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REMOTE SENSING FOR WATER PRODUCTIVITY

TECHNICAL REPORT: CAPACITY DEVELOPMENT SERIES

Implementation of on-farm water management solutions to increase water productivity in Ethiopia

International Water
Management Institute

Technical Report: capacity development series

Implementation of on-farm water management solutions to increase water productivity in Ethiopia

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Acronyms and abbreviations

CV	coefficient of variation
DAP	Diammonium phosphate (fertilizer)
ET	Evapotranspiration
FC	field capacity
GBWP	gross biomass water productivity
ha	hectares
ICT	information and communication technologies
IWMI	International Water Management Institute
kPA	kilopascal
LED	light emitting diode (on the sensors and detectors)
MCM	million cubic meters
Mm3	millions of cubic meters
mm	millimetres
NGO	non-governmental organisations
N	nitrogen
NPP	net primary production
OM	organic matter
P	phosphorus
P	precipitation
PWP	permanent wilting point
QC	quaternary canals
SD	standard deviation
TC	tertiary canals
T	transpiration
WaPOR	the FAO portal to monitor WAter Productivity through Open access of Remotely sensed derived data
WFD	wetting front detectors
WUG	water user groups

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1. Introduction

Given the scarcity of land and water resources, global strategies to increase food production should focus efforts on increasing production per unit resources, i.e. the combined increase of production per unit land surface (yield expressed in kg/ha1) and the increase of production per unit water used (water productivity expressed in kg/m^3). Improving land and water productivity is a complex task which requires: (i) monitoring of current levels of productivity in various crop production systems; (ii) assessment of observed productivity relative to potential; (iii) identification and analysis of the underlying causes of the productivity gaps; and (iv) evaluation of options and identification of viable solutions to close the productivity gaps in the local context.

To support these processes, the WaPOR project (http://www.fao.org/in-action/remote-sensing-for-water-productivity/en/) is applying and analysing high resolution satellite images in conjunction with specific algorithms to determine spatial and temporal variability of agricultural water and land productivity. Through the project activities, a validated remote sensing based methodological framework has been created to assess and monitor land and, more specifically, water productivity. The provision of near real time information through an open access data portal enables a range of service-providers to assist farmers attain more reliable yields and to improve their livelihoods; irrigation operators have access to new information to assess the performance of systems and to identify where to focus investments to modernize the irrigation schemes; and government agencies are able to use the information to monitor and promote the efficient use of natural resources.

The International Water Management Institute (IWMI) is implementing Component 4 of the project to meet the objective of improving the capacity of the direct beneficiaries to improve water productivity in both rain-fed and irrigated systems in a sustainable manner, through the WaPOR database (link) and the development of locally relevant interventions. The direct beneficiaries include: (i) national institutions involved with ICT services for water and agriculture as well as NGOs and the private sector; (ii) water user associations and extension services, irrigation authorities; and (iii) the farmers themselves. The capacity development program has been targeted at individual sites, and these pilot activities will generate lessons, good practices and learning materials that will enable replication and out-scaling in other areas and countries.

The implementation of the Component 4 activities is guided by three key objectives:

Objective 1	*Identify relevant stakeholders and undertake stakeholder needs assessment*
Objective 2	*Identify current activities for ICT and other solutions in agricultural water management and undertake capacity building with identified partners*
Objective 3	*Develop, design, pilot, and evaluate potential solutions to increase water productivity sustainably*

This Technical Report addresses Objective 3, for the Koga irrigation scheme in Ethiopia, where activities have built on ongoing and past work undertaken by IWMI and have focused on the implementation of locally appropriate solutions to build capacity to improve water productivity at the scheme level.

1.1 Improving water use in irrigated agriculture

Intensification of rainfed agriculture through irrigation is seen as one of the key agricultural economic development pathways within Sub-Saharan Africa (SSA) in a response to climate adaptation whilst meeting the growing food demand (African Union, 2020). In countries like Ethiopia irrigation development is tackled through irrigation solutions for individual smallholders (e.g. motorized fuel and solar pumps) as well as the rehabilitation or development of medium and large irrigation schemes. However, in both cases less attention is paid to on-farm water management once irrigation is introduced.

Sub-optimal management of irrigation water in irrigation schemes frequently leads to actual irrigated land being far below the designed command area. This results in a low return on public investment and reduced impact on farm livelihoods as irrigators being relatively ‘new’ to irrigation grapple to translate their water and nutrient inputs into optimal yields. This results in higher input costs, low returns on investment and on-farm water productivity, soil degradation (through leaching), over withdrawal of water resources and contamination of water resources downstream. Access to climate or soil moisture information could reduce both on-site and off-site impacts of irrigated agriculture as it aids in improving irrigation decision making, both in terms of timing and amount of water reducing probabilities of over-irrigation.

Providing useful in-situ information to guide irrigation applications has been of interest in many parts of the world. Remote sensing data are increasingly being applied at the scheme to field level to guide irrigation management decisions, and can help monitor water productivity in an objective and cost effective way. In-field sensors and prediction models (i.e. both climate and crop models) are also typically used to determine crop water demand in the field. With the rapid advances in ICT technology and artificial intelligence a variety of high-tech platforms have been developed using single or a combination of aforementioned technologies. However, these products mainly serve farmers in highly developed countries given its cost, complexity and demand for data and a good network coverage. Hence, in developing countries suitable information systems are either insufficiently grounded into local socio-economic and agricultural contexts, too expensive and/or complex for smallholder farmers or not able to function under a sparse network coverage. Furthermore, there is likely a trade-off between investments in high precision irrigation information and incremental gains from the technologies in smallholder public funded irrigation schemes. Earlier small-scale field trials using low cost technologies such as the wetting front detector showed potential in improving irrigation practices and wheat and vegetable productivity under different irrigation systems (Schmitter *et al.* (2017), Taye *et al.* (2017) and Schmitter *et al.* (2018)).

By combining analysis of the remote sensing-based water productivity parameters provided through the WaPOR portal, with the application of these in situ technologies, the study reported here provides a blueprint for scheme level water productivity diagnostics, targeting of interventions, and application of low cost, capacity building solutions to improve water productivity at the both the Water User Group (WUG) and irrigation scheme level which can be upscaled in Ethiopia and elsewhere.

2. Project objectives

The activities reported here were undertaken in order to characterize the status of water use and productivity in the Koga irrigation scheme through use of the WaPOR database, and to explore to what extent low cost tools and irrigation information supported farmers in improving their irrigation practices leading to improved crop and water productivity across the scheme. Activities were designed on the basis that changes in crop water productivity can be achieved in smallholder fields through two entry points:

1) Reduction in water either consumed or applied during the irrigation season;
2) Increased yield due to improved irrigation practices and/or enhanced fertilizer use efficiency.

Hence, the effect of interventions might influence on-farm water productivity in different ways. For example, if the first objective is met but the second objective is maintained at the status quo, or vice versa, the crop water productivity in the field increases. However, if the second objective proportionally increases in relation to the first objective, the crop water productivity increases could be negligible.

Against this background the project objectives were to:

1) Investigate the use of the WaPOR database to characterise scheme level water productivity and target project interventions to improve water productivity;
2) Use low-cost irrigation tools to building farmer capacity and improve irrigation practices;
3) Determine whether farmers were able to improve their irrigation practices by receiving the information without access to the tool;
4) Evaluate the effect of the interventions on crop and water productivity;
5) Identify opportunities and challenges for smallholder farmers in the use of irrigation scheduling tools and/or access to information in irrigated agriculture

3. The Koga irrigation scheme

3.1 Irrigation infrastructure and water supply

The project was implemented in the Koga irrigation scheme, a semi-modern scheme located in Amhara Region, Ethiopia (Figure 3.1) which was commissioned in 2010. Agriculture in the Koga com2 mand area follows two seasons, rainfed (June to November) and irrigation season (December to May). The scheme is supplied with water from the Koga reservoir which has a maximum storage capacity of 83×10^6 m^3, covering a maximum surface of around 1,750 ha. The reservoir fills up naturally during the rainy season through the collection of runoff originating upstream. In the dry season, the reservoir provides water to a command area of around 7,000 ha covering approximately 10,000 beneficiaries. The main canal has a total length of 19.7 km distributing water from the reservoir to 11-night reservoirs and 12 irrigation blocks (Figure 3.1).

The potential irrigable land size in each block ranges from 290 to 864 ha (Table 3.1). Each block has one secondary canal which supplies water to the tertiary canals (TC). These in turn supply water to the various quaternary canals (QCs), further diverting water through field canals. The number of tertiary and quaternary canals depends on the block size as well as the topography within the scheme. Each quaternary canal has two outlets, each supplying water to 8 ha on a rotational basis of 8 to 14 days depending on the cropping pattern. More information on the scheme characteristics can be found in Agide, *et al.* (2016), Haileslassie, *et al.* (2016) and Schmitter, *et al.* (2017).

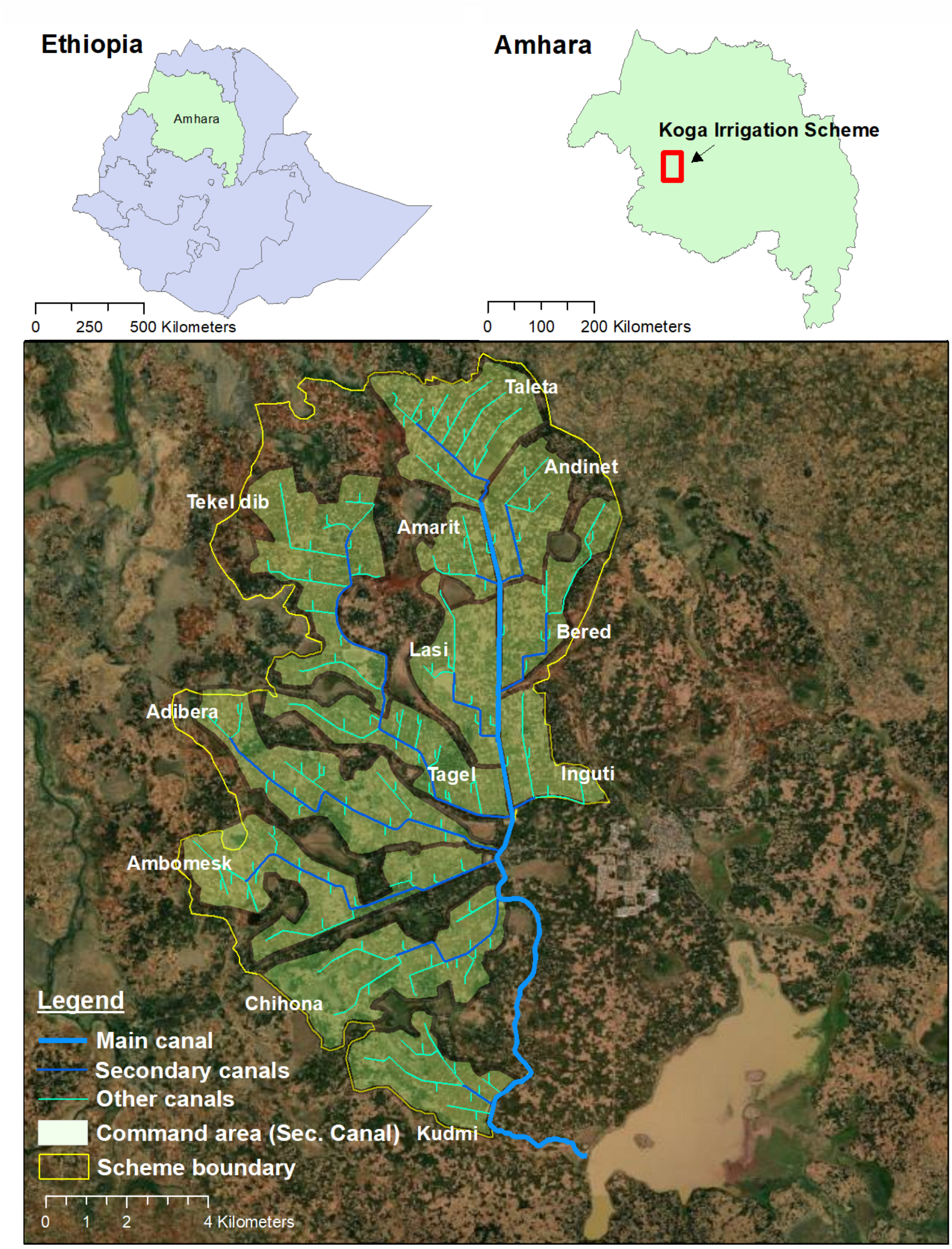

Figure 3.1 Location of the Koga irrigation scheme in Ethiopia, and details of scheme layout.

Table 3.1 Overview of the various irrigation blocks in the Koga irrigation scheme and their respective and currently irrigated land area (Schmitter *et al.*, 2017).

Irrigation Block	Irrigation potential area (ha)	Currently irrigated area (ha)	Total participating farmers	Total Male farmers	Total Female farmers	Irrigation volume released annually (Mm^3)	Night storage reservoir capacity (Mm^3)
Kudmi	373	368	715	657	58	3.97	20.01
Chihona	617	561	788	655	133	6.06	35.59
Ambomesk	812	676	1927	1834	93	7.30	40.18
Adibera	803	287	607	604	3	3.10	N.A.
Tagel	616	562	1338	1288	50	6.07	37.73
Tekel dib	864	821	1268	1132	136	8.87	44.61
Inguti	393	385	824	793	31	4.16	19.20
Lasi	484	435	417	357	60	4.70	25.20
Bered	468	453	557	499	58	4.90	24.73
Andinet	497	418	465	431	34	4.51	40.70
Amarit	290	203	353	330	23	2.20	-
Taleta	787	662	1097	1049	48	7.16	41.89
Total	7004	5828	10356	9629	727	63.00	329.82

The water supply varies across the different irrigation blocks and throughout the irrigation season[1]. At the head of the scheme, Kudmi and Chihona perform well in terms of adequate water supply (i.e. the 0.03 m^3/s design discharge) though performs medium in terms of adequacy and reliability throughout the season (Table 3.2). The blocks in the middle of the scheme (i.e. Adibera and Tagel) perform poorly in terms of adequacy. Farmers here receive less water compared to Kudmi and Chihona and the amount varies throughout the season and as a function of the field location. In Tagel and Adibera, water supply drops significantly below the designed discharge and farmers receive less water compared to the head blocks. However, the supply in Tagel remains relatively constant within the block over time and varies less among the different QCs compared to Adibera. This shows that Tagel overall receives significantly less water but can distribute this in an approximate equal manner. At the tail of the scheme, Adinet does manage to supply similar discharges at the Qc outlet as Kudmi and Chihona, but it varies throughout the season and across the TCs. Taleta, a neighbouring block at the tail end, scores poorly in equitable water supply among the different Qcs and this throughout the irrigation season. As a result, the average discharge at the farm level varies between 0.012 and 0.028 m^3/s during the cropping season as a function of Tc and block.

