The Education, Research, Society, and Policy Nexus of Sustainable Water Use in Semiarid Regions—A Case Study from Tunisia

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Abstract The present study analyzes the interrelations of the education, research, society, and policy nexus on sustainable water use and agriculture in semiarid regions of Tunisia. The selected region of Tunisia is one of the most water-stressed regions in northern Africa, strongly exporting fruits and vegetables to European mainland whereas at the same time strongly lacking water resources and reducing production of food for

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its own growing population. Water scarcity is the major problem in the agriculture of semiarid regions. Along with the population growth, water resources (qualitatively and quantitatively) for food production is exposed to severe strains and has become an important topic for science and politics as well as for the general public in these countries as well as globally. Natural water resources in Tunisia are faced with serious problems related to their quantity and quality (Mekki et al. 2013). Only 8.4 % of the total shallow groundwater has salinity levels that do not exceed 1.5 g/L (Benjemaa et al. 1999). Thus, there is also a lack of fresh drinking water for the population, caused by the extensive use of deep and fossil ground water by agriculture. Due to the lack of conventional water resources, water of marginal quality is used for agricultural irrigation.

Keywords Education · Tunisia · Society · Policy · Semiarid regions

1 Introduction and Methodology of System Analysis

Sustainable development is named as a core principle when it comes to planning of future scenarios for the society, environment, and economy, locally and globally (United Nations General Assembly 2012). The challenge behind is, that working with sustainability contexts is complex, as a huge variety of impact variables, perspectives, values, the present as well as future states need to be reflected and taken into consideration when it comes to find solutions and innovations that guide the way for a sustainable future (Mader 2013).

Water scarcity is a cause for major challenges in the agriculture and life of arid and semiarid regions (El Kharraz et al. 2012; Zeng et al. 2013). The United Nations Environmental Programme names the following major water challenges for Arica that is most relevant for semiarid regions in Tunisia (UNEP 2010: 124):

- Provide safe drinking water
- Provide water for food security
- Meet growing water demand
- Prevent land degradation and water pollution
- Manage water under global climate change
- Enhance capacity to address water challenges

Along with the population growth, water resource management—qualitatively and quantitatively—is exposed to severe strains and has become an important topic for science and politics as well as for the general public. As such, 75.9 % of all water withdrawals are being used by the agricultural sector, 3.9 % by the industry, and 12.8 % by municipalities (UNEP 2010).

Of special relevance to this paper, is the water situation in Tunisia. Tunisia is a northern African country, with a population of 10,778 million and a nominal GDP of 45.611 billion US$ (as of 2012, IMF 2014). According to the International Monetary fund staff estimates, the population will grow within the 7 years of 2011–2018 by app. 1 million (2011: 10.647 millions; 2018: 11.646 millions). The combination of

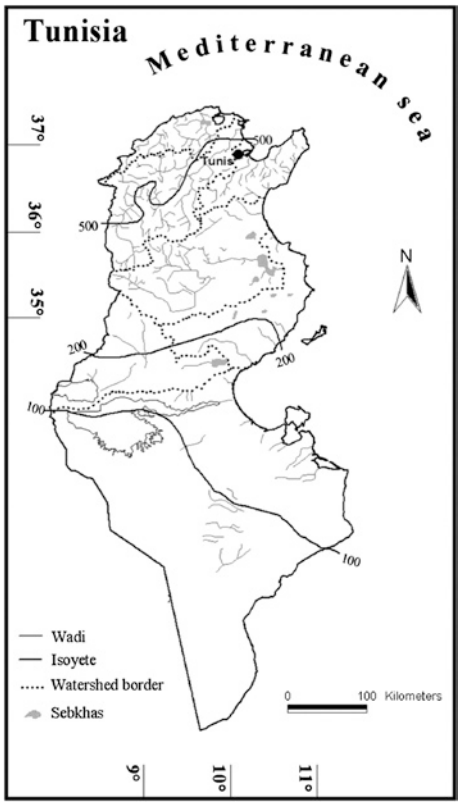

Fig. 1 Tunisian map, drainage area, and rainfall characteristics. Neighboring countries are Libya in the east and Algeria in the west (after DGRE 1983)

strong population growth and at the same time shrinking agricultural land resources due to salivation and domestication causes strong challenges for the present and future. A schematic map of the country is seen in Fig. 1.

