (water flow) in Wadi Zabid is 136.73 million m^3 (from 1970 to

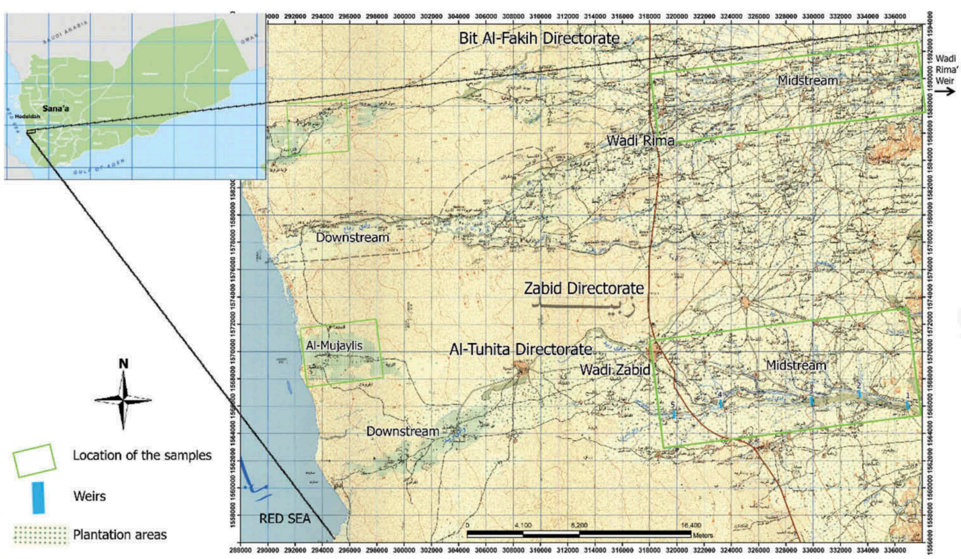

Figure 1. Location of the sample communities Al-Mujaylis and Wadi Zabid and Wadi Rima, Tihama Coastal Plain, Yemen; Zabid sheet no. D38-39 1:100,000 (Survey Authority, 1986).

1987) and in Wadi Rima is 85.68 million m^3 (from 1976 to 1987) (DHV, as cited in NWRA, 2008). Only after exceptional heavy rainstorms does the runoff reach the sea (Tesco-Viziterv-Vituki, 1971a).

The population in the middle and downstream part of Wadi Zabid (Zabid and Al-Tuhita directorates) and Wadi Rima (Bit Al-Fakih directorate) was 464,545 in 2004 (Central Statistical Organization, 2005). The population mainly depends on agricultural activities and ranching for its income. The total cultivated area in the three directorates is about 66,223 ha (Tihama Development Authority (TDA), 2007).

Materials and methods

A combination of PRA techniques was used, as described in detail by Mascarenhas et al. (1991), Cavestro (2003), Bhandari (2003) and Van der Schans and Lemperiere (2006). In order to ensure accuracy, to avoid bias, to find points of consensus/contradiction, to facilitate mutual learning, to integrate knowledge and to reach the reliability and validity desired, we used the following approach:

- A combination of six PRA tools was selected, namely semi-structured interviews (individual and group discussion), resources sketch mapping, daily calendars, time lines, transect walks and direct observations, and the preparation of problem and solution trees (Table 1). Each tool was used to address a specific topic (Table 2), and verification of the data was achieved by methods triangulation of at least three tools to cross-check the results of the different tools. In addition, the triangulation of the data sources was achieved by involving different respondents (farmers, key informants and emigrants), from different areas (downstream and midstream) and including secondary sources of information (previous studies, available data records, maps, Google Earth etc.). Moreover, the investigator triangulation was achieved by involving an interdisciplinary team from different local institutions (the observations of different investigators

Table 1. Participatory rural appraisal (PRA) tools and number of times tools were applied in the study.

	Semi-structured interview		
Area	Individual interviews	Group discussions	Other PRA tools
Al-Mujaylis	25 (four with key informants and 10 with people who migrated from the area)	Four (one group with women)	One resources map One daily calendar One time line Two transect walks and direct observations Two problem and solution trees with ranking
Wadi Zabid	22 (six with key informants)	Three (one with women)	One daily calendar One time line Two problem and solution trees with ranking
Wadi Rima	22 (five with key informants)	One group	One resources map One time line One transect walk and direct observation Three problem and solution trees with ranking

Sources: Al-Qubatee et al. (2013, 2015).

Table 2. Participatory rural appraisal (PRA) tools applied in the study area.

PRA tools		Description of the tools	NTTA[a]
Semi-structured interview	Individual Group discussion Key informant Emigrant	To know the situation in the area, the problems and the suggested solutions. Open questions were used that allowed the interviewer and respondents to raise new issues and topics during the discussion (Butler, Monroe, & McCaffrey, 2015). Stakeholders were interviewed individually to avoid the influence of or on others, especially in areas where there is mistrust as a result of unsolved conflicts over water resources. Group discussion was used to reach consensus and variety. Key informant opinion is important from the technical, institutional, legislation and political prospective. Some who migrated were interviewed as they are victims of the environmental degradation in the area	44 8 15 10
Resource sketch map		To know the socio-economic status and activities of people. We explained to respondents the purpose of this tool. From ideally the highest location in the area, respondents used local materials (chalk and coal) to draw the sketch map. The resources sketch map included land use, land-use change, and the features and infrastructures in the area	2
Daily calendar		To know farm and household activities in the area, the economic situation and working hours in the fields. Farmers were asked for their opinions on working hours, their main income sources, a household's activities and constraints	2
Time line		To know the situation in the area over the last 50 years. Respondents were asked (especially elderly people) to define major historical events that occurred in the past. Then they can make links between certain water and environmental issues and those events (easy to remember). This tool indicated the changes over time in the land use and agriculture productivity, groundwater situation, desertification, sand dune movement, and migration in the study area. Flip charts were used for this activity	3
Transect walk and direct observation		To know the current situation and to validate the information that was extracted by the other PRA tools. Simple measurements were carried out	3
Problem and solution tree		To know the causes and suggested solutions of the problems in the area from the part stakeholders' point of view. Groups of people sat together to define the water resources problems in their areas using a tree diagram. It was used as a problem analysis technique. Respondents were asked to rank the causes and suggested solutions of the problems according to their point of view and their preferences. A flip chart matrix was used	7

Notes: [a]NTTA, number of times tools are applied.