Table 3.2 Performance indicators measured for each block

Performance	Kudmi	Chihona	Adibera	Tagel	Andinet	Taleta
Adequacy	1.02	0.91	1.17	1.14	0.97	0.84
Equity	0.14	0.14	0.18	0.04	0.19	0.36
Reliability	0.1	0.31	0.27	0.05	0.23	0.05

Good	Fair	Poor
0.9 < x < 1.1	0.7 < x < 0.9	< 0.7 of > 1.1
< 0.1	0.1 < x < 0.25	> 0.25
< 0.1	0.1 < x < 0.2	> 0.2

---

[1] Three performance indicators (adequacy, reliability and equity) were calculated using 435 discharge measurements at 18 locations across 6 blocks (see Annex 1).

3.2 Cultivation of wheat in the irrigation season

In both the rainfed and irrigation seasons, cereals are the dominant cultivated crops. In the rainy season (June – October), maize (>90% of farmers) is predominantly cultivated followed by teff and millet. During the irrigation season (November-May), 72% is cultivated with wheat, 14% with potato, 6% with onion, 3% with barley, 3% with head cabbage and the remaining by tomato, pulses and chili (Taye, *et al.*, 2017). Soil analysis showed that soils are acidic (pH – H_2O 4.9) in nature and overall well-draining with a 21%, 22% and 54% of clay, sand and silt content, respectively.

The irrigation season started with water being released late October or early November depending on when maize is harvested at the end of the rainy season. Once water is released fields are ploughed in November and wheat is sown in beds during December or January. Fertilizer is applied at the initial stage (December-January) under the form of diammonium phosphate (DAP; 18% N, 46% P) and urea (46% N). Although Adet agricultural Research centre (the nearby Ethiopian research centre) has a fertilizer recommendation for wheat (DAP 100kg/ha; urea 160 kg/ha), the application depends on farmers' financial capacity, experiences and traditional practices. The household survey carried out by FAO and IWMI (2018) showed a high variability of fertilizer use for wheat in the scheme ranging from 50 to 1000 kg/ha (median 300 kg/ha) DAP and 6 to 600 kg/ha (median 200 kg/ha) urea. During project implementation, the monitored fertilizer use ranged for DAP between 67 to 320 kg/ha and for urea from 20 to 600 kg/ha.

For wheat, furrow irrigation is the most common practice. The average irrigation interval ranged from 8 to 14 days depending on the amount of water released in the block and the location of the block in the field. According to FAO and IWMI (2018), the majority of farmers irrigate between 5 to 9 times (45% of surveyed households) or 10-14 times (38% of the surveyed households).

4. Adaptive learning approach to improving crop and water productivity

The project used an adaptive learning environment where stakeholders and water users were involved from the onset to co-identify which solution to test and strengthen agricultural water management capacity from farm to scheme level (Figure 4.1).

The flow diagram (Figure 4.2) reflects the different steps taken throughout the project. The objectives (Section 2) were refined as a result of the WaPOR analysis (Section 5) and the needs assessment (FAO and IMWI, 2018) in Koga. This resulted in a co-design of the interventions with water users and stakeholders (Section 6) and an M&E framework (Section 7). Results were analysed on a seasonal basis (Section 8). After the first season, farmers' feedback was sought (Section 9) and used to increase training and adapt the monitoring mechanism in the second season.

APPROACHES	
Stakeholder-driven and owned	✓ The interventions fit stakeholder needs and emerges through a process whereby stakeholders construct their own organization ✓ Farmer-led, bottom-up: Farmers are empowered to take decisions and held responsible for doing so
Coordinated horizontally and accross scales	✓ A multi-layered approach is used to scheme level management and users. The approach integrates a field to scheme level concept to capture the spatial and temporal variability in scheme performance and decision making. This is important to ensure continuity of consultation, planning and accountability within and across scales
Facilitates a holistic approach too productivity	✓ Multi-stakeholder roles and interests must be incorporated to create enabling environments for productivity to improve ✓ Allow other key actors to play their part in promoting productivity to agriculture practices, technologies and value chain development (e.g. development agents)

Figure 4.1 Adaptive learning approach employed for the project implementation

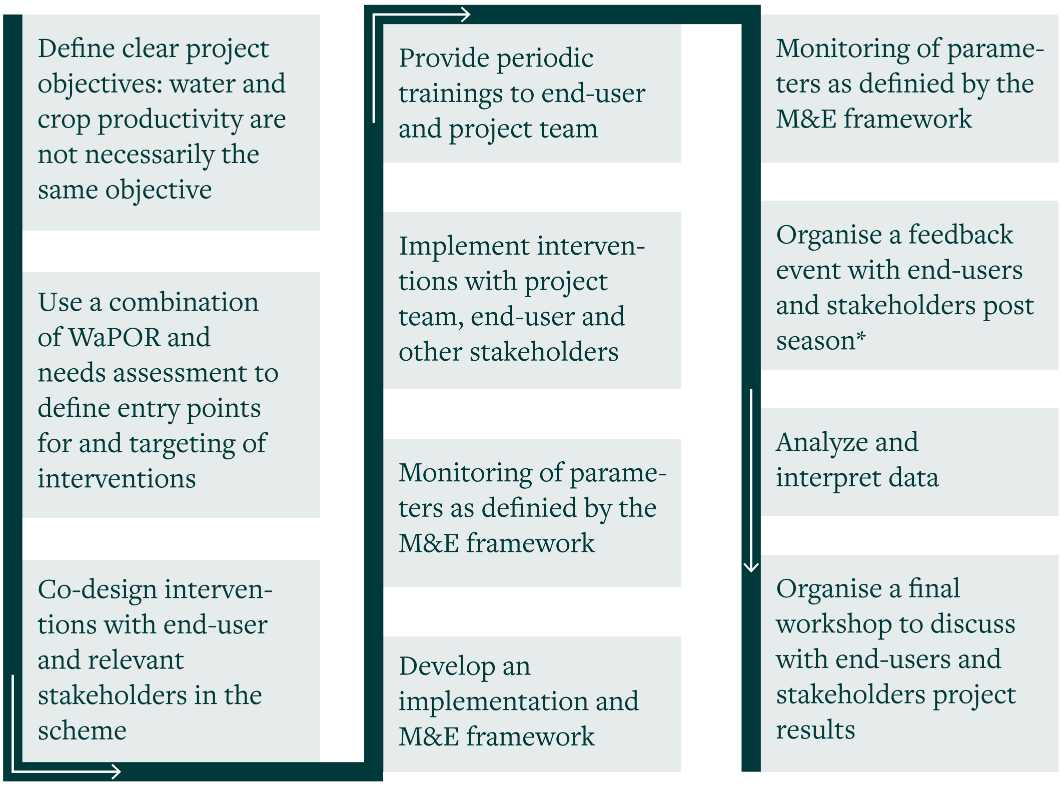

Figure 4.2 Overview of steps taken during project implementation. The farmer and stakeholder feedback after the first irrigation season was used to adapt interventions in the second season.

5. Irrigation scheme performance

The Koga irrigation scheme performance was evaluated using remote sensing derived datasets provided through the Water Productivity through Open access of Remotely sensed derived data (WaPOR) portal (https://wapor.apps.fao.org/home/WAPOR_2/1). Three indicators were derived from the primary WaPOR datasets for the period 2009 to 2017 to assess the irrigation performance:

1) Crop water consumption (the water consumed by the crop, quantified through the actual Evapotranspiration (ET));
2) Beneficial water use (the portion of the ET, which is transpired by the crops);
3) Gross Biomass Water Productivity (GBWP) the above ground biomass produced for the volume of water consumed.

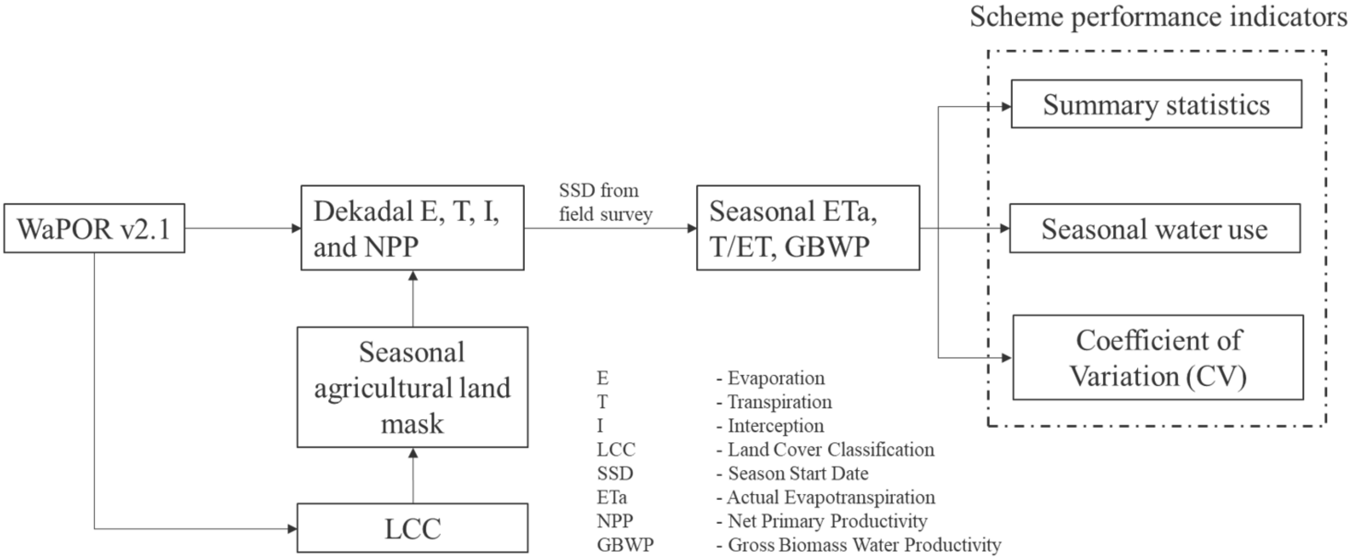

Figure 5.1 Methodology for assessing the irrigation performance of Koga scheme using WaPOR data

The WaPOR database consists of a set of water and land productivity indicators derived from remote sensing-based inputs for the Koga irrigation scheme. The list of available water and land productivity datasets in the WaPOR portal and the methodological approach behind its development is available in the "Database methodology: Level 3 data" document (FAO 2019). The dekadal datasets (every 10-days) representing Evaporation (E) and Transpiration (T) were used to derive secondary datasets of seasonal actual Evapotranspiration (ET) and the beneficial fraction of ET (T/ET) for the period 2008/2009 to 2016/2017 (Figure 5.1). The Land Cover Classification (LCC) dataset was used to derive a seasonal non-agricultural area mask, which were applied to the ET and T/ET datasets to extract only the cultivated area within the Koga irrigation scheme. A similar seasonal aggregation and masking process was applied for the Net Primary Production (NPP) dataset to ultimately derive the seasonal Gross Biomass Water Productivity (GBWP) using the methodological framework described in FAO 2019. While the WaPOR datasets are available from 2009, the irrigation scheme commenced operation only in 2010; the Koga irrigation scheme performance assessment was thus conducted from 2010 to 2017. Summary statistics were calculated for ET, the beneficial water use, and GBWP by aggregating the datasets at the block level to enable a comparison between different irrigation blocks in the scheme. The Coefficient of Variation (CV) was calculated for beneficial water use as a measure of variability within the scheme. The seasonal crop water consumption across the scheme was estimated by multiplying the pixel dimensions (30 m x 30 m) with the individual pixel values of ETa dataset and aggregating the values over the cultivated area.

5.1 Crop water consumption:

The ET over each annual irrigation season are presented in Figure 5.2. Two distinct patterns are evident from this time series i) the evolution of the irrigation scheme through the associated increases in water consumption as the scheme became increasingly operational, and ii) high spatial variability in seasonal crop water consumption within the scheme. The system-wide low ET values (~150 mm) were observed in the 2008/2009 season, which primarily reflects fallow land before the scheme commencement.

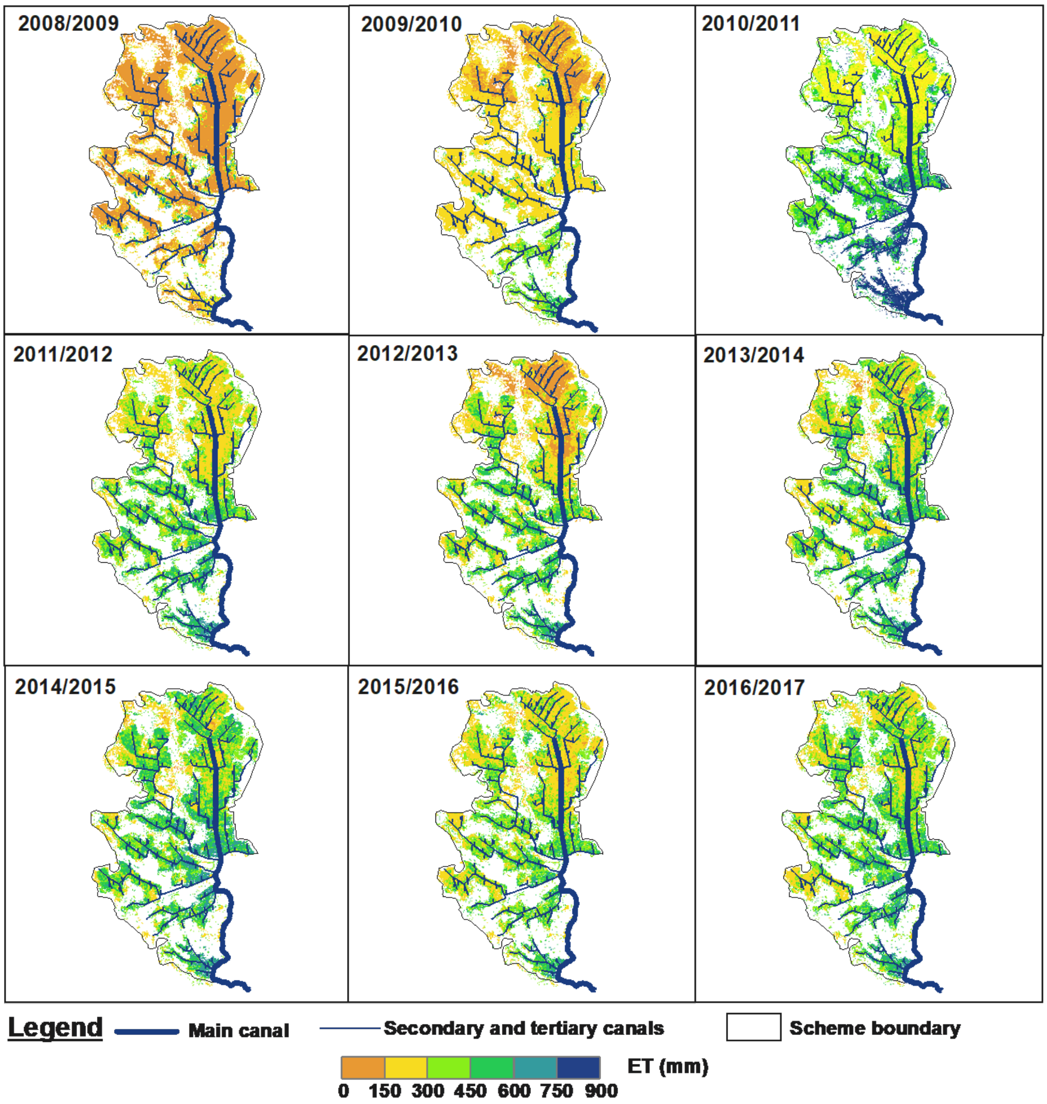

Figure 5.2 Actual Evapotranspiration derived for the Koga irrigation season (December-May) over the period 2009-2017 (Source: WaPOR 2020).