Natural water resources in Tunisia are faced with serious problems related to their quantity and quality. The water availability per capita is about 450 m^3/year (2008), far from the 1,000 m^3 per capita set as threshold value for water scarce countries. Due to the lack of conventional water resources, water of low quality is used for agricultural irrigation.

Following those given challenges in Tunisia and as in semiarid regions, the focus of this paper should be the role of interactions to take place in the nexus of education, research, society, and policy to achieve sustainable solutions. *The hypothesis put forward here is that strengthening exchange and capacity building for sustainable development in general in the nexus of education, research, society, and policy supports the development of essential innovations and transformation for sustainable water use in the whole system of water use in semiarid regions for the present and the future.*

This paper is structured by the following scheme:

First, the problem and today's most conventional ways of solving the problem are briefly outlined. Immediately, the reader might recognize that those solutions might not provide strong future perspectives, but only cure the immediate symptoms

of the problems. Consequently, authors provide a system analysis of the impact variables outlining the case of water scarcity in Tunisian agriculture. This system analysis supports a better understanding of challenges that are hidden by the problem of water scarcity. It becomes obvious that solutions do not only lie in the supply of more technologies and better irrigation systems, but are strongly connected to the awareness and education of society as a whole in regard to the sustainable use of water and protection of the environment.

The system analysis leads to focus the paper on the nexus of education, research, society, and policy. Capacity building in the nexus of those variables may provide new solutions that contribute to a holistic approach of transformation toward sustainable water use in semiarid regions. Modern or economically motivated practices often implemented without previous reflection on direct or indirect impacts on nature and society have often led to forget traditional practices, knowledge, and capacities that have been developed over generations. Through transformative research, those practices and knowledge are put in the context of today's local and global demands. Through joint research and knowledge exchange between researchers, farmers, and local stakeholders capacities are being built to provide sustainable solutions for practice and policy.

As the system analysis demonstrates, future solutions of water scarcity cannot be limited either to policy, technical innovations, or costly imports of goods. Future solutions are embedded by the transdisciplinary application of educational and research activities.

2 The Tunisian Case

In Tunisia, many challenges remain for the effective mainstreaming of water management and sustainable agriculture policies within the context of larger social and economic development policies. These include the following: (a) societal solutions, including economic incentives that are not always considered; (b) scientists do not play a sufficient strong role in defining public policies; (c) existing policies mesh poorly with economic development policies, which are further exacerbated by adverse subsidies and inappropriate incentives; and (d) international influences on national "mainstreaming" particularly in the form of development cooperation are typically not molded to the needs of the dry land peoples (Anderson et al. 2013).

Primary policy questions are usually underestimated or overlooked by decision makers. It is essential to find solutions to the current political institutions, and enable them to reverse their tendency of unsustainable behavior. For example, aridity is considered in Tunisia as a "fait accompli" and not an opportunity (Zafar et al. 2007). For that reason, it is difficult to develop strategies that promote investment in arid regions and to convince the government and other stakeholders to do so. Thus, a policy for sustainable agriculture in arid zones must be developed. This would aim, for instance, to optimize the use of water availability and to build on the comparative advantages of agricultural activities in arid lands. On the other hand,

an effort should be made to raise environmental awareness and behavior among all citizens, including the sustainable use of water. Thus, the Tunisian authorities must overcome the notion that aridity and water scarcity linked to human consumption are inevitable.

There is often a differential prioritization of environment and development issues in national agendas. Environmental and developmental priorities should be properly harmonized at the national level in order not to become an obstacle to success. Furthermore, environment and development approaches should operate more transdisciplinary with sufficient social analysis and social exchange, and should not be only vertically and sector specifically focused (Zafar et al. 2007).

