Sustainable Irrigated Agriculture

Subjects: Agriculture, Dairy & Animal Science
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The picture shows the water distribution in a gravity based water distribution of a large irrigation scheme fore sugar cane in Ethiopia.

Keywords: irrigation ; sustainable development ; agricultural water management ; integrated water management

1. Introduction

The natural resources soil and water are under increasing pressure worldwide; therefore, the protection of the natural environment must have the highest priority in order to secure adequate food for all and enable sufficient income and living conditions for ensuing generations. Global change impacts are radical with enormous implications. Megatrends like climate change, population growth, urbanization and resource-use conflicts are long-term and intertwined transformation processes that change the lives and livelihoods of people around the world. These trends are not neutral; they cause and contribute to global food price, energy, and fiscal crises. New economic, social, and ecological dynamics tremendously increase the hardships of the vulnerable and the poor [1]. In order to achieve sufficient agricultural production, humankind is interfering in many ways with the natural setting; hence conflicts of resource utilization are present or emerging. A strong partnership amongst all stakeholders is required to confront this. Decision makers (policies) and users (farmers, communities) have to respect each other equally.

Soon after humankind settled and started farming, irrigation appeared as well. During the long period since then, various irrigation methods have been developed and have reached a sophisticated level, especially in terms of technical performance and water applications with respect to plant water requirement. This irrigation development was accompanied by both successes and failures, as is documented by many authors. One of the famous river basins with a long tradition of irrigation lies in the area that was once ancient Mesopotamia. A compilation of information on Mesopotamia—home of irrigation culture—is provided in [2]. In Mesopotamia, irrigation systems were established according to a plan for the first time and a work force was responsible for maintaining the system. However, it has been concluded that the irrigated agriculture of the early Mesopotamian civilisation failed due to salt accumulation from irrigation leading to a degradation of fertile land. Mesopotamia is by far the most classical example of glory and decline and today still remains under various stresses. This was also acknowledged in a well-documented study of the Karkheh River Basin, as part of this region, describing historical water development and use from the time of ancient Mesopotamia to third millennium Iran. By performing a trajectory study, Marjanizadeh [3] concluded that: "*The Karkheh river basin has been a cradle of civilization for more than 3000 years and has experienced several periods of agrarian development based on settled agriculture and the development of irrigation from the river."* The Karkheh River Basin has recently seen extensive development and exploitation of its water resources, leading to severe consequences for the remnants of the internationally renowned Mesopotamian Marshes. A very enlightening compendium of societal development related to climatic changes, resources overuse, and social issues is provided by Diamonds [4]. He analysed worldwide historic developments to judge why some societies have survived and why others have not. It is interesting to note that, especially in northern parts of Europe, the focus in melioration was primarily on drainage and soil water management. This history of melioration in central European countries was elaborated by Kastanek [5]; he named Dünkelberg as a leading pioneer due to his work introducing new agricultural techniques to farmers [6]. Due to the increase of droughts, irrigation has also become more important even in regions where water was considered an ample resource.

To record human-induced changes, new technologies like satellite images have become a direct and invaluable tool for documenting information about spatial development over time, e.g., the change in size of different wetlands. For example, Müller [7] presented satellite images of Lake Aral (including a video animation of the changes from 2000 to 2011, with reference to the shore boundaries of 1960) to visualize its drastic reduction in size. show its drastic reduction in size. What was in the 1960s the fourth largest lake in the world has been reduced to a marginal size due to water withdrawal from the tributaries for irrigation of huge cotton fields in Kazakhstan and Uzbekistan [8]. Nevertheless, the demand of irrigated areas is still growing. The global irrigated area (Figure 1) increased between 1995 and 2018 by more than 40%, from 2,571,753 km^2 [9][10] to 3,670,000 km^2 [11]; this is approximately 2% of the total geographical area of the world or 18% of the arable and permanent cropping area.