Al-Mujaylis: 25 semi-structured interviews, four group discussions, two transect walks, one resources sketch map, one time line, one daily calendar, and two problem and solution trees with ranking in addition to direct observation.

Wadi Zabid: 22 semi-structured interviews, three group discussions, one time line, one daily calendar, and two problem and solution trees with ranking in addition to direct observation.

Wadi Rima: 22 semi-structured interviews, one group discussion, one transect walk, one resources sketch map, one time line, and three problem and solution trees with ranking in addition to direct observation.

Sources: Adapted from Al-Qubatee et al. (2013, 2015).

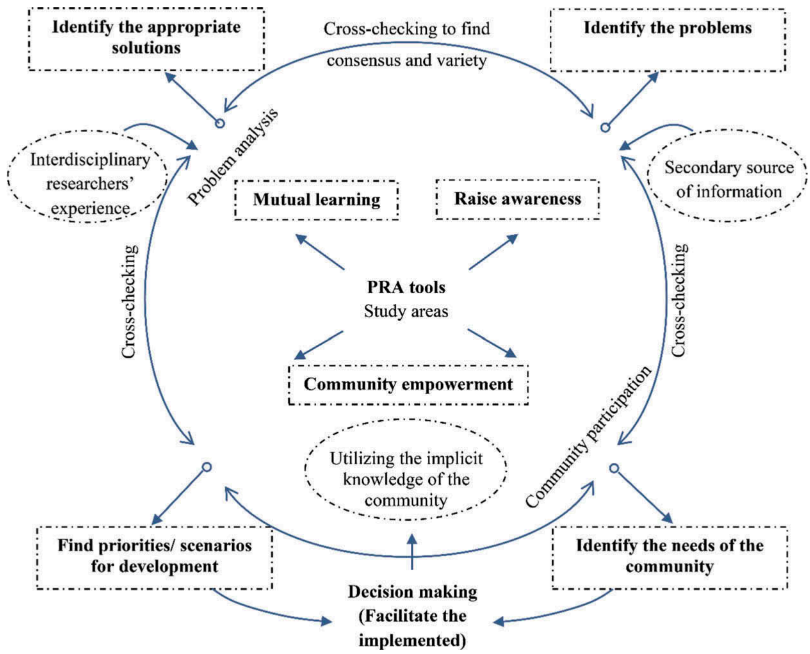

Figure 2. Interaction cycle among the different participatory rural appraisal (PRA) components (inputs) used for problem analysis, determination of priorities for development and community empowerment (outcomes).

in the same study area). Local materials, chalk, coal, stone and trees sticks were used to achieve the PRA activities in addition to flip charts, marker pens, maps, global position system (GPS) and cameras.

- The sampling method was 'stratified random sampling' in combination with 'purposive sampling'. Stakeholders from the areas downstream and midstream of Wadi Zabid and Wadi Rima were included. The sampling included different local communities and decision-makers such as farmers and most key informants (parliamentary representatives, managers, engineers, head of the Water User Association (WUA), head of the Irrigation Council, sheikhs, imams and teachers). The group discussions with the different stakeholder groups (farmers and key informants) included groups from the areas downstream and midstream of Wadi Zabid and Wadi Rima (Table 1).
- Cross-checking was performed between the results of different PRA tools to study the points of consensus and/or contradiction.
- The results obtained with the PRA tools were compared with available secondary sources of information.
- The study was conducted by an interdisciplinary team of four members from the Water and Environment Center (WEC), the Geological Survey and Mineral Resources Board (GSMBR), the National Water Resources Authority (NWRA) and the Tihama Development Authority (TDA) respectively. One team member was a female researcher who interviewed the women and conducted discussion groups with

them. This facilitated the communication process according to local customs and culture (a conservative community with a high percentage of illiteracy).

For data analysis, respondents defined and ranked the problems and solutions by themselves in the field. We used memos, flip charts (scanned with a digital camera) and/or audio and video to record all PRA tools applied in the field. Data coding was done manually for the semi-structured interviews and the results of discussion groups according to the objectives of the study (semi-structure questionnaires) and for any other emerging themes. Validity and reliability were achieved through the above-mentioned steps.

The interrelationship between the PRA components, inputs for problem analysis, determination of priorities for development and community empowerment, and the outputs are depicted in Figure 2. It shows how the implicit knowledge of the community, the interdisciplinary researchers' experience and the available secondary sources of the information were integrated (1) to identify the problems; (2) to identify appropriate solutions; (3) to find priorities/scenarios for development; and (4) to identify other needs of the community.

Results

Groundwater status

From the semi-structured interviews in Al-Mujaylis (Table 1), it was found that in this area groundwater is the major source for drinking, domestic, agriculture and livestock water use. People rely heavily on agriculture for their income in addition to fishing and remittances from their migrant relatives. The dominant agricultural crop is palm tree with some fodder for livestock. From semi-structured interviews, especially from the elderly men and women, we learned that the groundwater level in Al-Mujaylis was at a depth of less than 0.5 m below the soil surface 50–60 years ago. In 2013, the groundwater level had dropped to more than 12 m below the soil surface. From the interviews we also learned that there have been changes in well type and depth, drilling and water-pumping techniques.

Respondents expressed their assessment of water quality based on the taste of the water and, in some cases, how it compared with the taste of bottled mineral water. They indicated that the water quality in most wells in Al-Mujaylis is still fresh while other areas have higher water salinity that results in dying of the date palms in Al-Fazah village downstream of Wadi Zabid. This was confirmed by information from secondary sources: electric conductivity (the indicator of total dissolved solids) in most wells in Al-Mujaylis is between 0.7 and 1.6 dS/m, whereas water salinity in Wadi Zabid is between 0.8 and 17.8 dS/m and in Wadi Rima is between 0.6 and 10.9 dS/m (NWRA, 2009).

With one-group discussions (more than 10 respondents) in Al-Mujaylis, time-line tools were used to characterize the changes in groundwater status, agriculture activities and production, desertification and emigration changes since 1962 (Table 3). During the interviews, respondents were asked to connect the previous status with distinct past events, and during the discussion attempts were made to connect changes in the status of groundwater, agricultural activities and production, desertification and emigration

Table 3. Time line in the Al-Mujaylis area.