In Tunisia, national policy remains weakly connected to science. Scientific research activities do not have an appropriate focus on emerging challenges. Relevant scientific knowledge should be disseminated and used in order to plan and achieve national and local policies, laws, regulations, and action programs closely in line sustainable agriculture and water use.

The Tunisian government can incite a reorientation of the existing institutions through sustainable land management. Decision makers should also encourage paying environmental services, particularly in rural areas, for improving sustainable agricultural activities and preventing unsustainable water use. This reorientation could be made possible through a better transparency and accountability of Tunisian governments, the participation of multiple stakeholders, quantifiable results, and follow-up systems (FAO 2013).

Financial support may be required for the implementation of new technologies in semiarid environments because of the generally unpredictable profits and risks of such technologies, and because of institutional constraints such as land property rights issues. Focused financial inducements and deterrents, as well as awareness awakening, can be used to enlighten and educate landowners and land users, and hence let them become more directly involved. Such a commitment can lead to the conception and spreading of interventions that could be understood and streamlined by the local population.

Enhancing knowledge and understanding for people of how national factors can impact locally—and vice versa—is important. Issues related to lack of awareness of the fragility of the natural resource base should be examined more intensely at the national level, in order to reduce obstacles to the development of the core program and strategy in Tunisia.

Education and capacity building of local populations and policymakers should receive high priority. Mainstreaming sustainable water use and agriculture requires the capacity building, education, and better communication among local populations but also of policy makers (Scoullos 1998). For example, in Tunisia, the large deforested areas had resulted in serious land erosion. One lesson learned from the subsequent reforestation intervention demonstrated the value of incorporating activities to address the economic needs of the local population; this resulted in successful and sustainable programs.

Education for Sustainable Development (ESD) aims to balance human and economic welfare and nature for present and future generations with cultural values

and respect for the environment. Besides, ESD empowers people to develop the appropriate knowledge and skills; to adopt attitudes and values, and shape behaviors in order to assume responsibilities for a sustainable future (Scoullos and Malotidi 2005). Higher education institutions (HEI) have a special responsibility to provide leadership on ESD. Indeed, HEI as facilities of interlinked education and research have the mission to promote development through research and teaching, disseminating new knowledge and insight, and building capacities of their students. As HEI educate and train decision makers, they play a key role in building sustainable societies (Mahjoub 2012). Some of the main key questions for Tunisian HEI are as follows:

- How the graduate will contribute to achieve sustainable water use, not as SD "specialist" but as a doctor, lawyer, teacher, journalist, chemist, etc.?
- How educational programs will impact the society of the 2050/consequences of the wrong short-sighted approaches and decision of yesterday and today?
- What is the quality and value of educational programs and skills of educators/ how it should be /how to improve it?
- How to shift from theory to specific actions (implementation)?

Furthermore, solid knowledge on science, technology, and economics is needed, but it is not enough. Understanding human behavior, social structures, culture, and cultural differences is critical when it is aimed to reach sustainable development (Scoullos and Malotidi 2005). Tunisia needs to pay attention to social and cultural sustainability. Without doing it, the global investment on environmental and economical sustainability will be lost. The recognition of practices, identity, and values plays a considerable role in setting directions and building commitments. It is important to investigate Tunisian's perceptions toward the environment and to meet with the current perceptions and values before setting up environmental education programs. HEI should contribute to social and cultural sustainability, and from that view point provide awareness, skills, and knowledge to solve the problems of environmental challenges (Mahjoub 2012).

3 Water Strategies and Participatory Approach

Throughout thousands of years, farmers have developed practices that quantitatively serve the agricultural production needs of the local population and at the same time do not harm the environment. These modes of agricultural production and water management are based on traditional knowledge. The latter fits perfectly into the geographic and social context of arid and semiarid areas. Population growth, internationalization of the food market, the use of chemical fertilization as well as the strong environmental pollution by industry and the population have caused tremendous challenges in qualitatively and quantitative water resource management. Consequently, the inherited traditional hydraulic systems, which were originally managed by farmers and the rural society, have obvious problems

with keeping their traditions. They have often been affected by limited financial measures, the lack of technical references, the absence of attendance and up keeping, the disorganization of production units, and the insufficient profitability of the proposed technologies and of the socioeconomic neglects.