The observed spatial patterns in 2010/2011 indicate that the blocks Kudmi, Chihona and Ambomesk in the system head and, Adibera and Tagel blocks in the middle (the blue-green areas in the 2010-2011 map) were receiving adequate irrigation water for cultivation of the wheat crop (ET>450 mm; Schmitter et al 2017). However, the lower ET values (ET < 300 mm) observed in the blocks in middle and tail end section located downstream of Tagel possibly indicate inadequate water supply to these sections. From its commencement in 2010, the Koga irrigation scheme was evolving to cover the designated command area until the full coverage was achieved in the 2013/2014 irrigation season. The irrigation seasons of 2013/2014 and 2014/2015 marked the first time in which two consecutive years of full irrigation coverage was achieved within the Koga command area. Extremely low ET values were observed in the blocks downstream of Lasi in 2012/2013 and 2015/2016, indicating possible impacts of low water availability in the reservoir due to lower than normal rainfall which led to drought conditions. For example, in 2015/2016, the total irrigated land was only 3,578 ha (50 % of the command area) due to the low water levels in the reservoir (Schmitter *et al.*, 2017). It is also evident Figure 5.2 that even during the drought years, the head section blocks (Kudmi, Chihona and Ambomesk) were more water secure than the middle and tail end sections of the scheme.

In order to further characterise the spatio-temporal variability found within the Koga irrigation scheme between the head and tail end sections, summary statistics of ET were calculated for each irrigation block (Table 5.1). The mean ET calculated for the command area of each block indicates a spatially declining trend over the observation period as we move from head (mean ET = 490.6 mm) to tail (mean ET = 261 mm) along the main canal. Over the period of analysis the head section of the irrigation scheme appears to have more consistent levels of water consumption (likely due to less disruptive supply of water) as evident from the low standard deviation in the ET (45.1 mm) when compared with the higher standard deviation values (86.6 mm) estimated for the tail end. The two drought years of 2012/2013 and 2015/2016 coincided with system wide low ET values. However, even during the drought years, the ET variability observed in the head section of the main canal is much lower (<10% of the mean) than the tail end. The assessment shows inequitable water distribution between the head, middle and tail end of the Koga irrigation scheme.

The spatial ET estimates (Figure 5.2) were aggregated at the scheme level to estimate total water consumption in the Koga command area during each irrigation season (Figure 5.3). From the initial 17.3 MCM consumed during the 2009/2010 irrigation season, the scheme recorded its highest water consumption in the 2014/2015 irrigation season (32.6 MCM). Both drought years (2012/2013 and 2015/2016) recorded lower water use of 24.5 and 26.2 MCM during each irrigation season respectively. Based on the irrigation coverage seen in the normal irrigation years (2013/2014, 2014/2015 and 2016/2017), around 30 MCM of crop water demand needs to be satisfied every year if the entire command area within the Koga irrigation scheme has to be cultivated assuming that the current cropping pattern prevails.

Table 5.1 Block-wise summary statistics for actual evapotranspiration

	Block-wise actual evapotranspiration (mm)											
Irrigation season	**Kudmi**	**Chihona**	**Ambomsek**	**Adibera**	**Tagel**	**Tekel dib**	**Inguti**	**Lasi**	**Bered**	**Andinet**	**Amarit**	**Teleta**
2009/2010	416.8	370.2	239.9	245.8	195.1	232.4	207.1	194.3	153.6	199.2	174.0	153.6
2010/2011	429.2	334.9	237.4	230.3	239.7	166.4	246.9	178.8	174.2	167.4	159.8	157.9
2011/2012	561.1	488.9	418.2	419.2	470.8	335.4	403.9	317.9	282.3	290.0	289.6	270.6
2012/2013	505.3	445.7	371.2	400.1	446.8	348.7	360.9	277.9	240.3	223.7	160.4	240.1
2013/2014	504.8	482.4	425.0	326.2	486.2	378.2	463.6	386.5	372.9	341.5	326.6	350.4
2014/2015	517.0	470.2	439.9	441.2	521.9	422.3	524.3	437.8	404.5	372.8	392.4	396.5
2015/2016	474.0	410.9	364.3	369.0	421.5	326.9	403.0	334.2	268.2	285.7	281.9	256.9
2016/2017	517.0	484.9	358.6	420.1	477.1	395.5	463.3	410.6	349.6	356.5	341.1	350.2
Max	561.1	488.9	439.9	441.2	433.9	524.3	437.8	404.5	396.5	372.8	399.7	388.3
Min	416.8	334.9	237.4	230.3	191.5	232.4	178.8	174.2	153.6	167.4	160.1	153.6
Mean	490.6	436.0	356.8	356.5	338.4	387.3	318.8	285.8	272.0	279.6	269.7	261.0
SD	45.1	54.5	73.7	76.1	87.6	97.0	87.4	78.2	83.7	71.4	86.6	86.2

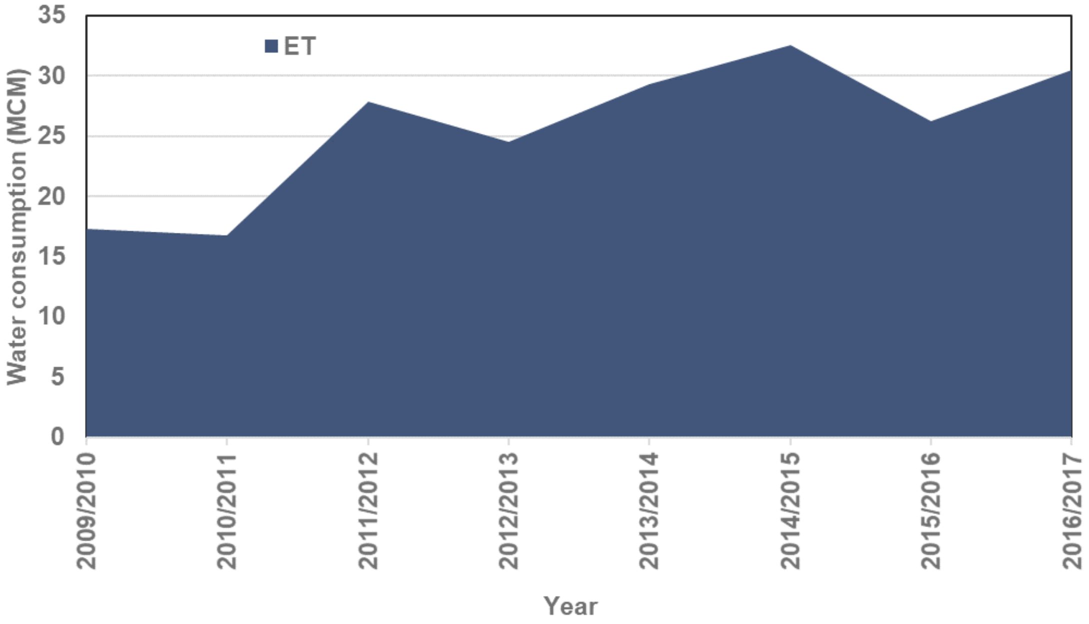

Figure 5.3 Estimation of irrigation water consumption for the Koga scheme based on WaPOR data

5.2 Beneficial water use

The ET derived from remote sensing data can be partitioned into three components; evaporation, interception and transpiration (FAO, 2019). The transpiration fraction represents the portion of the Evapotranspiration which is used to grow by the plants and is an indicator frequently used to assess the beneficial use of irrigation water. Referred to as the "beneficial fraction" and calculated as the proportion of the ET which is transpired, this indicator is demonstrated spatially for the Koga irrigation scheme in Figure 5.4. The head section of the scheme continuously demonstrated more productive use (a higher beneficial fraction) of available water for crop growth over the entire observation period (Figure 5.4). A marked spatial difference in the beneficial fraction can be observed within the scheme during the 2009/2010 and 2012/2013 seasons, with the blocks Bered, Andinet, Amarit, and Teleta in the tail end recording the lowest beneficial water use. These low values could be attributed to a lower transpiration component in the ET due to fallow land. As the cultivation expanded into the tail end of the irrigation scheme from 2013/2014 to 2016/2017, the middle and tail end demonstrate an increase in the beneficial fraction.

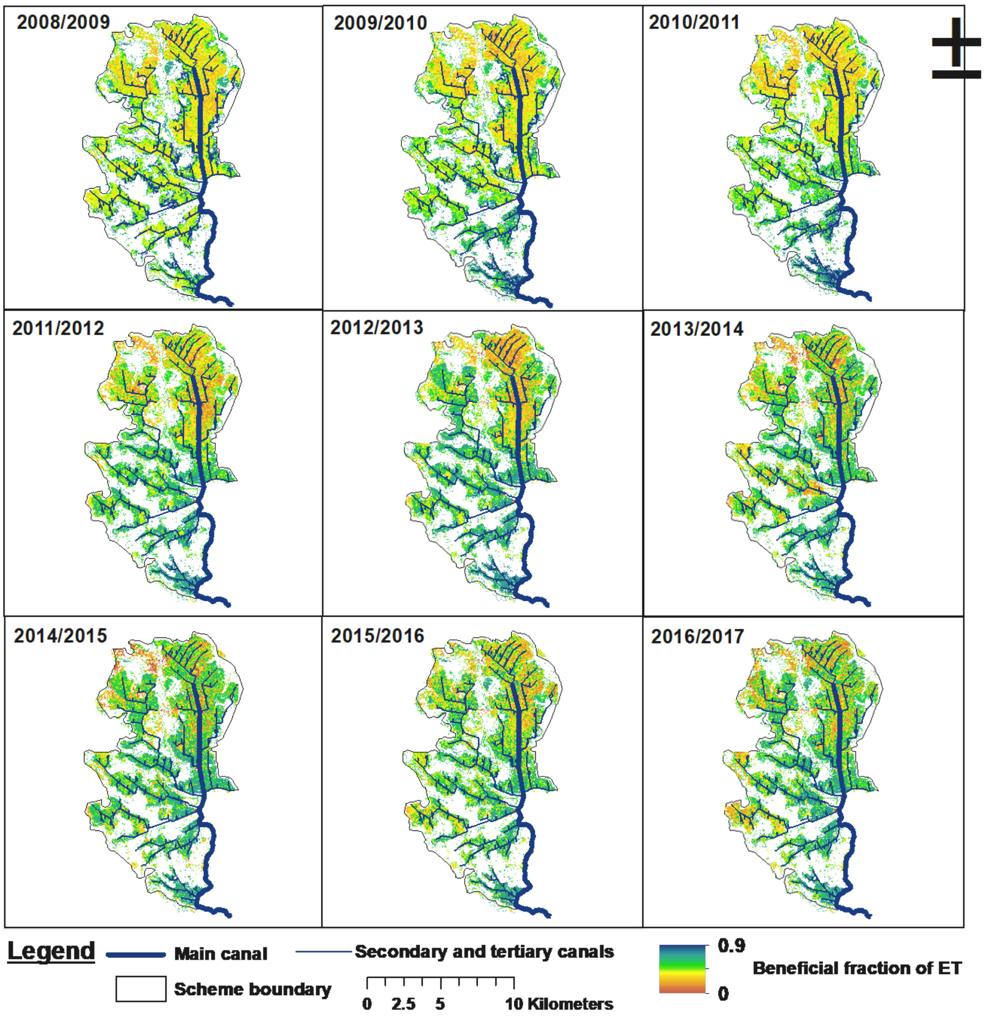

Figure 5.4 Beneficial fraction for the irrigation season (December-May)

Table 5.2 Block-wise summary statistics for beneficial water use

	Block-wise beneficial water use											
Year	Kudmi	Chihona	Ambomsek	Adibera	Tagel	Tekel dib	Inguti	Lasi	Bered	Andinet	Amarit	Teleta
2009/2010	0.68	0.65	0.58	0.58	0.57	0.53	0.57	0.55	0.56	0.51	0.55	0.51
2010/2011	0.68	0.62	0.54	0.53	0.54	0.45	0.54	0.47	0.48	0.43	0.46	0.44
2011/2012	0.70	0.66	0.62	0.62	0.65	0.55	0.61	0.55	0.50	0.49	0.51	0.50
2012/2013	0.73	0.71	0.66	0.67	0.70	0.65	0.67	0.60	0.58	0.56	0.56	0.51
2013/2014	0.77	0.76	0.70	0.65	0.74	0.67	0.72	0.69	0.69	0.66	0.66	0.63
2014/2015	0.76	0.73	0.72	0.71	0.75	0.70	0.75	0.71	0.70	0.67	0.67	0.66
2015/2016	0.76	0.74	0.70	0.71	0.74	0.70	0.73	0.70	0.66	0.64	0.67	0.66
2016/2017	0.75	0.73	0.67	0.71	0.74	0.68	0.72	0.69	0.67	0.66	0.67	0.64
Max	0.77	0.76	0.72	0.71	0.75	0.70	0.75	0.71	0.70	0.67	0.67	0.66
Min	0.68	0.62	0.54	0.53	0.54	0.45	0.54	0.47	0.48	0.43	0.46	0.44
Mean	0.73	0.70	0.65	0.65	0.68	0.62	0.66	0.62	0.60	0.58	0.59	0.57
SD	0.04	0.05	0.06	0.06	0.08	0.09	0.07	0.08	0.08	0.09	0.08	0.08

The block-wise summary statistics for the beneficial water use are shown in Table 5.2. Spatially, blocks in the head section (Kudmi, Chihona) demonstrated higher beneficial water use compared to the blocks in the middle and tail end during the early years of the scheme operation. The highest mean beneficial water use was observed in Kudmi block (0.73) while the lowest was in the tail end block Teleta (0.57). However, there has been a consistent increase in beneficial water use in all the blocks over the observation period. The difference in beneficial water use between the blocks reduced significantly over the recent years with Adibera, Tagel and Inguti blocks in the middle section performing equally well. The observations indicate that when there is an equal distribution of available water within the scheme (2013/2014, 2014/2015 and 2016/2017), the differences in the beneficial water use between head and tail end becomes narrow. Low beneficial water use in Ambomesk block (0.67) located in the head for the 2016/2017 irrigation season reiterate the differences in intra-block water availability between area closer to the main canal and tail end of the secondary canal. A similar pattern can be observed in the Tekel dib block, which is located in the tail end of another secondary canal.