		Groundwater status			Agriculture activities				
Year	Spat water	Total depth	Water level	Water quality	Area	Crop type	Yield (%)	Desertification	Emigration
1962	Floods come from heavy rainfall in the area	0.5 m, no drilling till 1975	Near the surface (< 0.5 m)	Fresh	All agriculture lands	Palm	100	None	None
1979	Same as above	As above	0.5 m	Fresh	All agriculture lands	Palm	100	None	Few (10 people)
1985	Same as above	6–8 m	5 m	Fresh	Start of agriculture lands shrinking	Palm	100	Start to cover palms	
1990	Same as above	12 m	7–8 m	Fresh	As above	Palm	25	As above	30%
2000	Rainfall shortage	16–17 m	5–9 m	Fresh	Continuous decrease in agriculture lands	Palm	25	Continuous cover of palms	60%
2011	Same as above	30–50 m	12	Fresh	Most decreased in agriculture lands	Palm	10	It remains at 15% of palms	

Sources: Al-Qubatee et al. (2013, 2015).

changes with distinct events. For example, there was agreement between participants that after 1985 the groundwater level started to fall, the total agriculture area started to decline, the desertification areas started to increase and people's emigration from the area increased. The participants also agreed that after 2000, rainfall became more scarce and this was associated with the continuous drop in groundwater levels, the reduction of agricultural areas, a decrease in yields and an increase in desertification, a result being that about 60% of the population in Al-Mujaylis village move away from the area (Table 3). In an interview, the head of the TDA indicated that the dams built in the mountain areas of Wadi Zabid decreased the water flow to downstream areas. That was confirmed in other interviews with the head of the Environmental Department of the TDA, Zabid Branch, and the head of the Irrigation Council in Wadi Zabid. The current situation in the area was assessed by transect walks (involving researchers and farmers) and direct observations. The cross-checking between the outcomes of the PRA activities and the data collected from external sources of information confirmed the results related to the changes in groundwater levels, wells types and depths. Triangulation was used not only to validate findings but also for deepening and expanding researchers' understanding (Yeasmin & Rahman, 2012). However, there is a critique of using this method (Blaikie, 1991). Each method has positive and negatives aspects, but we found that this method helped to get more accuracy and validity.

Impact of groundwater degradation on livelihoods

Negative externalities have emerged in the study area, e.g., desertification has increased and date palms are dying. A resource sketch map, which was drawn by local people in Al-Mujaylis, gives information about the socio-economic situation and people's activities in the area (Figure 3). The resource sketch map includes livelihood status, types of houses and infrastructure in the area. This tool allowed us to obtain a better understanding about the overall area because it was drawn when standing on the roof of a high building (a school). By combining direct observations with a Google Earth map, a high level of precision and validity was achieved. The photographs in Figure 3 show palm farms invaded by sand dunes, the heavy spread of *Prosopis juliflora* trees. *Prosopis juliflora* is an evergreen tree native from South America; it is fast growing, nitrogen fixing, and tolerant to arid conditions and saline soils (El-Keblawy & Al-Rawai, 2005). It survives where other tree species have failed and in many cases has become a major nuisance. In 2000, it was rated one of the world's top 100 worst invasive alien species (Lowe, Browne, Boudjelas, & De Poorter, 2000). Date palm trees are dying as a result of rainfall shortages, groundwater decline and spread of *P. juliflora*. The results of the PRA activities show that after 2000 sand dunes have covered about 60% of the agricultural lands (Table 3).

The increased depth of the groundwater is impairing the economic situation of the people as well. In the past, agriculture did not need extensive irrigation technology because the groundwater was shallow (< 1 m below the soil surface). Today's cost of drilling a borehole to a depth of 40–50 m with pumping equipment is high and can reach US$8400. Most people in the area cannot afford to do this; only those few who can obtain financial support from emigrated relatives or other sources can afford borehole wells.

The production cost of palm tree agriculture has increased due to the harsh natural conditions, and the yield of the palm trees has gone down from 30 kg per palm tree per

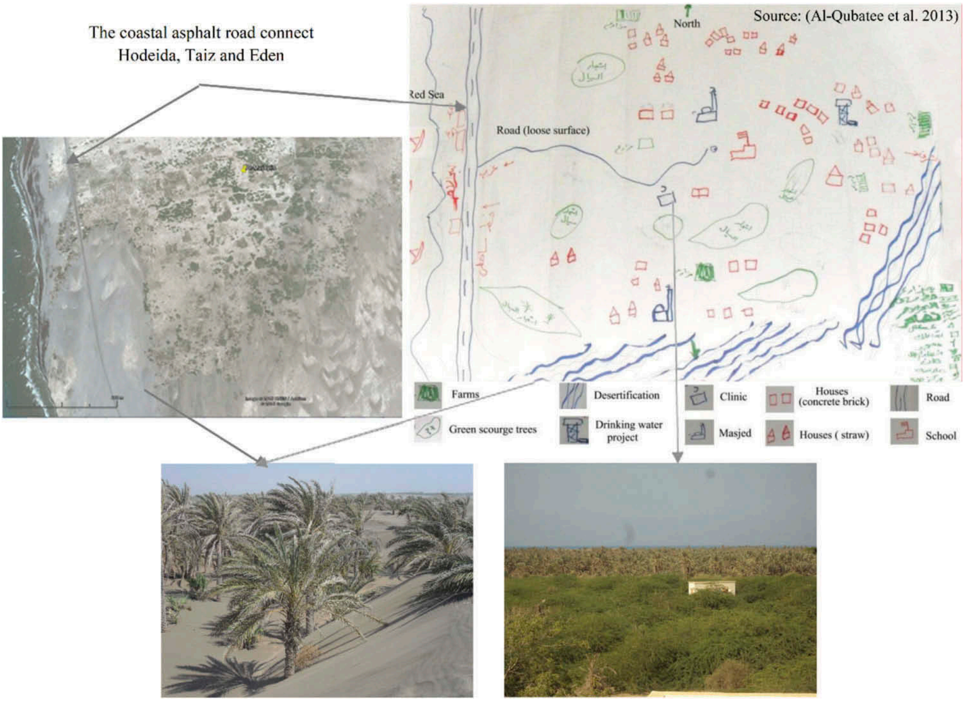

Figure 3. Resources sketch map of Al-Mujaylis with connection to Google Earth and direct observation (photographs) for precision and validity: (left) palm trees in Al-Zakham hamlet completely covered and in the process of being covered by sand dunes and (right) the heavy spread of *Prosopis juliflora* surrounding the palm trees and clinic centre. Photographic sources: Al-Qubatee et al. (2013, 2015).

year in the years before 1990 to only 5 kg per palm tree in 2011. Lack of rain, falling water tables, drought, sand dune movements and the spread of *P. juliflora* have impacted heavily on agricultural activities. Thus, palm tree agriculture is no longer the profitable business that it was previously.