The Tunisian water development model that has been carried out since the 1960s did not consider and involve farmers. The state had acted during the last five decades regardless of participation and aspirations of the beneficiaries. The latter left their lands and their traditional ways, hydraulic structures, and know-how management heritage for other sectors (like industry and tourism) (El Amami 1984; Ennabli 1993). This context eventually reproduced many dependencies and has nourished more "spirit of assistance," and introduced some regulation of unemployment and labor market employment in the regions (PNUD-FAO 1991). The state has continued to treat the rural world with a spirit of support aggravating the context of their marginalization and its depletion.

During the past decades, the proliferation of state institutions has prolonged the process that deconstructs, marginalizes, or gets rid of the traditional social institutions, which amounted to the task of organizing, coding, decision making, and participation of the community in the preservation and conservation of natural resources. Consequently, the problem that has arisen today is how to reinitiate an association and implementation of agricultural and rural populations to the imperatives of appropriate water management measures. Especially, agricultural and rural experiences with participatory development approaches are rare. The ones that are available had rather limited success (Jebari and Berndtsson 2013).

The university, society, and policy nexus of sustainable water use and agriculture in semiarid regions.

As outlined above, the socio-environmental system of sustainable water use in Tunisia consists of a diversity of variables that are relevant and of which the interrelations need to be considered by stakeholders, be it on local scale of villages, the national policy scale, or either international development cooperation or UN and global policy scale.

In Fig. 2, 19 core impact variables are presented within a system grid. This system grid is the result of an activity (x-axis) and sensitivity/passivity (y-axis) analysis through which the impact variables have been assessed in the course of an impact matrix. The impact of each of the variables on each other and subsequently their sensitivity of being impacted by one another has been assessed.[1]

In this system grid, 19 indicators provide a holistic picture for the analysis of the sustainable water use in semiarid regions of Tunisia. After assessing the active and passive impact, system variables have on each other (0… no impact, 1 light or indirect impact, 2 strong and direct impacts), results are being transformed from an impact matrix into the shown system grid to demonstrate the variables' role in the system according to their activity and passivity. The activity score results

[1] In the course of a fact finding mission supported by the DAAD, the German academic exchange service, researchers from Germany and Tunisia met in Tunis in December 2013 to analyze the current situation of sustainable water use in agriculture of Tunisia.