5.3 Gross biomass water productivity

The Gross Biomass Water Productivity (GBWP) expresses the quantity of output (above ground biomass production) to the total volume of water consumed (the ET) over the irrigation season and is one of the parameters provided through the WaPOR platform (FAO, 2019). The spatio-temporal patterns of GBWP at pixel and block level are shown in Figure 5.5 and Table 5.3. The Kudmi, and Chihona blocks demonstrate consistently higher GBWP over the observation period with Kudmi having the highest production values. In the initial irrigation season (2009/2010), the GBWP was in the range of 4 to 8 kg/m³ with a declining trend evident from head section to tail end. The GBWP range within the scheme increased substantially to between 7.2 and 10 kg/m³ in the recent 2016/2017 irrigation season. The head-tail difference in GBWP is apparent, with blocks Bered, Andinet, Amarit and Teleta in the tail end consistently recording the lowest values. Considering the relative variations in GBWP observed between different blocks in the Koga irrigation scheme, it is apparent that there exists substantial scope for interventions to increase the overall water productivity of the scheme.

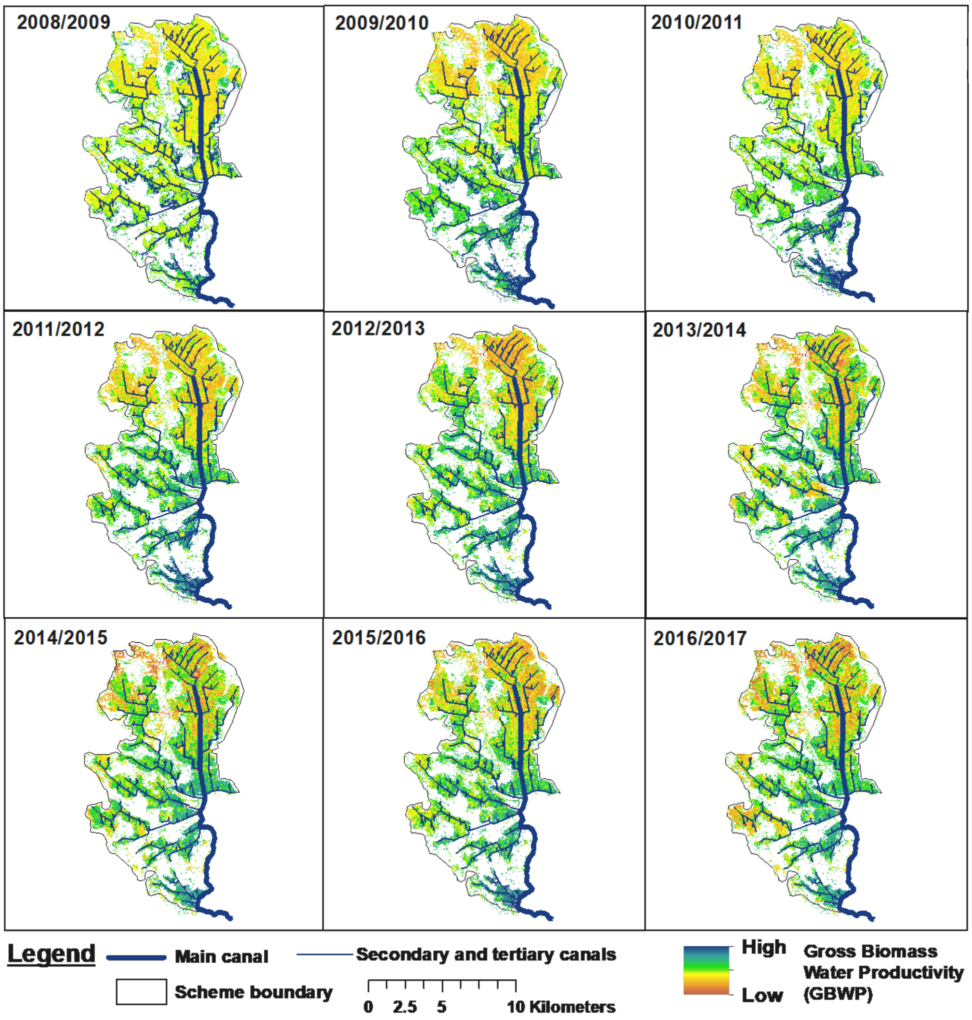

Figure 5.5 The Gross biomass water productivity estimated for the irrigation season (December-May)

Table 5.3 Block-wise summary statistics for GBWP (kg/m^3)

	Block-wise actual gross biomass water productivity (kg/m^3)											
Year	**Kudmi**	**Chihona**	**Ambomsek**	**Adibera**	**Tagel**	**Tekel dib**	**Inguti**	**Lasi**	**Bered**	**Andinet**	**Amarit**	**Teleta**
2009/2010	8.2	7.5	6.7	6.5	5.7	6.4	5.9	6.1	5.1	5.6	4.9	4.2
2010/2011	7.7	6.7	5.4	5.1	5.2	4.3	5.2	4.6	4.7	4.2	4.4	4.2
2011/2012	7.8	7.1	6.2	6.0	6.6	4.8	6.1	5.1	4.4	4.2	4.4	4.3
2012/2013	8.9	8.3	7.4	7.6	8.0	6.9	7.4	6.4	5.9	5.5	5.6	4.9
2013/2014	10.4	10.1	8.9	7.6	9.5	7.7	9.2	8.1	7.8	7.1	7.2	6.7
2014/2015	9.5	8.9	8.4	8.3	9.0	7.7	9.1	8.0	7.5	6.9	7.0	6.7
2015/2016	9.7	8.9	8.2	8.2	8.6	7.3	8.4	7.8	6.8	6.3	6.9	6.4
2016/2017	10.7	10.2	8.6	9.3	10.0	8.4	9.7	8.8	7.9	7.6	7.9	7.2
Max	10.7	10.2	8.9	9.3	10.0	8.4	9.7	8.8	7.9	7.6	7.9	7.2
Min	7.7	6.7	5.4	5.1	5.2	4.3	5.2	4.6	4.4	4.2	4.4	4.2
Mean	9.2	8.6	7.6	7.4	8.1	6.7	7.9	7.0	6.4	6.0	6.2	5.8
SD	1.1	1.3	1.2	1.3	1.6	1.4	1.6	1.5	1.3	1.3	1.3	1.2

5.4 Variability in crop water consumption and beneficial use

The Coefficient of Variation (CV) was calculated at pixel level for the beneficial fraction and used as a measure of variability within the Koga irrigation scheme (Figure 5.6). The variability of beneficial water use in Kudmi and Chihona blocks located in the head section was less than 10%. However, the variability increases in the blocks located further downstream with values up to 20% in Ambomesk, Adibera and Tagel blocks, and values up to 35% in the rest of the middle and tail end blocks.

The maps of crop water consumption and beneficial water use patterns indicate variations both between and within blocks. The highest variability was observed in the four tail end blocks Bered, Andinet, Amarit and Teleta. The Tekel dib block located in the mid-section of the scheme showed a substantial difference in beneficial water use between the area located in proximity to the head of secondary canals and its tail end sections. Part of the high variability in the mid and tail end section stems from the delayed onset of irrigation activities in the initial years compared to the head section, and occurrence of two drought years leading to inadequate water availability in the Koga reservoir.

Overall, the variability in beneficial water use demonstrates that blocks perform differently, indicating potential scope for improvements through targeted interventions. To address the variability in performance identified above, a multi-scale approach targeting interventions at the farm, Water Users Group (WUG), and scheme level are recommended. The project thus developed an implementation framework that captured the spatial variability across the head, mid and tail blocks.

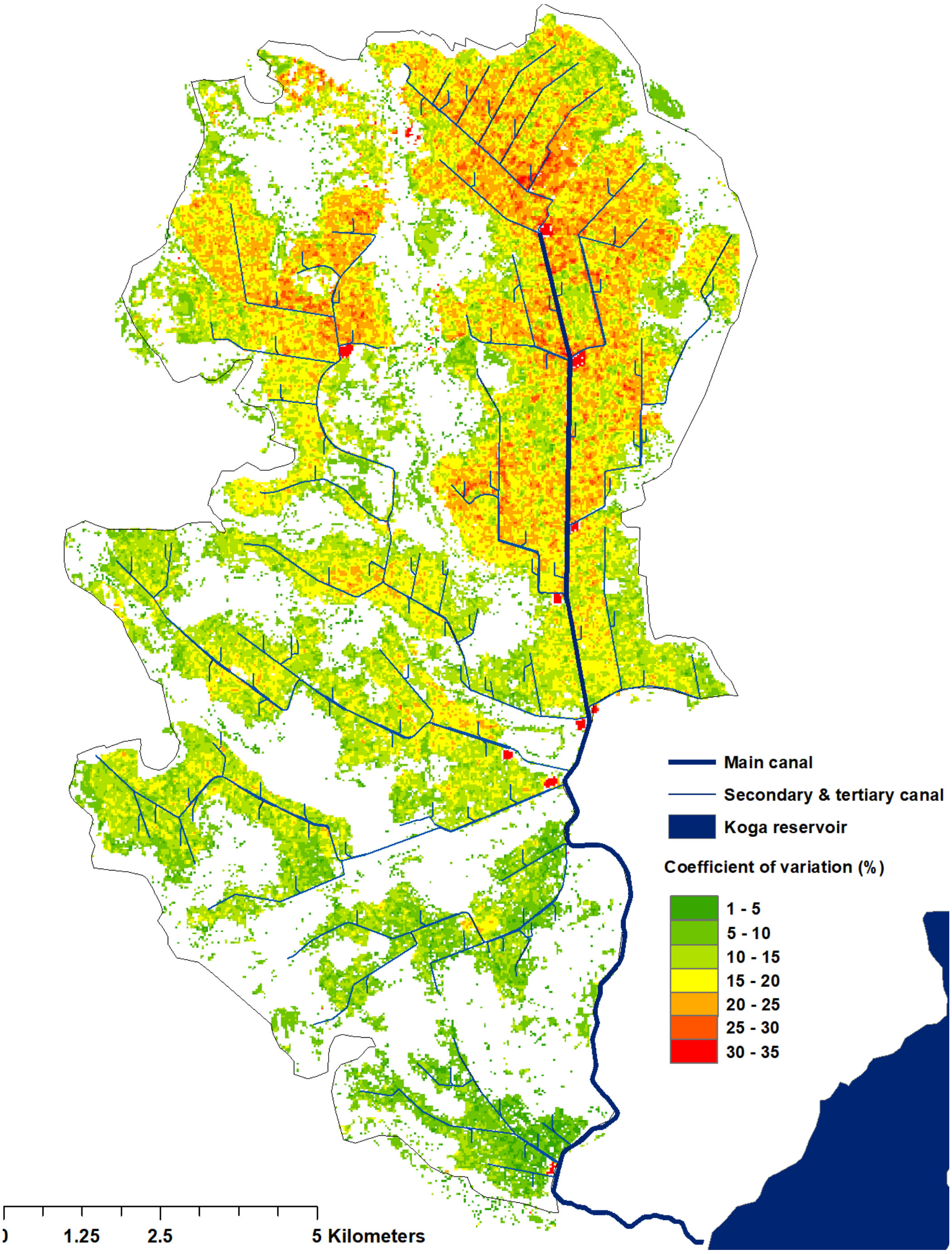

Figure 5.6 Coefficient of variation for beneficial water use within the Koga irrigation scheme (2010 to 2017).

6. A multi-scale approach to improving water productivity

While the cultivated area of crops like onion and potato has increased over the past years, most farmers still prefer the cultivation of wheat. According to the User Needs Assessment, 85% of the sampled farmers prefer to irrigate wheat as it is believed to be less vulnerable to unreliable water supply during the dry season (FAO and IWMI, 2018). However, wheat yields remain low (approximately 2.4 t/ha; FAO and IWMI, 2018). According to the farmers, shortage of water (74%), over-irrigation (23%), lack of water saving technologies (30%), and poor irrigation knowledge (32%) were among the main factors leading to low wheat yields (FAO and IWMI, 2018). Field observations also showed the evidence of wheat rust, a frequently occurring disease due to poor soil aeration. Hence, the project focused on water solutions to augment the decision making of wheat cultivators during the irrigation season (November/December until March/April/May), as it was believed to produce the largest gains in terms of crop and water productivity in the scheme.

6.1 Selection of low-cost irrigation technologies

The tools selected for the field intervention had previously shown promise in guiding smallholder farmers in Koga and other irrigation schemes in adapting their irrigation practices (Schmitter *et al.* (2017), Taye *et al.* (2017) and Schmitter *et al.* (2018)). Results had shown that under labour constraints (e.g. manual irrigation systems), farmers tended to increase their water application in onion cultivation by 30% whilst doubling their yield. The increased water application at critical growth stages resulted in higher profits. Under motorized irrigation (i.e. petrol pumps) of vegetables, the reduction of irrigation water applied resulted in a fuel saving between 50 to 150 $/ha. In Koga, under onion and potato the introduction of the low cost tools reduced N-fertilizer consumption by 20% and P consumption by 54% whilst decreasing water use by 30% resulting in crop water productivity gains up to 58%. Based on these initial findings with small farmer groups under different irrigation conditions in Ethiopia and in particular Koga, the project choose to introduce the same technologies at a larger scale.