According to local people, the overall decline in agricultural and livestock activities has led to increased poverty and migration from the area. This is reflected in daily farm activities: farmers spent just three hours per day in the field, and in the numbers of migration and current poverty levels. Al-Mujaylis, which consists of 10 hamlets, has a total population of 2642 (1328 male, 1314 female) according to the last census in 2004 (Central Statistical Organization, 2005). According to a key informant (a teacher), about 85% of the people are living in extreme economic poverty and the other 15% in moderate economic poverty (personal communication with Mr Ibrahim, 2013). Migration has increased after 2000, reaching 50–60% in 2015 (Table 3).

Stakeholder views on the causes and solutions of water resources problems

Eight different discussions groups, with 5 to 10 respondents in each group (including farmers and key informants), were formed to identify their problems and to propose solutions (Table 1). For example, the groups of people in the downstream areas close to the Red Sea (four different groups) identified and ranked the causes of the water

Table 4. Priorities of the water resources problems and the suggested solutions, downstream of the wadis.

Ranking	Al-Mujaylis	Al-Tefaf	Al-Gah (1)	Al-Gah (2)[a]
Causes of the water resources problems				
1	Rainfall shortage	Poverty	Rainfall shortage	Rainfall shortage
2	Random drilling wells (groundwater depletion)	Rainfall shortage	Spate of irrigation practices	Over abstraction, groundwater depletion
3	*Prosopis juliflora* trees	*P. juliflora* trees	Over abstraction and groundwater depletion	Increased agriculture areas
4	Spate irrigation	Construction of diversion structures	Farming crops consume a lot of water, such as banana	Constructed dams in the mountain catchment areas
5	Construction of weirs and dams	Crop pattern change upstream	Constructed dams in the mountain catchment areas	Crop pattern change, mango and banana instead of cereals
6		Groundwater depletion because of high abstraction upstream	Spread of *P. juliflora* trees	Absence of high-efficiency irrigation techniques
7		Random drilling of wells without the legal distance		
Suggested solutions				
1	Support farmers by modern irrigation etc.	Support farmers (marketing etc.)	*Zakat* giving	Implement high-efficiency irrigation
2	Cope with *P. juliflora* trees, desertification (reactivate the International Fund for Agricultural Development [IFAD] project)	Cope with *P. juliflora* trees and desertification	Implement high-efficiency irrigation techniques	Build dams and weirs in suitable places
3	Stop random well drilling and implement distance between wells	Build dams at the end of the wadis before water discharge into the sea	Regulate well drilling	Cultivate cereal crops
4	Water harvesting (at the end of the wadis before water discharge into the sea)	Solve the problem of diversion weirs to serve all people	Farm crops that can withstand drought	Use of natural fertilizers
5		Regulate well drilling	Select a suitable location for dams and weirs	

Note: [a]For this group no ranking was done in the field for the causes of the problem.
Sources: Al-Qubatee et al. (2013, 2015).

resource problems in the area, proposed solutions for these problems and ranked them according to their priority and preferences (Table 4).

People in the midstream of Wadi Zabid and Wadi Rima have their own interests and conflicts about the distribution of spate water. For example, people in midstream of Wadi Zabid depend on traditional water rights called in Arabic '*arf*' (common law) that were introduced by Sheikh Al-Jabarti more than 600 years ago based on the general rule '*Al-a'la fi-l-a'la*' (priority for the upstream riparian residents). These rules give priority to spate water rights to three groups of users in the midstream of Wadi Zabid within the 20 km downstream of the weirs. The water that exceeds their needs flows further downstream and (only in exceptional cases) reaches the Red Sea, 50 km from the

Table 5. Priorities of the problems in the midstream of Wadi Zabid and Wadi Rima.

Ranking	Al-Gerbah area, within the first group of Wadi Zabid	Al-Gerbah area, within the first group of Wadi Zabid (2)	Al-Mawi canal, within the second group of Wadi Zabid	Al-Jarubah area, Wadi Rima
Causes of the water resources problems				
1	Rainfall shortage	Rainfall shortage	Rainfall and spate water shortage	Convert the spate water of Wadi Rima to the southern area
2	Groundwater depletion because of banana farming and an increase in agriculture areas	Random drilling of wells, the water law is not implemented	Banana farming, which consumes a lot of water	No fair spate water distribution
3	Constructed dams in the mountain catchment areas of Wadi Zabid	Spate irrigation	Constructed weirs and dams in the mountain catchment areas of Wadi Zabid	Rainfall shortage
4	Water law not implemented fairly	Banana farming, which consumes a lot of water	Random drilling of wells	Crop pattern change, banana farming instead of cereals
5			Absence of high-efficiency irrigation techniques	
Suggested solutions				
1	Stop building harvesting dams in the mountain catchment areas of Wadi Zabid	Implement water law and stop the random drilling of wells	Stop or decrease banana farming	Justice in spate water distribution and implement the law
2	Implement the regulation for drilling of wells	Construct water-harvesting structures	Support farmers by high-efficiency irrigation techniques	Support farmers with diesel, marketing and technical
3	Implement new spate water-distribution systems as the system in the southern part of Yemen (Lahj & Abyan[a])	Support farmers by high-efficiency irrigation techniques	Regulate the drilling of wells	Educate farmers on how to conserve water
4	Replace banana crops with other crops like cereals	Decrease banana farming by farming another crops like cereals	Regulate the construction of dams and manage the water of constructed dams	Reduce crops that consume a lot of water, such as banana
5			Raise the awareness of farmers about the importance of water	

Note: [a]Spate water rights in those areas: farmers upstream use the spate for irrigation only once, thereafter letting the water pass to the next farm, and so on until the water reaches the last beneficiary who depends on the amount of the spate. The second spate would then begin from the farmer after the last one to receive the previous spate, and so on.
Sources: Al-Qubatee et al. (2013, 2015).

foothills. The outcome of the problem and solution tree exercise for the midstream stakeholders shows the most important causes of the problems and the priority for the suggested solutions in midstream Wadi Zabid and Rima (Table 5). Although there is neither cooperation nor conflict between downstream and midstream residents of the wadis, there were clear similarities in their views about the problems and possible solutions. The leading causes of the problems mentioned in both areas are: (1) rainfall shortage; (2) the effect of the construction of dams and diversion structures; (3) changes in cropping pattern and the low efficiency of irrigation techniques; and (4) random

Table 6. Usefulness of participatory rural appraisal (PRA) tools to achieve the objectives of the study, arranged from the most to the least useful.