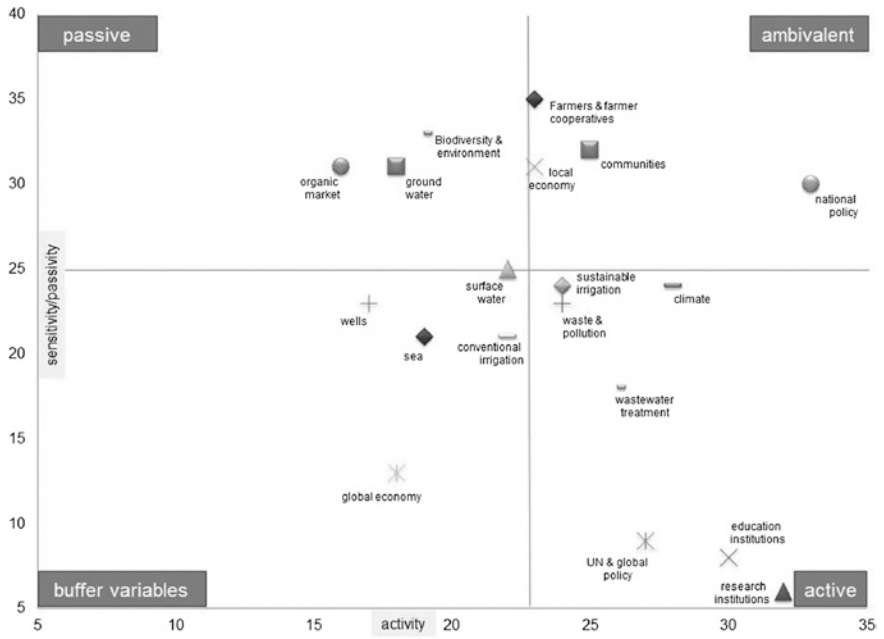

Fig. 2 System grid for sustainable water use in semiarid regions

from the sum of impact points the variable has on other variables. The passivity score results from the sum of impact points other variables have on the variable. According to the system grid, we can define four different groups of variables as they are separated by lines representing the mean activity and sensitivity/passivity scores (activity mean = 23; passivity mean = 25) (Scholz and Tietje 2002).

Ambivalent variables: The variables "national policy," "communities," "farmers," and "local economy" are considered above average in both sensitivity and activity, which places them in the ambivalent quadrant. This analysis demonstrates the strong relevance of those variables. It shows that for any upcoming system relevant actions the role of national policy, the needs, values and experience of communities, farmers as well as the local economy need to be considered, reflected, and involved.

Active variables: The five variables "UN/global policy," "education," "research," "wastewater treatment," "waste and pollution," "climate," and "sustainable irrigation" shown in Fig. 1 are considered above averages in activity and below averages in passivity; they are located in the active quadrant. As a consequence, it needs to be recognized that education, research, and global policy have a strong impact on either ambivalent or passive and buffer variables. Future strategies for sustainable development need to consider their central role for development. Aspects of waste and pollution, wastewater treatment, climate as well as sustainable irrigation have shown a strong impact on the system. Subsequently, their effects need to be considered for future strategies.

Passive variables: In contrast to this, four variables stand in the passive quadrant: "Organic market," "ground water," "surface water," and "biodiversity and environment." If one wants to change the future conditions of ground water, biodiversity, the environment as well as organic markets that contribute to healthy society and living local economy, the ambivalent and active nexus variables of society, education, research, and policy need to work together to develop sustainable innovations.

Buffer variables: Finally, five variables as "global economy," "conventional irrigation," "sea," and "wells" are called buffer variables because they are below average in both, activity and passivity/sensitivity.

Pointing out the impact variables representing the nexus, one experiences from this system grid, that education, research, and UN/global policy have a strong active role in the system and national policy, farmers, local community, and local economy have an ambivalent role which means they are either very active in impacting the whole system or and at the same time have a strong sensitivity by being affected by other variables.

The strong system activity of the nexus variables are education, research, society (farmers and local community) as well as policy (national and global policy/UN), consequently representing leverage points for the whole system of sustainable water use in semiarid regions, taken the representative case of sustainable agriculture and water use in Tunisia.

In the following system graph (Fig. 3), the role of the nexus system variables as leverage points becomes even more obvious:

The system graph (Fig. 3) shows that national policy through, e.g., introducing groundwater injection of treated wastewater has an immediate impact on the ground water (C4) and farmers, but would need to take place in combination with community involvement, research, and educational activities so to have a transformative effect on the whole system. Community needs to be aware on the positive and negative effects this technology accompanies. Surely, groundwater injection on the one hand may stabilize the ground water level on a very local scale, but on the other hand likely contaminates the aquifer with micro-pollutants as well as with high level of nitrate and microorganisms. So its consequences on the environment, soil fertility, quality of food, the biodiversity, and the community are hardly predictable. Through involvement of all nexus "parties," the challenge can be analyzed systematically and alternative solutions can be developed that tackle and transform the whole system toward sustainability.