6.1.1 *Wetting front detectors*

Wetting front detectors[2] are mechanical devices, which depending on the soil type, irrigation method and quantity, are installed in pairs at a specific depth below the soil surface. The tool indicates to farmers when a wetting front has reached a specific depth. When field capacity is reached and soils gravitationally drain, water is collected within the reservoir below the funnel. Depending on the amount of water collected in the reservoir (i.e. suction > 3kPa) the float will be activated (Schmitter, *et al.*, 2017). Each pair consists of a yellow and a red indicator. The shallow detector (yellow indicator) is installed around half of the effective root zone whereas the deep detector (red indicator) is

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[2] https://research.csiro.au/scientistsgarden/fullstop-wetting-front-detector/

generally installed around 2/3rd of the root zone. Installation depth depends on the irrigation system (furrow, drip, surface, etc.) and soil condition (Figure 6.1). The information obtained when the detector is activated is useful to determine whether water has been excessively used (red detector, Figure 6.1) but provides little information to the irrigator on when to irrigate.

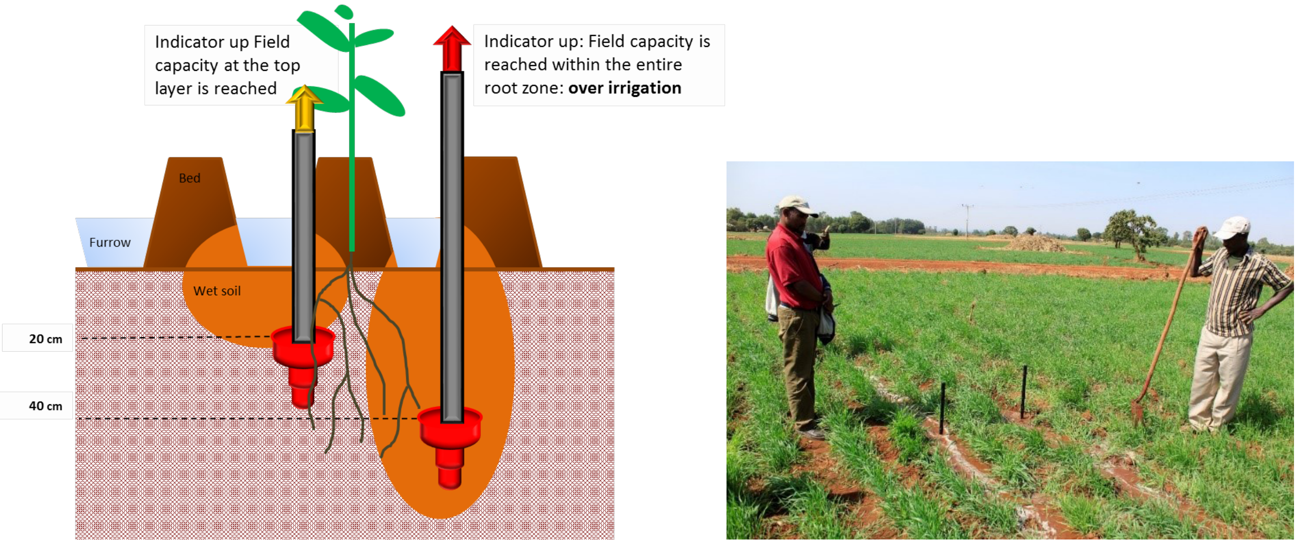

Figure 6.1 Schematic representing the response of the detector when the wetting front is reached (left) and the installation of the wetting front detector in a furrow system for wheat (right). Photo by IWMI.

6.1.2 *Chameleon sensors*

Chameleon sensors[3] are created out of gypsum blocks that measure the resistance, which can be translated into soil water tension indicating the "easiness" for the crop to extract water from the soil. The sensors are installed in the soil at specific depths depending on the root zone development of the crop. The sensors are connected to a WiFi reader containing 3 led lights (each light corresponds to one specific depth). Each led light has three colour options: blue, green, red informing the farmer whether the soil is wet, moist or dry, respectively (Figure 6.2). The switch from blue to green occurs between 20-25 kPa and from green to red > 40-45 kPa, respectively. Hence, the sensor provides information to the farmer on the "dryness" of the soil through a colour coding system (Figure 6.2). Based on this the farmer can decide whether to irrigate and whether sufficient irrigation water has been applied.

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[3] https://research.csiro.au/scientistsgarden/chameleon-soil-water-sensor/

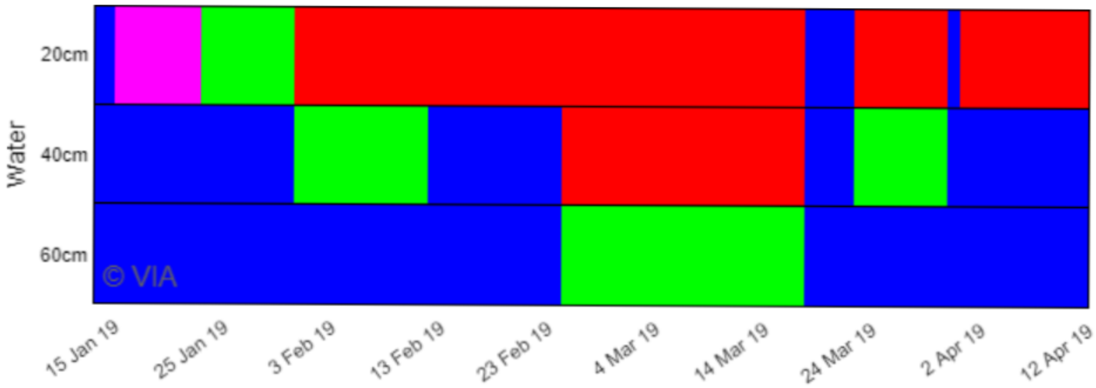

Figure 6.2 Example of changes in soil tension for an irrigated wheat field in Koga in 2019.

6.2 Co-designing interventions with water user groups across irrigation blocks

Firstly, blocks and tertiary canals (TCs) in the scheme were selected with scheme managers and block leaders based on their location (head, mid and tail) in the scheme and the block, respectively. The reason for selecting blocks from head to tail and multiple Tc within a block was to capture the variability in water supply which could influence farmers' decision making in irrigation practices and potentially yield and crop water productivity. A description of the selection procedure is described in Haileslassie and Tegegne (2017). From the twelve blocks in Koga, the selected blocks were: 1) Kudmi and Chihuna (head); 2) Adibera and Tagel (mid), and 3) Andinet and Taleta (tail) (Table 6.2).

Water user groups (WUGs) along the TCs were selected with the support of the senior agronomists in the scheme along the 18 TCs based on the following criteria:

- Minimum of 4 ha of wheat cultivation in the irrigation season
- Minimum of 7-8 farmers cultivating wheat

This resulted in a selection of 90 WUG at 90 quaternary outlets. Six meetings (i.e. one per block) were organised together with the senior agronomist responsible for the block, the block leader, the Tc and the WUG leaders. Each WUG was asked to bring a list of farmers interested in project participation and their respective land area.

During the meeting the project and technologies were introduced (Figure 6.3) and the need for control groups were discussed. The water user group leaders and deputies were asked to state their technology preference for their WUG. From the 90 WUG, 74 WUG stated their preference. From those that stated their preference, 81% selected the WFD while only 18% selected the chameleon and 1% preferred to be a control. Chameleon sensors were seen as technologically more advanced and leaders expressed concerns that farmers might struggle in their operation or that instabilities in network or electricity would restrict use.

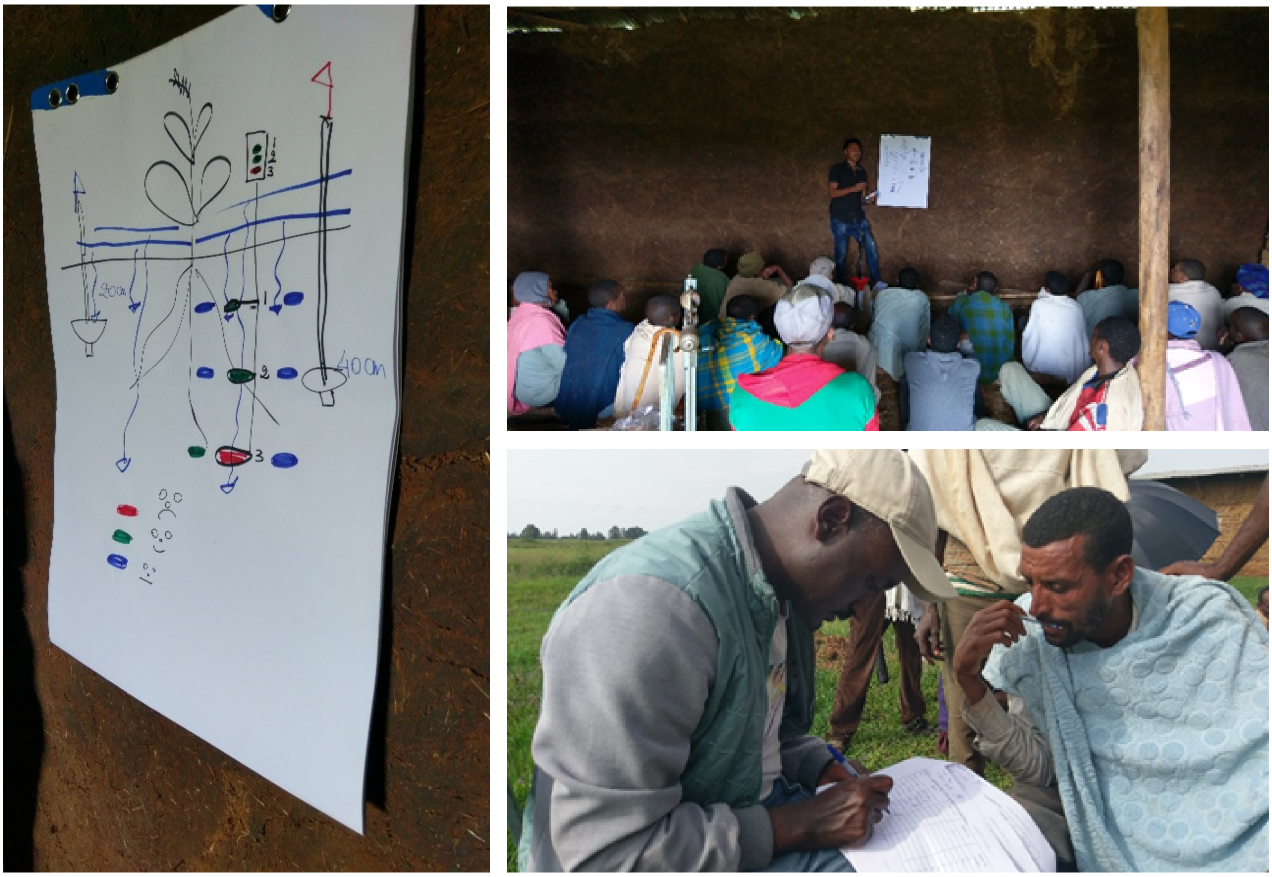

Figure 6.3 Explanation of the technologies (left) in the farmer meeting (top right) and farmer registration after the meeting (bottom right). Photos by IWMI.

Furthermore, the project aimed at understanding whether farmers require in-situ technologies to adapt their irrigation practices, or whether access to information could result in a similar improvement in crop water productivity as when the technologies would be installed. Hence, water user group leaders were asked who would receive the technology and who would receive the information. They were also asked how farmers could benefit if they did not receive the technology.

The questions asked, and examples of the most frequent answers given are summarized below (not in order of importance):

1) How could farmers benefit from the technology?
    - *All farmers should have a technology*
    - *We can share the technology so we install and uninstall each time we need to irrigate*
    - *We can share the information on how much water to irrigate*

2) We can share the information on how much time it takes to irrigate
    - *What type of information would you transfer?*
    - *I will let them know how much time I took to irrigate my field so they can estimate*

for their field size
- *I will let them know how much time I irrigated one furrow*
- *I will go and observe what the other farmers are doing and instruct them to irrigate more or less*

3) How would you transfer the information?
    - *I will tell them verbally when I hand over my water access to the next farmer as he will be present in the field*
    - *I will inform by phone (very rare occasion)*

At the end of the meeting, the WUG leaders were asked to decide whom within their group would receive the technology and who would receive the information. The project team did not interfere in their selection to ensure that the power relations and information flows would be respected. However, during project implementation, the team verified whether the physical conditions (e.g. distance between fields, planting dates, etc.) are suitable.

6.3 Implementation of on-farm management interventions

The interventions were implemented during the irrigation seasons of 2017-2018 and 2018-2019. The study followed a split plot design with technology (Control, WFD, and Chameleon) as the main factor and information sharing as sub-factor in the WFD and the Chameleon groups. The Control and WFD were implemented in all six blocks whereas the chameleon was implemented in three out of the six blocks due to a limitation of available sensors. An overview of the total number of WUG per intervention per block is given in

Table 6.1 Overview of the selected blocks and the number of WUGs within each of the blocks assigned to a particular intervention.

Selected blocks	**Location in the scheme**	**Number of WUG – WFD**	**Number of WUG – Chameleon**	**Number of WUG – Control***	**Total number of WUGs**
Kudmi	Head	6	-	6	**12**
Chihuna	Head	6	6	6	**18**
Adibera	Mid	6	6	6	**18**
Tagel	Mid	6	-	6	**12**
Andinet	Tail	6	-	6	**12**
Taleta	Tail	6	6	6	18
Total		36	18	36	90

* Control refers to no information access on irrigation scheduling.

As the project was implemented in an adaptive learning environment with the scheme, Tc, and WUG leaders the technology preference was respected to stimulate learning and enhance future scaling potential. Hence, in each block, the primary treatment was assigned based on the stated preference of the WUG leaders. As 60 WUGs preferred the WFD, 36 WUGs were randomly assigned to the WFD treatment whilst the other 24 were randomly assigned among the control and the Chameleon treatment.

In the WFD and Chameleon WUGs only four farmers received the technology. The WUG leaders together with the farmers decided who would receive the technology. Farmers who installed the technology shared the irrigation information with the other wheat cultivators within the same WUG. The irrigation information transferred was how much time it took to irrigate one furrow or the entire field.