PRA tools and other sources of information	Objectives: To assess the degradation of groundwater resources – Groundwater status	Objectives: To assess the degradation of groundwater resources – Livelihoods	Objectives: To obtain stakeholders' views on the problems and their solutions	Objectives: To overcome lack of data[a]
Semi-structured interview	+ + + + +	+ + + + +	+ + +	+ + + +
Transect walk and direct observation	+ + + + +	+ + + +	+ + +	+ + + +
Groups discussion	+ + + +	+ + +	+ + + +	+ + + +
Time line	+ + + + +	+ + + +	+	+ + + + +
Problem and solution trees	+ + +	+ +	+ + + + +	+ + +
Key informant interview	+ + + +	+ + +	+ + +	+ + +
Resource sketch map	+	+ + + +	+ + +	+ + +
Daily calendar	–	+ + +	–	+

Notes: Many plus signs (+) mean the strong contribution of the method to the achievement of the objectives; a negative sign (–) means no contribution at all).
[a]Groundwater status, spate water, traditional rights of spate water distribution, irrigation system, land use, livelihoods status etc.

drilling of wells and over-abstraction of groundwater. The common solutions suggested are (1) to support farmers to introduce high-efficiency irrigation techniques and assistance to market their crops; (2) the selection of suitable locations for future dams and diversion structures and better management of the water in the existing harvesting structures; (3) the regulation of well drilling and implementation of the water laws; and (4) the cultivation of crops that can withstand drought and have lower water requirements, e.g., cereals.

Key informants were asked about their role in the solutions for all the above-mentioned problems. The response of one parliamentary representative in the region was that each institution should take its responsibility to improve the situation. Suggestions included ideas such as to improve cooperation between government and related institutions and to improve legislation related to water resources to overcome the weak points in the laws (both formal and tradition laws). These results confirmed our expectation that each PRA tool applied was well suited to the various objectives of this study (Tables 2 and 6).

Discussion

There is strong support for more change from the current management practices towards a more adaptive and flexible approach to get more attention paid to tackle water management from an integrated approach, including human, physical, biological and biogeochemical components (Pahl-Wostl, 2007). The trend in the latest literature is towards considering water as interrelated to other sectors, within the broader context, through a problemshed rather than a watershed approach (Hussein & Grandi, 2017). Many arguments exist regarding the involvement of stakeholders in information production, which is regarded as strategic in shaping policies. In fact, the critical hydro-politics literature argues that discourses are constructed and deployed by powerful groups in a society or by powerful riparian countries in order to drive towards certain (favourable) solutions – while closing less favourable policy solutions (Zeitoun & Warner, 2006). The construction of discourses is linked to public opinion on how they absorb and reproduce through daily practices these discourses, and on how they may challenge and contest dominant discourses. Korfmacher (2001) stated that there is an ongoing debate on the subject of public involvement in the processes of knowledge production and decision making. He mentions several issues that justify the involvement of society, such as the democratic, substantive and pragmatic aspects of the process. The argument he made is that citizen involvement in watershed modelling will support decision-making and the implementation of those decisions. This perspective also supports the idea of educating people with the expectation that better understanding will lead to significant support of policy output. Baldwin and Ross (2012), based on a case study of the water-stressed Lockyer Catchment in Australia, stated that applying an action research methodology and consensus-building techniques in the early stage of the regulation process reduces the number of conflicts, leads to mutual learning and builds trust between parties (government and local communities).

However, there are also arguments against stakeholder involvement. Bureaucratic theory takes the view that some aspects of the decision-making process need technical expertise and are, therefore, best left to agencies with expertise. Korfmacher (2001) argues against public participation in watershed modelling, because they may lack expertise. He argues that there can be the risk of biased input, de-legitimization and/or over-legitimization, misrepresentation of consensus and insufficient influence. Moreover, Moote, McClaran, and Chickering (1997) stated that providing a forum for social discussion (participatory democracy approaches) on its own does not ensure successful collaboration, consensus and/or that decisions will be acceptable to all stakeholders, especially where different interests emerge.

Raadgever et al. (2012) argues that effective collaborative research will only work where the stakeholders are highly motivated (an accurate stakeholder analysis is required) and have equal input in and influence on the research process. This takes time and calls for an intensive collaborative research process.

In our study, we found that PRA tools are an effective method to benefit from the implicit knowledge of the community in which to fill gaps in our knowledge and data records. The PRA technique facilitated the generation of information over the groundwater status (in the past and at the moment), livelihoods of the local community, problems/constraints and views on appropriate solutions that this study aims to address (Table 6). This approach helped us to formulate appropriate solutions and to obtain a better understanding of people's preferences. The application of a combination of PRA tools helps us to reach a better understanding of the current groundwater situation and its effects on the livelihoods of people in the area.

The reliability of the generated information was assessed via triangulation and cross-checking between the outputs of the PRA process with external sources of information. The groundwater table contour map prepared by Tesco-Viziterv-Vituki (as cited in Tipton & Kalambach, 1980) confirms our findings that in areas close to the sea the groundwater table was at a depth of 10 m $^{+}$MSL (mean sea level), less than 1 m below the soil surface (Tipton & Kalambach, 1980, based on Tesco-Viziterv-Vituki, 1971b).

Based on our results, the involvement of stakeholders in problem assessment and the identification of proposed solutions is both important and desirable. This approach gave us insight into the community's perspectives on the issues under discussion, which is virtually impossible to do with just a quantitative approach. The communities suggested solutions that they felt were possible for effective implementation. However, we suggest that adopting a research approach between top down and bottom up is more valuable and effective, especially in the areas with high illiteracy. Lack of knowledge of the community on some issues can lead to unrealistic suggestions that may create conflicts and/or create other problems in future. In this respect, we had to assess whether the suggestions were realistic or unrealistic from a specialist point of view, including the various social, technical and economic aspects.

The disadvantages of applying the PRA method include the greater effort required to analyse the qualitative data generated by six different tools and because of the different emerging themes and, therefore, the difficulty of applying statistical methods for generalization compared with the analysis of quantitative data (structured and closed-ended questionnaire). Also, the difficulty in getting representation from the whole community required much time and resources. We overcome this by applying as many of the different PRA tools along the wadi as possible (Table 1) and to concentrate more on the results that were ranked by the stakeholders in the field. Another disadvantage of this method is the risk that the discussions are dominated by certain group(s) of people (especially where illiteracy is high). We overcame this by use of individual and group interviews. Individual interviews avoided influence from and on others, while group discussion led to increased mutual understanding and conjunctive learning between researchers and stakeholders.

