Agricultural Water Management 210 (2018) 286–295

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

A participatory design approach for modernization of spate irrigation systems

Giulio Castelli[a,*], Elena Bresci[a], Fabio Castelli[b], Eyasu Yazew Hagos[c], Abraham Mehari[d]

[a] Department of Agricultural, Food and Forestry Systems, University of Florence, Via San Bonaventura, 13, 50145, Florence, Italy
[b] Department of Civil and Environmental Engineering, University of Florence, Via di S. Marta, 3, 50139 Firenze, Italy
[c] Institute of Water and Environment, Mekelle University, P.O. Box 231, Mekelle, Ethiopia
[d] MetaMeta Research, Postelstraat 2, 5211 EA's Hertogenbosch, The Netherlands

ARTICLE INFO

Keywords:
Participatory design
Participatory rural appraisal
Ethiopia
Gabions
Diversion headworks

ABSTRACT

Spate Irrigation represents the main source of livelihood for rural population of many communities living in arid and semi-arid areas of the world. The area of Raya Valley (Ethiopia), is one such example that is used here to analyse the importance of participatory approach in making this irrigation technique sustainable, effective and durable. Spate irrigation development projects realised in Raya Valley during the last twenty years led to a partial failure, due to the low involvement of local farmers who have experience of the local environment and who have been practising the techniques from centuries. This paper describes the implementation of a participatory methodology, based on the integration of Participatory Rural Appraisal and Participatory Design, for the design of effective improvements in a traditional spate irrigation system in Raya Valley. Water is harvested from seasonal floods of wadis (ephemeral rivers) using diversion bunds made by local materials or concrete. Farmers' participation allowed to defining gabions as a suitable solution and to realise a technical design of improved structures. The design of an improved diversion structure and a gabion wall against bank erosion was completed. The structures resulted in line with operation and maintenance strategy and with traditional spate irrigation management. New insights from local farmers knowledge, to be considered for future spate irrigation development projects, are analysed and presented.

1. Introduction

Spateirrigation is an ancient and complex form of water management, based on the diversion of water flows from ephemeral rivers located in arid areas (wadis). The so-called 'spate' flows are produced in the mountainous zones of wadi catchments by intense and scattered precipitation and are deviated to irrigated areas by using artificial earthen bunds, built within the river bed. The technique was originally born in Yemen around five thousand years ago. Today, it covers around 3 million hectares of irrigated land around the world, in areas distributed in arid and semi-arid zone of Near East, Africa, South and Central Asia and Latin America (Ghebremariam and Van Steenbergen, 2007; Mehari et al., 2005b; Tesfai and Stroosnijder, 2001; Van Steenbergen et al., 2010; Zimmerer, 2011). In these contexts, spate irrigation is the most important source of water available for food production and represent one of the main sources of livelihood for the poorest part of rural population (Hagos et al., 2014b; Komakech et al., 2011; Van Steenbergen et al., 2010). Differently from irrigation systems on perennial rivers, that are working by abstracting a moderate amount of water from a river where discharge is always present, spate irrigation systems relies on episodic and intense rainfall that generate occasional and violent flows within dry river beds (Komakech et al., 2011). The spate flows are characterized by a high degree of unpredictability (Ghebremariam and Van Steenbergen, 2007; Van Steenbergen, 1997) and by an exceptional sediment load (Embaye et al., 2012; Van Steenbergen et al., 2010).

Communities dependant on spate systems have developed consistent knowledge of wadi systems and management strategies appropriated to these unpredictable flows and extreme conditions (Castelli and Bresci, 2017; Mehari et al., 2007, 2005b; Van Steenbergen, 1997). On the other hand, spate irrigation, despite its relevance for rural livelihoods and food security in arid wadi catchments, has not received the same attention of perennial irrigation by scholars, development agencies and local governments (Komakech et al., 2011; Mehari et al.,

* Corresponding author.
E-mail addresses: giulio.castelli@unifi.it (G. Castelli), elena.bresci@unifi.it (E. Bresci), fabio.castelli@unifi.it (F. Castelli), eyasu.yazew@mu.edu.et (E.Y. Hagos), ameharihaile@metameta.nl (A. Mehari).

https://doi.org/10.1016/j.agwat.2018.08.030
Received 8 October 2017; Received in revised form 10 August 2018; Accepted 21 August 2018