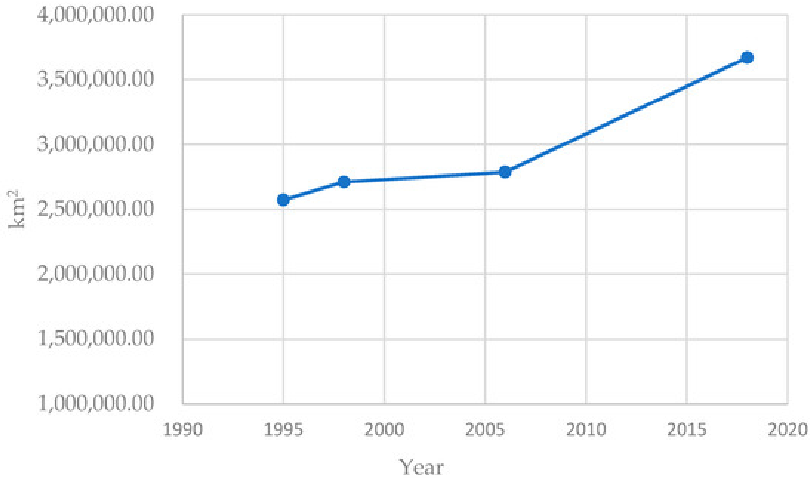

Figure 1. Development of global irrigated area; adapted from [9][10][11].

A few selected cases are presented here to demonstrate the bias of human developments but could be extended with many more. Here they serve to raise awareness that any intervention has to be undertaken with specific care and in accordance with sustainable development—as required by the EU Sustainable Development Goals (SDGs) [12]. Hence, modern irrigation interventions and management need a sophisticated holistic approach.

2. Aspects of Local and Societal Conditions of Irrigation

2.1. Integrated Water Use Analyses

With the development of societies (in numbers and in welfare), the demand for water increased accordingly; hence integrated water resources management (IWRM) is needed [13][14][15]). IWMR is a water policy framework mostly applied on a river basin spatial scale. The use of water for irrigation has very well-known figures: it counts for approximately 70% of global freshwater withdrawal and moreover 85% of consumptive water use is for irrigation. According to the FAO, irrigated agriculture produces 40% of the world's food [16].

It is obvious that to obtain water security at a catchment (river basin) level, a legal stewardship is needed. For instance, the EU-WFD (EU Water Framework Directive—integrated river basin management for Europe) provides a single uniform system of water management for river basins according to natural hydrology and geography [17].

Natural systems are not market-conformed or short-term oriented. Changes occur over long time periods and may be gradual or abrupt, by shocks. Short-term benefits should be dropped in favour of the interests of future generations. This is especially needed when we discuss water management and interventions in any ecosystem in general.

We have the tools to analyse and even forecast the development status of a catchment. Trajectory [18] and water accounting studies [19] describe the course of water utilization in the past, telling us why the situation is like it is at the present stage. Building on this knowledge, a sensitivity analysis of different scenarios may lead to an insight into how a specific decision will most likely affect future development. At the beginning of water resource exploitation, water use is at low level and the potential of development is high (Figure 2). Water allocation is not limited by natural resources. The utilization stage is characterised by interventions in the infrastructure (dams, reservoirs, pumping stations, etc.). Finally, when the water resources are fully committed and the potentially available limit is approached, the allocation stage is reached (Figure 2). It is important to set a threshold value, mainly to take into account reductions of the potentiality of the water resource due to climate change impacts.

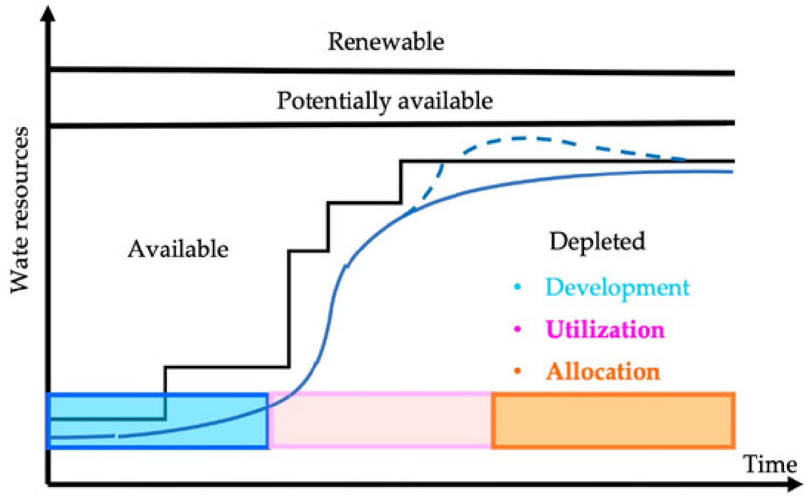

Figure 2. Stages of river basin development (adapted from Molle 2007 [18]). Stepped are e.g., date on certain years, blue is a smoothed function and dashed is an alternative option of water utilization.