Conclusions and recommendations

This paper suggests that PRA is a useful method for assessing the degradation of groundwater and its effects on the livelihoods of the inhabitants of the Al-Mujaylis area, overcoming gaps in the available data and getting a better understanding of the local stakeholders' views on the problems, their causes and appropriate solutions. The method gave a clear picture about groundwater degradation with regard to the groundwater drawdown and the effect this had on the livelihood of the community (a higher cost of farming, increased poverty and migration from the area). The challenge was to select the most appropriate and useful combination of tools to address a specific topic. The strongest tools are the semi-structured interviews, the transect walk in combination with direct observations and groups discussion, time lines, and problem and solution trees (Tables 2 and 6). The result of group discussion and the use of problem and solution trees reflect the stakeholders' views on the problems, the causes of the problems and appropriate solutions. By applying PRA techniques, stakeholders were able to analyse the causes of the problems and to propose appropriate solutions for mitigating or resolving the water problems in the area. The results of all the groups' input were compared with found areas of consensus (common solutions between the groups living downstream and midstream of the wadi).

The application of the PRA method contributed to obtaining an appropriate amount of data regarding the status of groundwater, land use, livelihood situations and the economic situation of the community. The method fits with our context as less attention has been paid to the social aspects of water studies. However, applying a complete bottom-up approach is not useful, especially in areas of high illiteracy. For example, respondents suggested that the government should subsidize the installation of high-efficiency irrigation techniques. From an experts point of view, however, it can be argued that high-efficiency irrigation techniques in closed water basins will not result in a high water saving because part of the water used in irrigation will return (non-consumptive water) to the aquifer over the short and/or long terms (Frederiksen & Allen, 2011; Gleick, Christian-Smith, & Cooley, 2011). Respondents also suggested that the government should continue the diesel subsidy. From an expert's point of view, however, economic incentives such as irrigation techniques and/or a diesel subsidy can be better oriented to water-saving activities (Hellegers, Perry, Al-Aulaqi, Al-Eryani, & Al-Hebshi, 2008). This is especially true for areas threatened by environmental catastrophes, such as groundwater depletion, seawater intrusion and desertification, as in our case study area. On the other hand, applying a pure top-down approach is not fully successful and faces some limitations. For example, the government implemented a project to cope with the desertification, but that project was not completely successful because people in the area preferred a water drinking project. Therefore, they were later allowed to convert some of those wells for drinking water. Furthermore, between 2004 and 2006, the government increased the height of two weirs in the midstream area by 1 m because sediments had accumulated upstream of it. Stakeholders downstream were unsatisfied with this, but on the other hand stakeholders on both sides of the weirs suffer from sediment accumulation in front of the weir. Participatory study and consensus-building was required along with the technical study.

From our study we conclude that adapting a research approach that is balanced between a totally top-down and a bottom-up approach and between delegitimization and over-legitimization will be more integrated and useful. The community views and suggestions have to be taken into account and studied by the concerned government institutions in a multidisciplinary approach, including technical, social and economic factors. Only then can appropriate decisions be made about solutions to be implemented.

The next step in our study will be participatory groundwater modelling to determine the most appropriate solutions suggested by stakeholders. The implicit knowledge of the local communities helped us to fill the gaps in our data recorded that will be used as inputs in this groundwater modelling. In addition, attention needs to be given to examining the wider impacts of the suggested solutions; the production value of the water; and to find the most commonly preferred solutions by stakeholders. These further developments will help in the policy and decision-making process and facilitate effective implementations.

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References

Abu-Lohom, N. M. (2002). *Hydrogeological, geophysical and geochemical investigation of the aquifers in Wadi Siham, Tihama area, Republic of Yemen* (Unpublished doctoral dissertation). Pune: University of Pune.

Al-Eryani, M. L. (1979). *Hydrology and ground water potential of the Tihama-Yemen Arab Republic* (Unpublished doctoral dissertation). Tempe: University of Arizona.

Al-Kebsi, A. Y. (2000). *Assessment of saltwater intrusion in a costal aquifer, Wadi Surdud, Yemen Republic* (Unpublished doctoral dissertation). Mumbai: Indian Institute of Technology.

Al-Qubatee, W. (2009). *Artificial recharge assessment of groundwater through Mekhtan Dam Bani Husheish, Sana'a basin – Yemen and ways to improve it out of the perspective of IWRM* (Unpublished master's thesis). Jordan University & Cologne University.

Al-Qubatee, W., Ibrahim, A., From Dalseng, C., Al-Weshali, A., & Van Steenbergen, F. (2013). *Groundwater depletion, Sand dune Formation and Local Responses: Case study Al-Mujaylis. CoCoon: Groundwater in the Political Domain*. Sana'a: Water and Environment Center, Sana'a University & 's Hertogenbosch: MetaMeta Research.

Al-Qubatee, W., Ibrahim, A., From Dalseng, C., Al-Weshali, A., Van Steenbergen, F., & Ritzema, H. (2015). Assessing the effectiveness of water governance in combating groundwater degradation in Al-Mujaylis, Tihama Coastal Plain, Yemen. In M. Fayyad, S. Sandri, M. Weiter, & D. Zikos (Eds.), *Social water studies in the Arab Region* (pp. 197–216). Berlin: Humboldt-Universität zu Berlin.

Baldwin, C., & Ross, H. (2012). Bridging troubled waters: Applying consensus-building techniques to water planning. *Society & Natural Resources*, *25*(3), 217–234. doi:10.1080/08941920.2011.578120

Barreira, A. (2003). The participatory regime of water governance in the Iberian Peninsula. *Water International*, *28*(3), 350–357. doi:10.1080/02508060308691709

Bhandari, B. B. (2003). *Participatory rural appraisal (PRA) Virgina*. Japan: Institute for Global Environmental Strategies.