Considering the average irrigation interval (8 – 14 days) for wheat, the soil type and the furrow irrigation practice resulted in the following installation:

- WFD: shallow detector 20 cm and the deep detector at 40 cm
- Chameleon sensors were installed at 20, 40 and 60 cm depth within the wheat beds.

In both cases, the technologies were installed approximately 75% of the furrow length. Farmers in both technology groups were asked to prepare similar furrows and to do the plantation at the same time which helped to ensure that the information transfer on time used to irrigate one furrow was compatible.

In total 144 WFD and 72 Chameleon sensors were installed across the treatment groups over the 6 blocks (Table 6.2). The total number of area cultivated and number of farmers participating in each treatment group is provided in Tables 6-3 and 6-4.

Table 6.2 Overview of the number of WFD and Chameleon sensors installed per block

Selected blocks	Number of WFD per block	Number of Chameleon sensors per block
Kudmi	24	-
Chihuna	24	24
Adibera	24	24
Tagel	24	-
Andinet	24	-
Taleta	24	24
Total	144	72

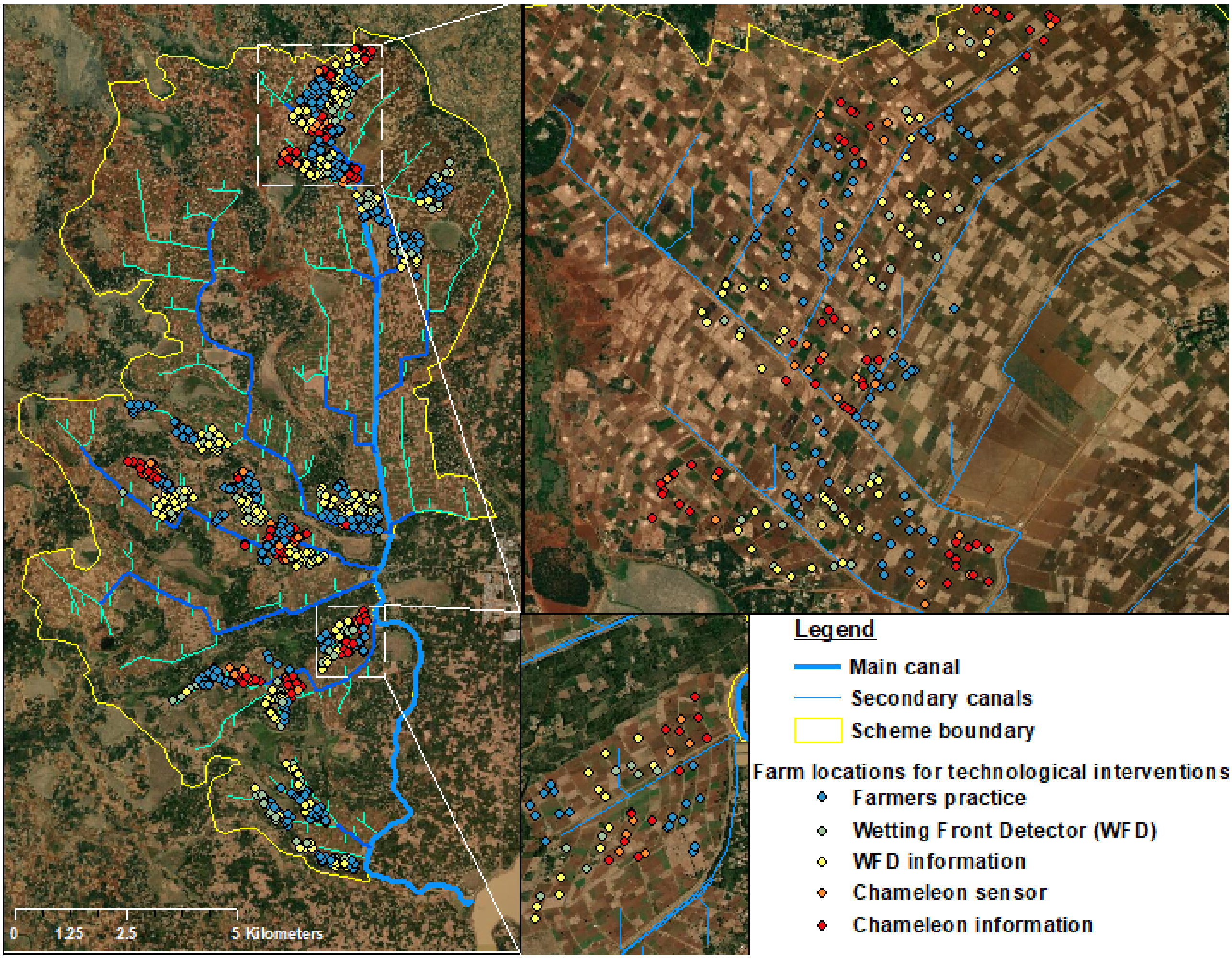

Figure 6.4 Location of fields within the Koga scheme which were included in the implementation with their respective treatment

The project provided several trainings to support farmers enrolled in this pilot to install the interventions, design data collection mechanisms and exchange information. All farmers in the treatment groups were trained at the onset of the irrigation season on how to use the WFD and Chameleon sensors. Farmers who installed the WFD used the response of the shallow indicator to decide about their irrigation, and farmers who obtained the chameleon sensor would decide based on the colour of the LED cells after irrigation. Whilst the majority of farmers indicated that the allocation is relatively flexible within the 8-14 irrigation interval, the timing of water supply to a field is mainly decided by the WUG leaders. During project implementation, there was no interference of the allocation schedule nor on the number of irrigation events from the project team. The farmers were left to decide whether or not they wanted to irrigate when it was their turn, and to use the technologies or the information to decide whether sufficient water was applied.

The amount of fertilizer applied was not controlled in the first season so that farmers could assess the impact of their irrigation practices on yield based on their fertilizer practice. In the second year the recommended fertilizer rates[4] were provided to improve both water and fertilizer use. This led in the second season to a significant reduction of P application but insignificant reduction of N application (see section 8.1.1).

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[4] .Fertilizer recommendations are given in section 3.2

Table 6.3 Overview of the total number of farmers in each of the treatments and the corresponding land size covered (ha) in the 1st irrigation season (2017/2018).

Technology	Number of Farmers							Land cultivated (ha)						
	Head		Mid		Tail		TOTAL	Head		Mid		Tail		TOTAL
	Kudmi	**Chihona**	**Adibera**	**Tagel**	**Andinet**	**Teleta**		**Kudmi**	**Chihona**	**Adibera**	**Tagel**	**Andinet**	**Teleta**	
Control	57	60	61	64	53	80	375	17.2	22.0	22.8	26.1	17.1	29.9	135.1
WFD	24	24	24	24	24	24	144	6.3	11.5	13.5	9.3	8.4	12.3	61.2
WFD (Info)	31	27	60	50	23	69	260	9.4	11.5	26.5	18.8	8.0	26.8	100.9
Chameleon		24	24			24	72		10.0	9.5			10.4	29.89
Chameleon (Info)		34	43			62	139		13.0	18.8			21.3	53.0
Total	112	169	212	138	100	259	990	32.9	68.0	91.0	54.1	33.5	100.5	380.0

Table 6.4 Overview of the total number of farmers in each of the treatments and the corresponding land size covered (ha) in the 2nd irrigation season (2018/2019).

Technology	Number of Farmers							Land cultivated (ha)						
	Head		Mid		Tail		TOTAL	Head		Mid		Tail		TOTAL
	Kudmi	**Chihona**	**Adibera**	**Tagel**	**Andinet**	**Teleta**		**Kudmi**	**Chihona**	**Adibera**	**Tagel**	**Andinet**	**Teleta**	
Control	51	54	60	61	42	77	345	13.0	13.1	16.9	25.0	12.4	29.3	109.7
WFD	22	23	2	24	21	22	136	5.2	7.0	8.9	9.8	6.9	10.6	48.4
WFD (Info)	24	22	58	47	21	65	237	5.8	6.4	20.6	17.4	7.8	24.3	82.2
Chameleon		23	23			23	69		7.3	9.1			10.6	27.0
Chameleon (Info)		30	41			59	130		7.5	14.5			22.9	44.9
Total	97	152	206	132	84.0	246	917	24.0	41.3	70.0	52.1	27.1	97.6	312.1

7. Monitoring and evaluation of interventions

7.1 Discharge and irrigation practices

As described in Section 3.1 and Table 3.2, the water supply performance assessment revealed fluctuations in water supply through space (i.e. block, tertiary canal, quaternary outlet, etc.) and time within the cropping season. Data were collected during specific cropping stages to assess spatio-temporal variability in the water supply at the farm level. In total 934 discharge points from 108 farmer fields were collected throughout the irrigation season. The field discharge data were used to investigate significant differences between farmer fields within the same Qc, Tc and block. Discharge data were found to be primarily influenced by the block and the Tc and varied to a lesser extent within a particular Qc. Hence, discharge data were averaged per Tc and used to calculate the applied irrigation depth for each irrigation event for each of the monitored farmers. Data collected for each irrigation event included date of irrigation, start and end time of each irrigation events. The total time taken per event was multiplied with the average discharge to estimate the irrigated volume per event. All irrigation events in each season were aggregated for the entire season to obtain the total irrigation depth applied for each farmer.

7.2 Monitoring of soil characteristics

Despite the general observation that soils are relatively homogenous, we verified the variability in texture, field capacity and wilting point. Across the six blocks, 144 soil data points were taken and analysed on texture, organic matter, field capacity (FC) and permanent wilting point (PWP). In general, soils were relatively homogenous across the different blocks for OM, Clay content, FC and PWP (Table 7.1).

Table 7.1 Mean and standard deviation of measured soil parameters across the six blocks.

	Kudmi	**Chihona**	**Adibera**	**Tagel**	**Andinet**	**Taleta**
OM (%)	2.9±0.4^{a}	3.3±0.6^{a}	3.1±0.4^{a}	3.4±1.2^{a}	3.2±0.6^{a}	2.8±0.4^{a}
Clay (%)	59.6±9.4^{b}	59.3±10.0^{b}	58.6±5.7^{b}	57.9±12.1^{b}	69.0±13.7^{a}	64.7±11.0^{ab}
FC (%)	35.1±4.5^{a}	34.5±2.3^{a}	34.6±2.0^{a}	34.4±3.2^{a}	33.5±1.4^{a}	34.2±2.3^{a}
PWP (%)	22.1±3.3^{c}	24.2±2.6^{a}	24.1±2.2^{ab}	22.4±1.7^{c}	25.4±3.0^{a}	23.5±2.4^{bc}

[1] Note: values with a different superscript show a significant difference at a $p< 0.05$ for the tested parameters of OM, Clay, FC and PWP.

7.3 Agronomic performance

Information on field size, number of furrows and beds, bed and furrow length and width were collected as well as the GPS co-ordinates for the field's centre. The type and quantity of agro-chemical inputs (fertilizer and pesticides) applied was monitored throughout the cropping season. During the initial stages, plant density was recorded using 1m^2 quadrants as sowing practices could have varied and therefore potentially influenced observed yield responses. Wheat is harvested either manually or through the use of a combiner. For manual harvests, wheat bags were counted and weight whilst for those using a tractor/combiner, yield was automatically recorded. Data collection sheets used are provided in Annex II. Crop water productivity was calculated as the ratio of yield over total irrigation depth applied (CWP_{Irr}) for the field data, as the ratio of yield over actual evapotranspiration (CWP_{ET}) from the remote sensing data.

7.4 **Farmer feedback**

After the first irrigation season (2017-2018), meetings were held per tertiary canal in each block to reduce the travel time for farmers and to increase participation. From all invitees, 409 farmers (41%) participated (53 from Kudmi, 86 from Chihuna, 91 from Adbera, 52 from Tagel, 46 from Andinet and 81 from TelET block) which which 94 were WFD users, 44 were Chameleon sensor users, 72 were farmers who received information from those using the WFD technology and 37 from those using Chameleon sensors. The control group (i.e. 164 farmers) were asked only general questions in terms of water governance.

7.5 **Impact of interventions on irrigation practices, crop yield and water productivity at farm level**

The impact of the interventions on water use, crop yield, and crop water productivity was assessed using a combination of field measurements and data abstracted from the WaPOR database (Table 7.2). Proc MIXED in SAS was used to assess whether the interventions significantly influenced the amount of water irrigated and increased wheat productivity and wheat water productivity. The analysis was carried out for each irrigation season separately using a nested design with technology and information access within each technology as fixed effects across all 6 irrigation blocks. Farmers within the same quaternary canal in the same treatment were taken as repeated effects reflecting the variability in plant density, applied nitrogen and phosphorus. In a second analysis, the project looked at block specific performance by adding block as an additional fixed factor in the nested model. Hence, the model investigated whether responses to the interventions varied among the different blocks, the technology within the block and the access to the information within the block. Models were established for each of the variables in Table 7.2 checked for homogeneity of variance and normal distribution of the residuals. Variables were log transformed when needed.

Table 7.2 Overview of the data used for the on-farm field level assessment

	Symbol	**Source**
Variables analysed		
Irrigation depth applied per event	Event_{irr} (mm)	Field observations
Total Irrigation depth applied	Total_{irr} (mm)	Field observations
Seasonal (ET) at field level	ET (mm)	WaPOR
Beneficial fraction	B-ET (mm)	Calculated using WaPOR (ratio T/ET)*
Ratio of evapotranspiration over total water received	$\text{ET}/\text{Total}_{Irr}+\text{P}$	Calculated using WaPOR and field data*
Wheat grain yield	Y (t/ha)	Field observations
Crop water productivity	CWP_{Irr} or CWP_{ET}	Field observations and WaPOR
Additional variables included in the model as random effects		
Nitrogen applied	N (kg/ha)	Field observations
Phosphorus applied	P (kg/ha)	Field observations
Plant density	PD (#/m)	Field observations

*see Section 5.2

8. Improving water productivity at the farm level

8.1 Impact of interventions on irrigation practices and evapotranspiration at farm level

Results confirm that access to irrigation scheduling tools and information did influence farmers irrigation practices, which resulted in a reduction in the amount of water irrigated per event and therefore to an overall reduction in the amount of water irrigated within the season (Table 8.1). Overall, the analysis highlighted that the extent to which farmers reduce irrigation depends on the reliability of water in the scheme, the trust the farmers have in the technology aiding them in their irrigation practices or the information provided by their neighbours (see Section 9).

Across the six different blocks, the coefficient of variation among the different treatments varied between 20 to 30% indicating a medium variability among the on-farm results in each treatment group. However, the reduction in water application per event and over the entire season varied strongly among the various blocks (Figure 8.1 and 8.2) and was influenced by the number of irrigation events and the reliability of the water supply.