In the nexus of education, research, policy, and society, the role of education and research is to reflect societal (in this case: community and farmers) needs, to take up experiences and knowledge that exist in the society, and that might almost have been forgotten (traditional knowledge) in research. This cocreative and transformative approach is called transdisciplinary research and education (Pohl 2008). Together with policy and society, transdisciplinary education and research build the sustainability nexus and contributes to the development of transformative solutions. Those solutions have long-term perspectives and are developed through

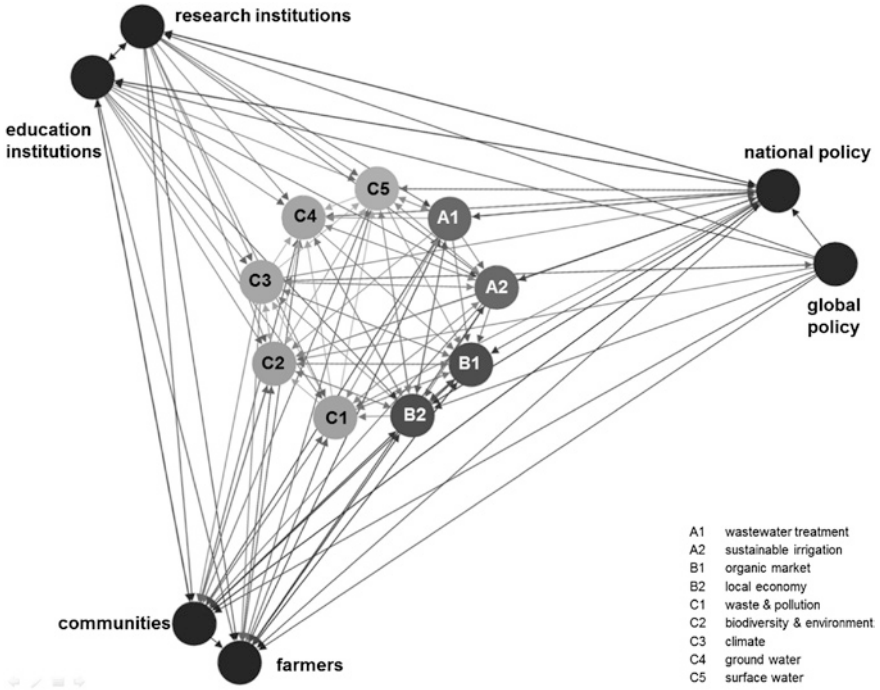

Fig. 3 System graph of education, research, society, and policy nexus in sustainable water use and agriculture in semiarid regions (own figure)

shared visions, responsibility, and agency. Society, policy, education, and research as well as economy need to change behavior and to become aware of the impacts their habits have.

Transformation toward sustainable development implies a shared system understanding, vision for the future, and agency for ones own responsibility, being part of the system (Mader et al. 2013). It is the policy responsibility to establish the necessary frameworks, so capabilities for education and research institutions as well as the society are available to take and to support agency of each individual and collective. Those necessary frameworks might be for example to implement global policy recommendations and programs like the UN Decade on ESD. It is not a coincidence that the UN has promoted the years of 2005–2014 as a decade on ESD and will follow this strategy in the course of the global action program on ESD with the aim of embedding sustainability competences into the scopes of all formal and nonformal educational institutions (UNESCO 2013). Through ESD, embedded from kindergarten up to universities and lifelong learning facilities, learners from all ages may acquire the necessary competences to take agency for sustainable development. This again implies system understanding as well as future envisioning, and reflective agency in multi-stakeholder environments (UNECE 2012).

4 Case Study: Combining Traditional Farmers Knowledge, Research, and Policy for Sustainable Development

Traditional knowledge is nothing else than techniques and practices that passed on through generations. It considers appropriate use of natural resources, allows protecting ecosystems, and plans sustainable agriculture. It was shown that innovative solutions can be driven from this indigenous know how. It is a dynamic knowledge that has always been able to renew and to adapt itself allowing societies to produce for the long-term benefit of the community while managing resources and environment in balance (UN 1992; in Agenda 21).

The World Bank promotes traditional knowledge as advanced innovative techniques appropriate to enhance local resources, to support diversity, and to promote human creativity. Based on research, several international organizations (e.g., UN, FAO, UNCCD, UNESCO, UNEP, and OECD) have confirmed the validity of the traditional knowledge and recognized its contribution to science and technology (TKWB 2007). Nowadays, most NGO's promote traditional knowledge as a new approach to international development and cooperation.