Blaikie, N. W. H. (1991). A critique of the use of triangulation in social research. *Quality & Quantity*, *23*, 115–136. doi:10.1007/BF00145701

Bots, P. W. G., Bijlsma, R., von Korff, Y., Van der Fluit, N., & Wolters, H. (2011). Supporting the constructive use of existing hydrological models in participatory settings: A set of 'rules of the game'. *Ecology and Society*, *16*(2), 16. doi:10.5751/ES-03643-160216

Brunner, U., & Haefner, H. (1986). The successful floodwater farming system of the Sabeans, Yemen Arab Republic. *Applied Geography*, *6*, 77–86. doi:10.1016/0143-6228(86)90030-5

Burke, J., Moench, M., & Sauveplane, C. (1999). *Groundwater and society: Problems in variability and points of engagement*. World Bank Technical Paper: 31–52.

Butler, W. H., Monroe, A., & McCaffrey, S. (2015). Collaborative implementation for ecological restoration on US Public Lands: Implications for legal context, accountability, and adaptive management. *Environmental Management*, *55*(3), 564–577. doi:10.1007/s00267-014-0430-8

Cavestro, L. (2003). *PRA-participatory rural appraisal concepts methodologies and techniques*. Padua: University of Padua, Faculty of Agriculture. Retrieved 14 January, 2007, from http://wwwagrariaunipdit/agraria/master/02-03/participatory%20rural%20appraisalpdf

Central Statistical Organization. (2005). *Statistical year book 2005*. Yemen: Central Statistical Organization, Ministry of Planning and International Cooperation.

Chambers, R. (1994). Participatory rural appraisal (PRA): Challenges, potentials and paradigm. *World Development*, *22*(10), 1437–1454. doi:10.1016/0305-750X(94)90030-2

Cohen, J. M., & Lewis, D. B. (1979). Capital-surplus, labor-short economies: Yemen as a challenge to rural development strategies. *American Journal of Agricultural Economics*, *61* (3), 523–528. doi:10.2307/1239440

DHV. (1988). *Tihama basin water resources study, Groundwater development in the Tihama coastal plain*. Sana'a: Ministry of Agriculture and Fisheries Resources, Tihama Development Authority (TDA).

Dionnet, M., Daniell, K. A., Imache, A., von Korff, Y., Bouarfa, S., Garin, P., … Rougier, J.-E. (2013). Improving participatory processes through collective simulation: Use of a community of practice. *Ecology and Society*, *18*(1), 36. doi:10.5751/ES-05244-180136

El Ayni, F., Cherif, S., Jrad, A., & Trabelsi-Ayadi, M. (2012). Impact of agriculture activities on a coastal aquifer in Tunisia and options for a better water management. *Water International*, *37* (7), 871–883. doi:10.1080/02508060.2012.733671

El Ayni, F., Manoli, E., Cherif, S., Jrad, A., Assimacopoulos, D., & Trabelsi-Ayadi, M. (2012). Deterioration of a Tunisian coastal aquifer due to agricultural activities and possible approaches for better water management. *Water and Environment Journal*, *27*(3), 348–361. doi:10.1111/j.1747-6593.2012.00354.x

El-Keblawy, A., & Al-Rawai, A. (2005). Effects of salinity, temperature and light on germination of invasive *Prosopis juliflora* (Sw.) D.C. *Journal of Arid Environments*, *61*, 555–565. doi:10.1016/j.jaridenv.2004.10.007

Frederiksen, H. D., & Allen, R. G. (2011). A common basis for analysis, evaluation and comparison of offstream water uses. *Water International*, *36*(3), 266–282. doi:10.1080/02508060.2011.580449

Gleick, P. H., Christian-Smith, J., & Cooley, H. (2011). Water-use efficiency and productivity: Rethinking the basin approach. *Water International*, *36*(7), 784–798. doi:10.1080/02508060.2011.631873

Harrower, M. J. (2010). Geographic Information Systems (GIS) hydrological modeling in archaeology: An example from the origins of irrigation in Southwest Arabia (Yemen). *Journal of Archaeological Science*, *37*, 1447–1452. doi:10.1016/j.jas.2010.01.004

Hellegers, P. J. G. J., Perry, C., Al-Aulaqi, N., Al-Eryani, A., & Al-Hebshi, M. (2008). *Incentives to reduce groundwater extraction in Yemen*. The Hague: Wageningen University.

Hellegers, P. J. G. J., Perry, C. J., & Al-Aulaqi, N. (2011). Incentives to reduce groundwater consumption in Yemen. *Irrigation and Drainage*, *60*, 93–102. doi:10.1002/ird.538

Hussein, H. (2016). *An analysis of the discourse of water scarcity and hydropolitical dynamics in the case of Jordan* (Unpublished doctoral dissertation). Norwich: University of East Anglia.

Hussein, H., & Grandi, M. (2017). Dynamic political contexts and power asymmetries: The cases of the Blue Nile and the Yarmouk Rivers. *International Environmental Agreements: Politics, Law and Economics*. doi:10.1007/s10784-017-9364-y

Irrigation Improvement Project. (2002). *Water management in Wadi Tuban & Wadi Zabid, water Management plans & spate Management models*. Yemen: Ministry of Agriculture and Irrigation/The World Bank.

Jungfer, E. (1987). Grundwassererganzung und Grundwassernutzung in den Wusten des Yemen [Supplementing groundwater and using groundwater in the deserts of Yemen]. *Geographische Rundschau*, *39*(7–8), 408–410, 417.

Korfmacher, K. S. (2001). The politics of participation in watershed modeling. *Environmental Management*, *27*, 161–176. doi:10.1007/s002670010141

Land Resources Division. (1977). *Mountain plains and wadi Rima' project, a land and water resources survey, an investment and development plan for wadi Rima'*. London: British Ministry of Overseas Development.

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database*. The Invasive Species Specialist Group, World Conservation Union (IUCN), 12pp.

Margerum, R. D. (2007). Overcoming locally based collaboration constraints. *Society & Natural Resources*, *20*, 135–152. doi:10.1080/08941920601052404

Mascarenhas, J., Shah, P., Joseph, S., Jayakaran, R., Devavaram, J., Ramachandran, V., . . . Pretty, J. (1991). *Participatory rural appraisal: Proceedings of the February 1991 Bangalore PRA trainers workshop: RRA notes, No. 13*. London: IIED and Bangalore: MYRADA.

Ministry of Agriculture and Irrigation. (2012). *A promising sector for diversified economy in Yemen: National agriculture sector strategy 2012-2016*. Yemen: Author.