Most important is the water utilization with respect to basin closure. In a closed basin, water resources are fully committed to existing uses and all users and uses are interconnected through the hydrological cycle. Further supply augmentation is no longer possible without impacting existing uses. The scale for such analyses is mainly the catchment or river basin. Appropriate monitoring must be performed to avoid overexploitation of potential available water resources (Figure 2). In the opinion of the authors, a proper water potential analysis is indispensable for any irrigation intervention, especially in view of sustainability.

2.2. System-Oriented Characteristics of Irrigation

Irrigation systems are sociotechnical systems [14][20] embedded in a given natural and economic setting. Special focus should be given to the coordinated interaction of the two components. This is particularly important for irrigation systems, since the “technical” infrastructure of dams, canals, and distribution facilities is often given more attention than the “social” infrastructure represented by institutions (water users) [21].

According to the system orientation characteristics, two features may be highlighted:

- Target-oriented: irrigation systems are used—like all sociotechnical systems—for the provision of certain products or services. The selection of products and services is based on the objectives and interests of those individuals and groups that have influence on the management of the irrigation system.
- Environmentally open: irrigation systems can be characterized as open systems, since the required processes of resource/service provision and resource transformation must take place in close exchange with the environment.

Natural environmental parameters are determined by the Soil–Plant–Atmosphere Continuum (SPAC); more specifically, for irrigation, the crop water requirement (CWR) and hydrological conditions. The other factors are linked to irrigation management. In this frame all components contribute to the success of an irrigation intervention. The weight of the factors may vary according to local conditions.

Related questions to be assessed concerning local and societal conditions include:

- Economic aspects: is an investment beneficial to the prosperity of a community? What economic value is provided in general?
- Irrigation techniques: what techniques are appropriate for a given local setting? How effective is the management structure (both irrigation systems and irrigation management, e.g., decision support tools)? Do the water use efficiency (WUE) and water productivity (WP) match the available resources?
- Sociocultural aspects: what are the consequences of an irrigation intervention for a community? Is there willingness and ability among farmers to introduce new technologies?
- Ecological requirements: what are the environmental flow conditions (e.g., minimal required discharge in a river)? What environmental services in a catchment have to be maintained?

- Administrative aspects: what authorities or institutions are in charge of water distribution and control at the time of investigation? Do water boards exist?

- Legal aspects: what water rights exist? Who possesses ownership of the land? What general legislation exists? What is the status of land ownership?

The different aspects are not only related to the given natural conditions but also directly linked to each other, e.g., economic and technological aspects due to the availability of devices. Ecological and legal aspects are interconnected by water availability, water quality and other facets, as well as being connected to sociocultural conditions. Administration is mainly driven by legal and sociocultural conditions.

Each specific setting has its own dominant requirements, conditions and interferences. To address these aspects at a country level, the water resources and irrigation development in Ethiopia were assessed [22]. The results of this project "Impact of Irrigation on Poverty and Environment" provide a general overview of water resources, a database of irrigation, the utilizable potential of irrigation, and an environmental and health impact assessment [22]. The implementation was done by the International Water Management Institute (IWMI) and the University of Natural Resources and Life Sciences, Vienna (BOKU), Austria, in collaboration with other Ethiopian and Austrian institutions.

2.3. Irrigation Management—Resource Utilization

Irrigation management based on an integrated approach aims to quantify available resources and identify potential uses and users, as well as environmental needs. Managing water for agriculture covers a spectrum from rainfed to irrigated systems—or, in other terms, green and blue water [14]. Such management defines whether full or supplementary irrigation is needed for a given area.

The guiding principles of irrigation management can be summarized as follows:

- integrated management of water resources;
- improvement and safeguarding of water access;
- ensuring evidence-based water policy and management;
- understanding of the interaction of agriculture with the ecosystem;
- inclusion of all stakeholders and provision of transparent decisions;
- improvement of livelihoods and gender equality as pathways to poverty reduction.