During hundreds of years, indigenous Tunisian people have traditionally harvested water and grown crops on sloping mountain valleys and harsh dry lands. They acquired and continuously developed innovative techniques and systems for efficient small-scale water management. These systems that are called nowadays water harvesting techniques and traditional hydraulic systems are scattered throughout Tunisia and have different shapes and specific characteristics according to the bioclimatic prerequisites (El Amami 1984).

Research efforts on better use of traditional hydraulic systems started from the 1960s at the CRGR (Research Center for Rural Engineering, currently the National Research Institute for Rural Engineering, Water and Forestry: INRGREF). Their impact on runoff, infiltration, and soil loss characterized the 1970s period through an experimental program investigating specific techniques. Recent and ongoing modeling work aims at defining the role of different hydraulic systems in providing blue and green water[2] for improved agricultural productivity to ensure sustainable rural development. The output of the latter research is crucial for setting suitable future water resources strategies (Jebari et al. 2014). In fact, the Tunisian authority that has based water development sector on mobilization policy and projects through large reservoirs is nowadays facing serious problems in managing limited water resources at regional scale. All the observed difficulties seem to be the consequences related to the absence of balanced hydraulic schemes at catchment level during the last five decades. In fact,

[2] Blue water: the fraction of water that reaches rivers directly as runoff or, indirectly, through deep drainage to groundwater and stream base flow.
Green water: is that fraction of rainfall that infiltrates into the soil and is available to plants.

considering simultaneously the large hydraulic projects managed by the state and the water harvesting techniques, which are in the responsibility of the farmers, would have certainly created a more sustainable agricultural context, less vulnerable rural society, and better availability of the water resources. Finally, combining modern and traditional hydraulic knowledge is becoming crucial to ensure a sound development (Berndtsson et al. 2014).

In Tunisia as well as in other semiarid regions, tackling the challenge of increasing water use in growing agriculture and increasingly polluted environments, people from all backgrounds need to learn to take responsibility while responding on others' values and perspectives.

5 Conclusions

Facing the challenges of population growth, environmental pollution, salinization of agricultural lands, increasing water scarcity, and climate change, Tunisia has to tackle huge challenges in the future. Immediate actions are required to prevent further noninverting damages to the natural resources of Tunisia. The paper has shown that such as actions need to be considered through cocreation of the whole nexus of education, research, society, and policy. And, only if this nexus works together on sustainable solutions, the growing problem of water scarcity can be tackled.

Future prospects:

Implementation of ESD in all formal and nonformal learning environments supports the establishment of a holistic system understanding of the individual and collective impact on the quality and quantity of water resources. ESD transforms the behavior of people toward a more conscious interaction with the natural resource of water and the environment. The consequences would be less environmental pollution and a reduction of water consumption through the use of, e.g., sustainable irrigation systems in agriculture and reduction of pollution through industry.

Research needs to adopt *transdisciplinary methods* to work together with society in the development of solutions and innovations for sustainable agriculture and sustainable water use.

Society including farmers, local economy, and communities need to *strengthen the market of sustainable agriculture*. Transparency in production, communicating the negative impacts of fertilizers on ground water as well as promoting the production and consumption of organic food, irrigated through sustainable systems could cause mind shifts among the community toward more conscious consumption as well as open up new business opportunities for farmers and the local economy competing the global market.

Policy needs to provide the adequate legal framework to enable education institutions, research, farmers, and community to make use of their capabilities in becoming agents for change toward sustainable development. Those requirements include the following:

- The development of a national ESD strategy reflecting the national sustainability challenges as mentioned above.
- Adopting quality criteria of research and incentivize transdisciplinary water research and higher education.
- Establishing legal frameworks to limit pollution by industry, farmers as well as citizen and incentivize organic production and sustainable irrigation modes, so society and farmers get easier access to sustainable products.

Finally, it is the responsibility of each individual to change the perspective from short term to long term and from problem orientation to system orientation to balance the human, economic, and environmental development of the country.

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