Moote, M. A., McClaran, M. P., & Chickering, D. K. (1997). Theory in practice: Applying participatory democracy theory to public land planning. *Environmental Management*, *21*, 877–889. doi:10.1007/s002679900074

Nasher, G., Al-Sayyaghi, A., & Al-Matary, A. (2013). Identification and evaluation of the hydrogeochemical processes of the lower part of Wadi Siham catchment area, Tihama plain, Yemen. *Yemen Arabian Journal of Geosciences*, *6*, 2131–2146. doi:10.1007/s12517-011-0471-8

National Water Resources Authority (NWRA). (2008). *Tihama water resources assessment, Zabid water resources management, district (Wadi Zabid & Wadi Rema'a), Well inventory results*. Sana'a: Ministry of Water and Environment.

National Water Resources Authority (NWRA). (2009). *Wadi Zabid and wadi Rima water quality*. Sana'a: Ministry of Water and Environment.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management*, *21*, 49–62. doi:10.1007/s11269-006-9040-4

Qaid, K. Q. (2007). *Assessment study of the impact of agricultural demonstrations program on production and income in Zabid and Tuban valleys*. Sana'a: Irrigation Development Project.

Raadgever, G., Mostert, E., & van de Giesen, N. C. (2012). Learning from collaborative research in water management practice. *Water Resources Management*, *26*, 3251–3266. doi:10.1007/s11269-012-0070-9

Ritzema, H., Froebrich, J., Raju, R., Sreenivas, C., & Kselik, R. (2010). Using participatory modelling to compensate for data scarcity in environmental planning: A case study from India. *Environmental Modelling & Software*, *25*, 1450–1458. doi:10.1016/j.envsoft.2010.03.010

Ritzema, H. P., Quang Anh, L., & Thi Kim, B. (2011). Colloborative research to improve the water management in two polders in the Red River Delta in Vietnam. In A. Van Paassen, J. Van Den Berg, E. Steingröver, R. Werkman, & B. Pedroli (Eds.), *Knowledge in action* (pp. 57–84). Wageningen: Mansholt Publication Series, Wageningen Academic Publ.

Sharma, K. D. (2009). Groundwater management for food security. *Current Science*. *96*, 1444–1447. Retrieved from http://re.indiaenvironmentportal.org.in/files/Groundwater%20 management%20for%20food%20security.pdf

Sijbesma, C., & Postma, L. (2008). Quantification of qualitative data in the water sector: The challenges. *Water International*, *33*(2), 150–161. doi:10.1080/02508060802022209

Smiley, S., De Loë, R., & Kreutzwiser, R. (2010). Appropriate public involvement in local environmental governance: A framework and case study. *Society & Natural Resources*, *23*, 1043–1059. doi:10.1080/08941920802627491

Survey Authority. (1986). *Topographic map, Zabid sheet No. D38-39 1:100,000*. Yemen: Author.

Taher, T., Ward, C., Fadl, N., Saleh, A., & Sultan, M. (2013). Planning for integrated water resources management: Case study Sana'a Basin, Yemen. *Iwtj 4*, Retrieved from http://iwtj.info/wp-content/uploads/2014/06/V3-N4-P61.pdf

Tesco-Viziterv-Vituki. (1971a). *Survey of the apicultural potential of the Wadi Zabid*. YAR; land tenuer and water right. Budapest: Author.

Tesco-Viziterv-Vituki. (1971b). *Survey of the apicultural potential of the Wadi Zabid. YAR; Technical Report 2 – hydrology and hydrogeology*. Budapest: Author.

Tihama Development Authority (TDA). (2007). *Cultivated area in different seasons and main crops in each district of Hodeidah Governorate, Monitoring and evaluation deportment, spreadsheet*. Hodeida: Author.

Tipton and Kalmbach. (1974). *Proposed plan for water allocation, Wadi Zabid irrigation project*. Hodeida, Yemen, and Denver, CO: Tihama Development Authority (TDA).

Tipton and Kalambach. (1980). *The Wadi Zabid groundwater potential*. Hodeida, Yemen, and Denver, CO: Tihama Development Authority (TDA).

Trimble, M., & Lázaro, M. (2014). Evaluation criteria for participatory research: Insights from coastal Uruguay. *Environmental Management*, *54*, 122–137. doi:10.1007/s00267-014-0276-0

van der Schans, M. L., & Lemperiere, P. (2006). *Manual: Participatory rapid diagnosis and action planning for irrigated agricultural systems (PRDA)*. Rome: Food and Agriculture Organization of the United Nations.

Van Steenbergen, F., Lawrence, P., Haile, A., Salman, M., Faures, J., Anderson, I., … Ratsey, J. (2010). *Guidelines on spate irrigation*. Rome: Food and Agriculture Organization of the United Nations (FAO).

Vermillion, D. L., & Al-Shaybani, S. (2004). *Small dams and social capital in Yemen: How assistance strategies affect local investment and institutions*. Colombo: International Water Management Institute.

Von Korff, Y., Daniell, K. A., Moellenkamp, S., Bots, P., & Bijlsma, R. M. (2012). Implementing participatory water management: Recent advances in theory, practice, and evaluation. *Ecology and Society*, *17*(1), 30. doi:10.5751/ES-04733-170130

Ward, C. (2009). Water conflict in Yemen: The case for strengthening local resolution mechanisms. In N. V. Jagannathan, A. S. Mohamed, & A. Kremer (Eds.), *Water in the Arab world* (pp. 233–267). Washington, DC: The World Bank.

Yeasmin, S., & Rahman, K. F. (2012). 'Triangulation' research method as the tool of social science research. *Bup Journal*, *1*, 2219–4851. Retrieved from http://www.bup.edu.bd/journal/154-163.pdf

Zanetell, B. A., & Knuth, B. A. (2002). Knowledge partnerships: Rapid rural appraisal's role in catalyzing community- based management inVenezuela. *Society & Natural Resources*, *15*, 805–825. doi:10.1080/08941920290107576

Zeitoun, M., Allan, T., Al Aulaqi, N., Jabarin, A., & Laamrani, H. (2012). Water demand management in Yemen and Jordan: Addressing power and interests. *The Geographical Journal*, *178*, 54–66. doi:10.1111/j.1475-4959.2011.00420.x

Zeitoun, M., & Warner, J. (2006). Hydro-hegemony – a framework for analysis of trans-boundary water conflicts. *Water Policy*, *8*, 435–460. doi:10.2166/wp.2006.054

Zvoleff, A., & An, L. (2014). Analyzing human–landscape interactions: Tools that integrate. *Environmental Management*, *53*, 94–111. doi:10.1007/s00267-012-0009-1