Irrigation management has to acknowledge the fact that, due to climate change and overuse, water resources are gradually depleting, soil water storage has been reduced, and soil degradation—due to reduced vegetation cover and secondary salinization—has been increased. To combat soil and land degradation, in many cases traditional or abandoned knowledge can be reintegrated into the relevant society, this being valid for traditional irrigation as well as for rainfed agriculture. Unsuitable land management and cultivation practices combined with climate change lead to a vicious cycle of water scarcity and soil degradation. Under physical water scarcity scenarios—as highlighted in various global studies and assessments [23][24]—and in arid areas, water resources, soil water storage, and water for productive use are naturally limited. Management of these resources, which have a direct impact on soil conditions and microclimates, is of utmost importance if this downward spiral is to be stopped or even reversed. For the Njoro River catchment in Kenya, the interactions between land use/land cover and climate change were analysed to quantify the impact on the local hydrological conditions. The study was performed using SWAT2005 (Soil Water Assessment Tool) [25]. Greater impact was found to result from deforestation than overall climate change at the time of investigation. The results provide the basis for strategies of adaption to the changing environmental conditions.

Water scarcity forces on-farm conservation practices, like storing water above ground or in soil, and alternative ways of water utilization. Irrigation water is deployed for multiple uses—e.g., for fisheries—in many countries in Africa [26]. The reuse of waste water is another water source which may become even more important in the future [27]. Irrigation increases the salt content of soils and it is estimated that about 25% to 30% of irrigated land is affected by this [28]. For salt-affected soils, specific management is required [29]. On the other hand, water scarcity also triggers discussions about the use of water of poorer quality and in particular has led to a discussion of so-called saline agriculture. Especially in countries with a high population growth rate and/or severe rates of soil degradation, the use of brackish water could substantially contribute to food security and poverty reduction [30]. Montague [31] estimated a doubling of available water for agriculture if all of the world's brackish water were used for irrigation.

Finally, irrigation management is—besides its roles in handling water utilization, allocation, conservation, maintenance, etc.—strongly linked to conflict avoidance and resolution. Conflicts start with a contradiction, e.g., competition for water in an irrigation system or inefficient water distribution, both of which have a strong impact on farmers. Attitudes determine the visible behaviours of farmers and communities. An attitude covers the thoughts, feelings and centres of perception of a rural community [32] in response to the consensus of farmers and management with regard to allocation and distribution of water. The system of canals and structures should be clearly understood by the farmer community. Behaviour summarizes the visible components of a conflict; in the worst cases this can include destructive actions, like destruction of infrastructure, denial of allocation, and so on. Well-managed farmer associations result in constructive cooperation amongst members.

Galtung [33] presented the social conflict factors—behaviour, contradiction and attitude—in a triangle (Figure 3) to distinguish the visible and invisible components. Like an iceberg, most contributions to conflicts are invisible.

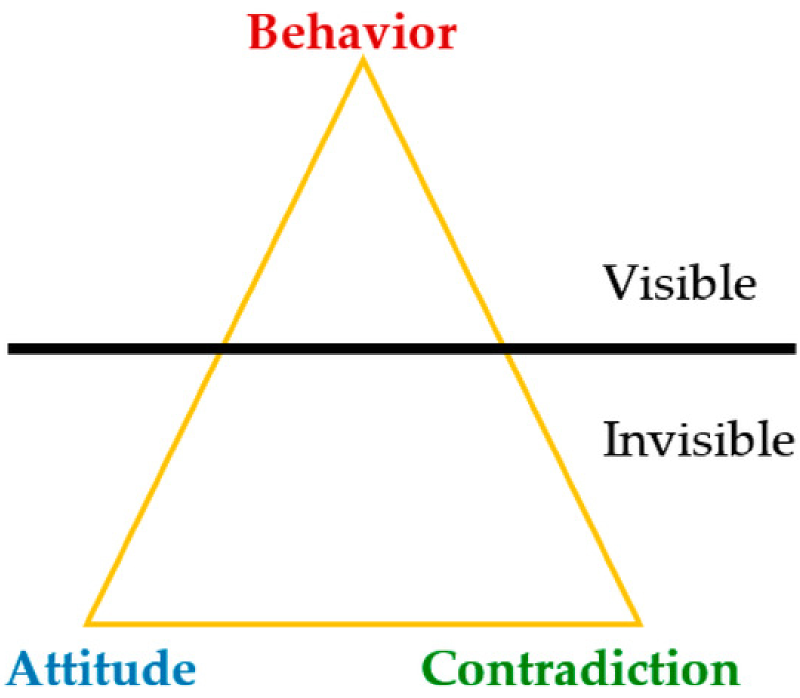

Figure 3. Conflict triangle according to Galtung [34].

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