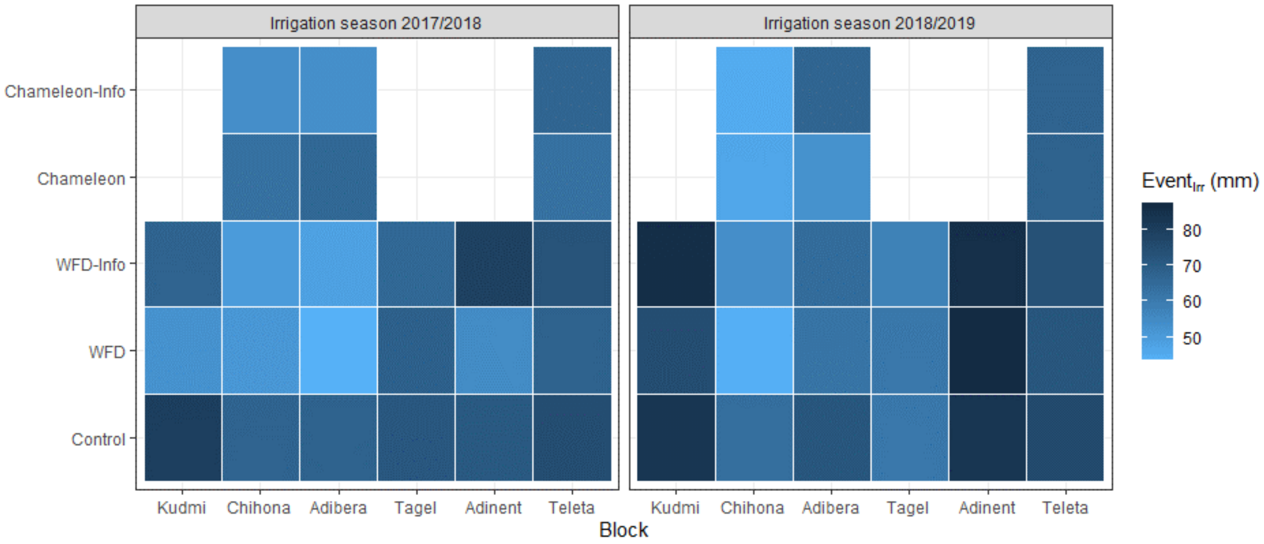


Figure 8.1 Heat map showing the median amount of water irrigated (mm) per event in each treatment per block for the 2017-2018 irrigation season (left) and 2018-2019 (right). Darker colors show a higher value.

Table 8.1 Descriptive statistics of the irrigation performance parameters monitored over two seasons for the three treatment groups (control, WFD and chameleon) and its distinction between whether the farmers had access to the technology or to the information.

		1st Irrigation Season				
Treatment		**Control**	**WFD**		**Chameleon**	
Intervention			Tech	Info	Tech	Info
Event$_{Irr}$ (mm)	N	384	122	224	64	139
	Mean ± SD	71±15^{a}	61±19^{b}	64±19^{b}	64±17^{b}	63±18^{b}
	Median	73	57	65	64	63
	CV(%)	21.3	30.9	29.0	26.7	29.2
Total$_{Irr}$ (mm)	N	384	122	224	64	139
	Mean±SD	655±164^{a}	583±190^{bc}	597±189^{b}	520±134^{cd}	525±156^{d}
	Median	640	567	581	517	492
	CV(%)	25.0	32.6	31.7	25.8	29.8
ET (mm)	N	336	102	189	59	120
	Mean±SD	490±118^{a}	489±119^{a}	502±106^{a}	507±112^{a}	478±111^{a}
	Median	501	509	522	506	477
	CV(%)	24.0	24.4	21.2	22.2	23.3
T/ET	N	336	102	189	59	120
	Mean±SD	0.75±0.07^{a}	0.75±0.08^{a}	0.76±0.07^{a}	0.75±0.07^{a}	0.74±0.08^{a}
	Median	0.77	0.77	0.79	0.77	0.76
	CV(%)	9.9	10.7	9.3	9.9	10.9
ET/Total$_{Irr}$ +P	N	336	102	189	59	120
	Mean±SD	0.60±0.19^{b}	0.66±0.23^{ab}	0.67±0.22^{a}	0.73±0.24^{a}	0.69±0.22^{a}
	Median	0.58	0.68	0.68	0.69	0.7
	CV(%)	31.8	35	31.9	32.9	31.6

Across the six blocks and depending on the season and the intervention, the median irrigation depth applied per irrigation event was between 71 and 73 mm in the control treatment. The estimated average irrigation depth applied decreased to 54 to 66 mm, a decrease by 7 to 24% depending on the intervention (Table 8.1).

On average farmers irrigated 8 to 11 times which corresponds to the findings from the baseline survey conducted during the User Needs Assessment (FAO and IWMI, 2018). Given the rotational schedule in the water user group, farmers did continue to take water when it was their turn out of fear that at a later stage they would not be able to access water (see section 9.3). Hence, the total median amount of water applied for wheat in the control treatment was 640 mm (season 1) and 586 mm (season 2). Farmers who were using the chameleon sensor or the information derived therefrom would reduce their irrigation up to 492 mm – 517 mm (season 1) or 427 mm – 503 mm (season 2). This was a reduction of approximately 25% compared to the control treatment, depending on the total number of irrigation events, the block and the intervention at the farm level.

Note: A difference in colour shows a significant difference between the three treatments (control, WFD and chameleon) at a $p< 0.05$ level. Different superscripts shows the significant difference for the treatments and the information-technology intervention therein at a $p<0.05$ level.

		2nd Irrigation Season				
Treatment		**Control**	**WFD**		**Chameleon**	
Intervention			Tech	Info	Tech	Info
Event$_{Irr}$ (mm)	N	344	126	204	61	130
	Mean±SD	73 ± 17^{a}	67 ± 19^{bc}	69 ± 18^{ab}	59 ± 16^{d}	65 ± 21^{cd}
	Median	71	64	66	54	65
	CV(%)	23	28.9	25.8	27.6	31.6
Total$_{Irr}$ (mm)	N	344	126	204	61	130
	Mean±SD	618 ± 154^{a}	570 ± 186^{b}	566 ± 164^{ab}	469 ± 127^{d}	521 ± 145^{c}
	Median	586	529	540	427	503
	CV(%)	25	32.6	29.0	27.2	27.9
ET (mm)	N	304	102	174	57	112
	Mean±SD	577 ± 90^{a}	573 ± 95^{a}	575 ± 93^{a}	581 ± 90^{a}	567 ± 91^{a}
	Median	590	589	599	590	574
	CV(%)	15.5	16.6	16.1	15.5	16.0
T/ET	N	304	102	174	57	112
	Mean±SD	0.79 ± 0.04^{a}	0.79 ± 0.05^{a}	0.79 ± 0.04^{a}	0.78 ± 0.04^{a}	0.78 ± 0.04^{a}
	Median	0.8	0.8	0.8	0.79	0.79
	CV(%)	5.3	6.1	5.0	5.4	5.8
ET/Total$_{Irr}$ +P	N	304	102	174	57	112
	Mean±SD	0.75 ± 0.18^{c}	0.80 ± 0.24^{bc}	0.81 ± 0.24^{c}	0.93 ± 0.22^{a}	0.86 ± 0.23^{b}
	Median	0.77	0.82	0.78	0.94	0.87
	CV(%)	24.4	30.4	29.5	24.1	26.3

Over both seasons the WUGs with chameleon technologies tended to outperform those using the WFDs. Although lower, significant reductions were also obtained in the WFD and WFD+ information treatments (Table 8.1). Across both technologies, little difference was found between those having the technology and those being dependent on the information (Table 8.1). Results suggested that, if information is provided and water supply is reliable, not each farmer necessarily requires technologies installed in their field.

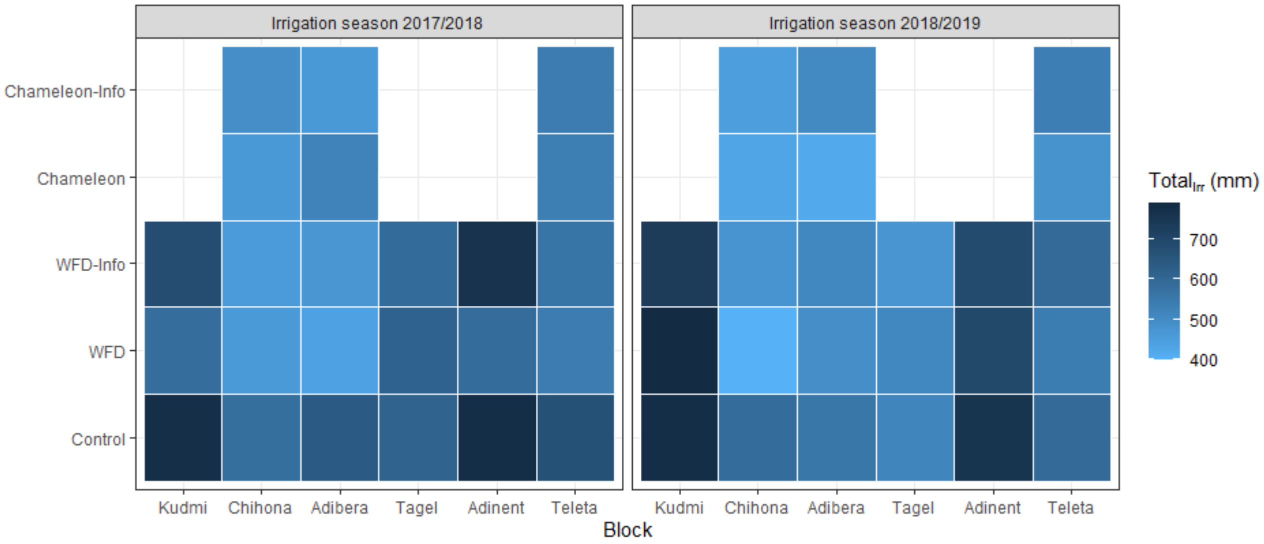


Figure 8.2 Heat map showing the median total amount of water irrigated (mm) in each treatment per block for the 2017-2018 irrigation season (left) and 2018-2019 (right). Darker col ors show a higher value.

However, the results were not conclusive among all the blocks and depended on the reliability of the water supply (see Section 2.3), the trust farmers felt for the information that was supplied as well as the confidence in their neighbours correctly using the technology (see Section 9). For example, the impact of the interventions on the amount irrigated per event and the total per season was not found to be significant for Tagel and Andinet compared to the control group.

Overall, the differences observed in water applied in each of the treatments was not captured through the remote sensing data, either in the pixel level actual evapotranspiration or in the beneficial ET (Table 8.1). This finding was consistent for both seasons As the water application method remained the same (i.e. furrow irrigation) the only factor influencing ET would be the increase of biomass and therefore the transpiration component. Aside from the expected uncertainty within the ET estimates, given the small field sizes it is also possible that the interventions have not significantly influenced above ground biomass production but rather influenced the grain production.

8.2 Impact of interventions on crop yield and water productivity at farm level during the irrigation season

Across both irrigation seasons, the wheat yield varied between 1 and 5 t/ha across the various treatments. Median observed yield in the control group was 2.7 t/ha (2017-2018) and 2.8 t/ha (2018-2019), on average 7 to 44% lower than the median observed in the 4 intervention groups (i.e. WFD-tech, WFD-info, Chameleon-tech, Chameleon-info). The coefficient of variation was moderate within the treatment, ranging between 22 and 34% depending season and intervention. The highest median yield was observed in fields under the chameleon-tech treatment in both seasons (4.0 t/ha 2017-2018 and 3.6 t/ha 2018-2019) followed by those receiving information in the same water user group (Table 8.2). Across the blocks, wheat yield was found to be significantly lower in the control group compared to the WFD and Chameleon interventions across the six blocks (Table 8.2). On contrary to the irrigation amounts, the yield was found to be lower when farmers received information compared to when farmers had access to the technology (Table 8.2).

In depth analysis within the various blocks showed a higher variability of treatment responses to crop yield. Wheat yield was highest in Teleta and Adibera and lowest in Chihona (Table 8.2). Furthermore, the median wheat response under WFD and WFD-Info showed a larger variability among the different blocks compared to the Chameleon treatments (Figure 8.3).

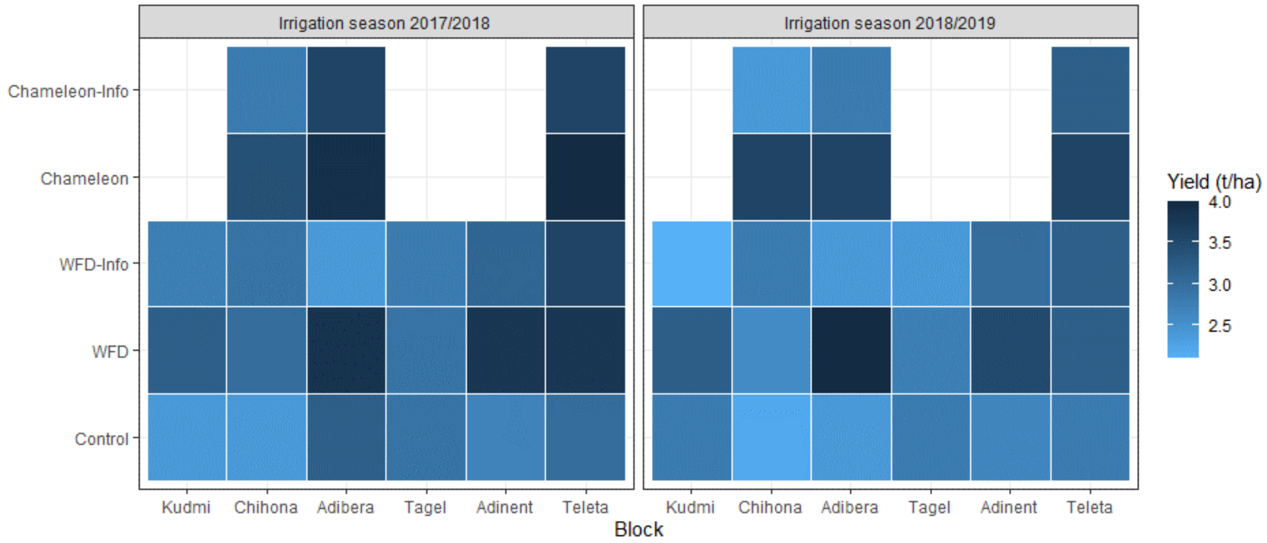


Figure 8.3 Heat map showing the median yield (t/ha) in each treatment per block for the 2017-2018 irrigation season (left) and 2018-2019 (right). Darker colors show a higher value.