List of symbols

A	Catchment area (m)
a	Width of the pier/bund (m)
d_{gab}	Mean diameter for stones filling the gabion
ELEV	Mean catchment elevation (m)
f	Full discharge factor
G_t	Growth factor for return period t
K_1	Correction coefficient which takes into account the shape of the pier/bund
K_2	Correction coefficient for the angle of attack of the flow
K_3	Correction coefficient for evaluating bed conditions
K_4	Correction factor for the size of bed material, which was calculated considering a d_{50} of 1.06 mm from the bed material analysis
L1	Width of northern branch (left)
L2	Width of southern branch (right)
MAF	Mean Annual Flood peak discharge
MAP	Mean annual precipitation (mm) for the period 1996–2012.
MSL	Main Stream Length (km)
n	Manning's roughness coefficient
P(y)	Cross section wetted perimeter, as a function of flow depth (y)
Q	Discharge calculated with slope-area method
Q_t	Discharge for return period t
Q^*	Full catchment discharge
Q^*_{max}	Full catchment discharge for the maximum discharge within living memory
Q^*_y	Full catchment discharge from the average of the maximum yearly levels within living memory
Q_{max}	Left branch discharge for the maximum discharge within living memory, calculated with slope-area method
Q_y	Left branch discharge from the average of the maximum yearly levels within living memory, calculated with slope-area method
S	Slope of the channel
SFs	Safety factor for local scour
SFτ	Safety factor for lateral drag
s	Local scour (m)
y	The flow depth (m)
γ_s	Stones specific weight
γ_w	Water specific weight (N/m^3)
θ_{gab}	Shields parameter for stones within a gabion
χ_{def}	Corrective coefficient
Ω (y)	Cross section wetted area, as a function of flow depth (y)

2007; Van Steenbergen, 1997).

Taking the arid parts of the Ethiopia as a typical example of the above extreme conditions, spate irrigation has been practiced from generations and represents a fundamental resource for rural livelihoods (Van Steenbergen et al., 2011). In the zone of Raya Valley, a dryland plateau bordered by mountains, located in the south of Tigray region, Spate Irrigation has been practiced from centuries. In the last two decades, the government of the region has made strong efforts for the modernisation of spate irrigated agriculture in the area (Kidane, 2009; Van Steenbergen et al., 2011). The modernisation process, based on the design criteria of irrigation systems for perennial rivers, resulted in disappointing outcomes. As indicated by the report of the Flood Based Livelihood Network Foundation (2016) the average efficiency of spate schemes modernised with the perennial river approach was about 9%, with 7 system out of 11 analysed that have completely failed.

In the traditional spate systems of Raya Valley, local rules and regulations allow to manage the unpredictability of spate flows. Traditional spate systems include multiple diversion structures made by local materials allowing to distribute risk and benefits, and not to be dependent on the operating conditions of a single structure. Farmers have the technical capabilities to reconstruct damaged diversions and to operate maintenance to have the system ready at the beginning of each flow event. According to Hagos et al. (2014a), local farmers have developed considerable technical skills in the use of seasonal flows for productive purposes, and they have developed well-structured irrigation rules, appropriated to the environmental context and perceived as fair by local communities. As a matter of fact most of modernised irrigation system of Raya Valley have failed or have been modified autonomously by local farmers for being operative, and traditional spate systems are still functioning and represent the very source of water for local farmers (Hagos et al., 2014a).

The main reason leading to the unsuitability of the modernisation process has been the lack of involvement of beneficiary farmers. Their technical knowledge, institutional agreements and management operations have never been implemented in spate irrigation modernisation and planning. This resulted in a reduced knowledge base for technical design, a lower participation of the farmers, lower sense of ownership of the modernised structures (Embaye et al., 2013; Hagos et al., 2014a; Kidane, 2009). Recently, three new schemes (Oda, Mersa and Guguf) have been constructed with hybrid diversion intakes. Hybrid intakes have been realised by considering the opinion of local farmers, and a first assessment of hybridized system efficiency, defined as the ratio between the actual command area and the command area planned in the design phase, showed an average value of 88% for 2016, confirming the promising adoption of mixed traditional-modernised solutions. However, efficiency analysis has been realised only for one year and there is a need of new insights for increasing the body of knowledge supporting spate irrigation development and management (Flood Based Livelihood Network Foundation, 2016).

Thus, the aim of this work has been to select and design effective improvements in spate irrigation systems with a participatory approach. The study was carried out in the traditional spate system of Harosha (Tigray region). A participatory methodology was realised by the integration of Participatory Rural Appraisal techniques and Participatory Design methodology. A participatory analysis of the problems of the scheme was realised, problems were ranked and suitable solutions were designed.

2. Evolution of spate irrigation in Raya Valley

The first modernised spate system in Raya Valley was Hara system, realised in 1998, followed by Tirke system in 2004. The design of both systems was based on the conventional approach for perennial rivers, neglecting the characteristics of spate flows. Diversion structures were realised with diversion weirs, closed intakes and works in concrete masonry, while the canal system was equipped with modern water distribution structures, canals and pipes street crossings (Embaye et al., 2013; Flood Based Livelihood Network Foundation, 2016). These systems became completely unused after the first rainy season due to the complete siltation of the system, as designers didn't take into account the exceptional sediment load of wadi catchments (Libsekal et al., 2015). After the failure of modernised structures, farmers in Hara began to divert water with traditional diversion structures located upstream, but in 2010 the entire scheme stopped functioning (Kidane, 2009; Mehari et al., 2013).

New spate irrigation schemes were built in Fokisa, Beryu and Burka in 2005 trying a different approach. Farmers were consulted about their knowledge and their preferences, but their involvement in the design was limited to the choice of the diversion angle and the off-take type. Following farmers' indications, the main changes in design from Hara