Table 8.2 Descriptive statistics of crop and water productivity performance parameters monitored over two seasons for the three treatment groups (control, WFD and Chameleon) and its distinction between whether the farmers had access to the technology or to the information.

		1st Irrigation Season				
Treatment		**Control**	**WFD**		**Chameleon**	
Intervention			**Tech**	**Info**	**Tech**	**Info**
Nitrogen (kg/ha)	**N**	384	122	224	64	139
	Mean±SD	97±38^{a}	92±32^{ab}	92±29^{ab}	89±30^{b}	87±35^{b}
	Median	82	82	82	82	82
	CV(%)	38.8	34.8	31.7	34.1	40.1
Phosphorus (kg/ha)	**N**	384	122	224	64	139
	Mean±SD	90±14^{a}	88±16^{a}	89±15^{a}	85±15^{a}	89±14^{a}
	Median	92	92	92	92	92
	CV(%)	15.1	18.2	16.4	17.2	15.9
Yield (t/ha)	**N**	384	122	224	64	139
	Mean±SD	2.8±1^{d}	3.3±0.9^{ab}	3.0±1.0^{cd}	3.6±0.9^{a}	3.2±1^{bc}
	Median	2.8	3.3	3.0	4.0	3.6
	CV(%)	34.2	27.6	34.4	25.7	31.4
CWP_{Irr} (kg/m^3)	**N**	384	122	224	64	139
	Mean±SD	0.45±0.17^{d}	0.62±0.24^{b}	0.53±0.23^{c}	0.73±0.23^{a}	0.66±0.25^{b}
	Median	0.42	0.61	0.48	0.72	0.61
	CV(%)	37.9	37.9	42.8	31.2	38.2
CWP_{ET} (kg/m^3)	**N**	336	102	189	59	120
	Mean±SD	0.62±0.29^{c}	0.74±0.33^{a}	0.62±0.29^{bc}	0.75±0.22^{a}	0.73±0.32^{ab}
	Median	0.57	0.69	0.57	0.78	0.69
	CV(%)	46.6	45.2	46.3	29.8	43.4

Note: A difference in colour shows a significant difference between the three treatments (control, WFD and Chameleon) at a $p< 0.05$ level. Different superscripts shows the significant difference for the treatments and the information-technology intervention therein at a $p<0.05$ level.

However, despite the larger variability in the WFD treatments and across the blocks, yield was found to be significantly lower in the control treatment in each block compared to the other interventions except for Kudmi and Tagel. The high variability of yield response among the blocks was a reflection of the amount of water and the amount of fertilizer applied in the block. For example, in blocks like Adibera were N and P rates generally were found higher and water application rates lower, higher yields were observed compared to Kudmi and Tagel.

The wheat yield response could be explained by a combination of the amount of water applied per irrigation event or the total amount of irrigation applied in a given treatment in combination with the amount fertilizer applied in that field. Results showed that the translation of improved irrigation practices on wheat yield are subjective to the amount of N and P applied. This could be explained by the correlation found between the irrigation depth applied per event and the N or P applied per ha in function of the intervention.

		2nd Irrigation Season				
Treatment		**Control**	**WFD**		**Chameleon**	
Intervention			**Tech**	**Info**	**Tech**	**Info**
Nitrogen (kg/ha)	**N**	344	126	204	61	130
	Mean±SD	98±20^{a}	96±21^{a}	96±21^{a}	95±21^{a}	99±32^{a}
	Median	98	95	95	92	96
	CV(%)	20.8	21.8	21.5	21.5	32.8
Phosphorus (kg/ha)	**N**	344	126	204	61	130
	Mean±SD	57±18^{a}	55±14^{b}	54±12^{b}	53±18^{b}	53±20^{b}
	Median	55	52	52	50	50
	CV(%)	31.3	25.5	22.8	33.3	37.7
Yield (t/ha)	**N**	344	126	204	61	130
	Mean±SD	2.7±0.8^{d}	3.1±0.8^{ab}	2.9±0.9^{cd}	3.5±0.8^{a}	3.1±0.8^{bc}
	Median	2.5	3.2	2.8	3.6	3.2
	CV(%)	29.1	26.4	31.7	22.6	27.6
CWP_{Irr} (kg/m^3)	**N**	344	126	204	61	130
	Mean±SD	0.47±0.2^{c}	0.61±0.26^{b}	0.56±0.27^{c}	0.78±0.24^{a}	0.63±0.25^{b}
	Median	0.42	0.56	0.5	0.77	0.58
	CV(%)	41.9	42.4	47.7	30.7	38.9
CWP_{ET} (kg/m^3)	**N**	304	102	174	57	112
	Mean±SD	0.49±0.16^{c}	0.57±0.19^{a}	0.52±0.2^{bc}	0.62±0.17^{a}	0.57±0.2^{ab}
	Median	0.48	0.57	0.5	0.65	0.57
	CV(%)	33.4	34.2	38	26.9	35.3

As a result of the interaction, the correlation between yield and amount of water irrigated per event was stronger for the chameleon treatment than for WFD treatment (Figure 8.4).

The translation of a reduction in water applied and corresponding yield increases was reflected in a significant increase in CWPIrr in function of the interventions. The median CWPIrr was 0.42 kg/m^3 for the control treatment and increased to 0.77 kg/m^3 for the Chameleon treatment (Table 8.2). Hence, median CWPIrr values increased between 14% (under the WFD-info, 2017-2018 season) to 83% (under the Chameleon, 2018-2019 season). As there was a difference in observed yield between the farmers who used the technology and those receiving the information, the effect was reflected in the CWPIrr values.

Furthermore, the CWPIrr values did vary significantly among the blocks with blocks with and adequate water supply having lower CWPIrr values compared to blocks with poor water supply performance indicators (Figure 8.5). This is not uncommon as water scarcity at the tail end leads to less over-irrigation compared to the head of the scheme.

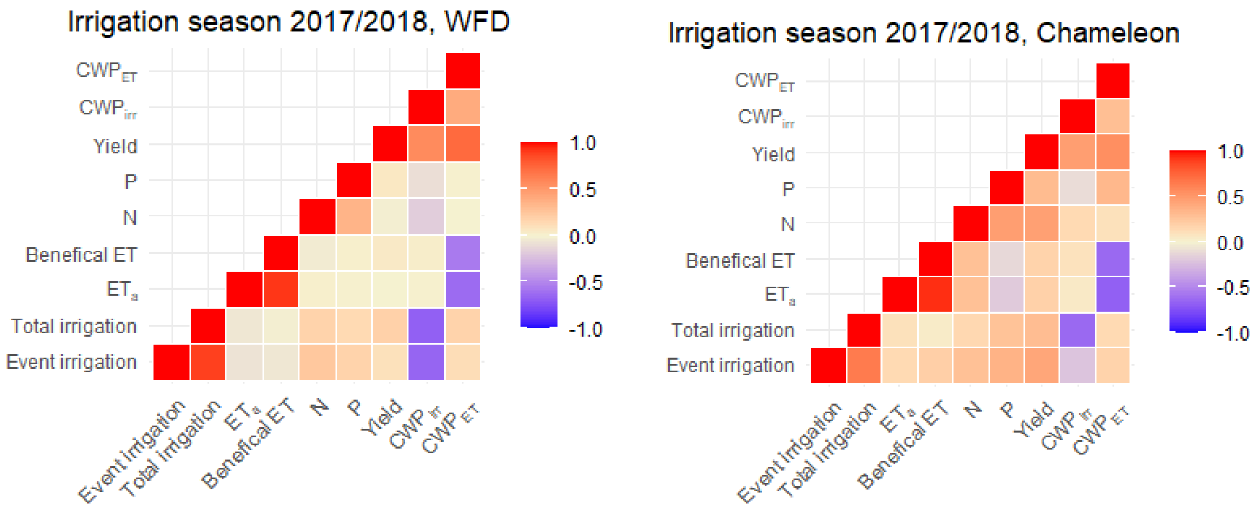


Figure 8.4 Heat map displaying the spearman correlation results between irrigation and crop performance indicators for the WFD (left) and Chameleon treatment (right) using data from 2017-2018.

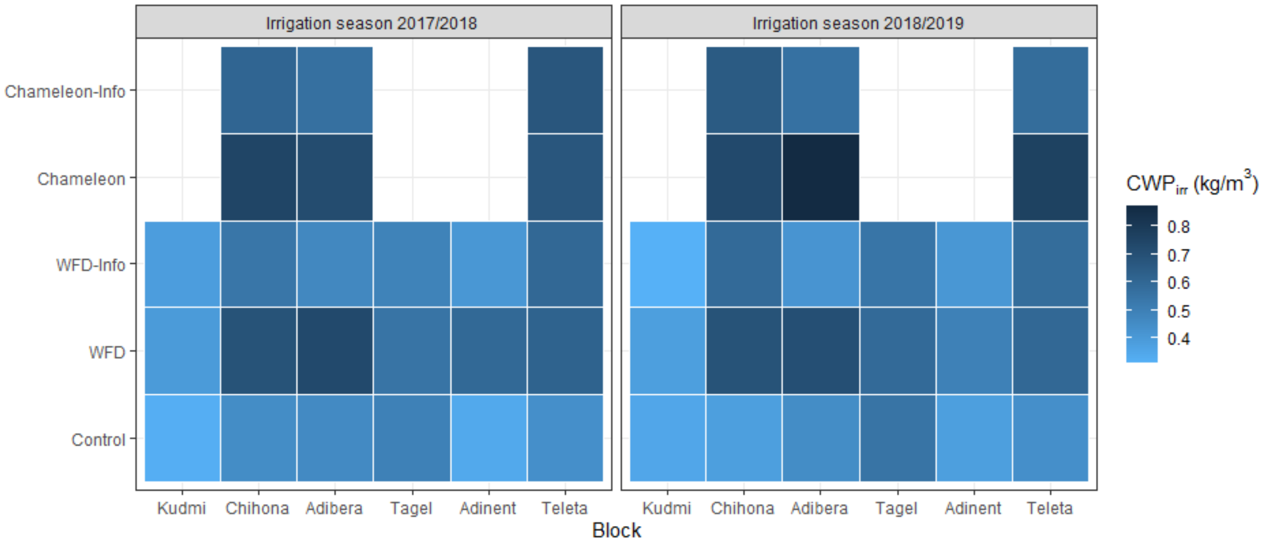


Figure 8.5 Heat map showing the median crop water productivity based on total irrigation water applied (CWPIrr, $kg\ m^{-3}$) in each treatment per block for the 2017-2018 irrigation season (left) and 2018-2019 (right). Darker colours show a higher value.

The CWPET values, calculated using the ET data from WaPOR, were slightly higher than the CWPIrr values (Figure 8.5). However, as ET values did not differ significantly between the fields under the control and the irrigation interventions (see Section 8.1), the difference between treatments using CWPET was found to be less pronounced (i.e. 0% to 37 %) and only reflected the incremental increase in yield in the second season.

9. Farmers perceptions on interventions

Further interpreting the results in Section 8 would require us to look beyond the field data and the interventions and to understand how farmers actually perceived the technologies and the information.

9.1 Farmers perception on using technologies and its impact on irrigation practice

In general, 74% of the WFD users and 32% of the chameleon users found the technologies easy to use (Table 9.1). From the farmers who received the WFD technology and participated in the focus group discussions, 5%, 21%, 38%, and 36% of the respondents answered that they found the technology difficult, not bad, easy and very easy to use, respectively. The few users who responded that the WFD technology was difficult explained that: i) they felt they had not received continous support and hence lacked the expertise, ii) they felt that the response of the WFD did not correspond with their own observation on the "wetness" of the soil; and iii) they did not always carry out the irrigation and the family member did not receive the appropriate training. The latter is interesting as it would suggest that family members would not transfer their technical knowledge or didn't feel they sufficiently mastered the knowledge to transfer appropriately or transfer responsibility to their family members.

Table 9.1 Perception of farmers who used the technology (values are average percentages of the respondents across the respective blocks).

	WFD	Chameleon
How do you rate the use of the technology?		
Very difficult	0%	6%
Difficult	5%	32%
Not bad	21%	31%
Easy	38%	23%
Very easy	36%	9%
Did you reduce your time to irrigate one furrow or for the entire field per event?		
Yes	66%	68%
No	34%	32%
Were there times that you wanted to irrigate based on the technology but you couldn't due to water access?		
Yes	82%	86%
No	18%	14%
Were there times that you couldn't follow the duration of irrigation based on the technology due to water restrictions in your water user group?		
Yes	62%	58%
No	38%	42%

The 21% of irrigators who ranked the WFD as "not bad", stated it was easy to understand the information it provided but that the understanding of how the information corresponded to the amount of water applied and the moisture in the soil was not sufficiently clear. These respondents mentioned they are still trying to understand the tool. The majority of the WFD users (74% of them) responded the WFD was easy since: i) the detector activates automatically (i.e. no reader needed) and the colour of the caps were easy to interpret (when the yellow flag activates it implies the water is enough and when the red flag activates it implies the water amount is too much), ii) data collectors and experts were supportive whenever there was a challenge, iii) understanding or "reading" the WFD does not need any special technical skill, (iv) WFD components are easy to fix; v) the training received was understandable and practical; and vi) farmers were comitted to work with the technology. As a result, all the respondents requested to get the tool for their other crops too in order to manage their irrigation.

For the chameleon users, 6%, 32%, 31%, 23%, and 9% of the respondents stated the chameleon was very difficult, difficult, not bad, easy and very easy to use, respectively. Around 38% of the respondents found the chamelon difficult to use because they: i) were not clear on how to connect the reader with the sensor; ii) didn't trust the information as the color pattern throughout the soil profile remained the same; and iii) color patterns are simple but the interprETtion is complex. The group also suggested that individual trainings were required rather than in group. The users who classified the technology as "not bad" explained that: i) the color display was clear to understand however, sometimes the same color is displayed across all depths which did not correspond to their observation or knowledge; and ii) the the reader had to be shared among the other farmers whilst they prefered to each have an individual reader. The farmers further explained that the training provided seemed simple but that they struggled to implement it in their field and "forgot" how to use it. Those who classified the use of the technology as easy elaborated that: i) the color patterns were clear to understand and apply; and ii) support was provided in the field by the project when challenges occured.

From the particpating farmers who owned a WFD, 66% mentioned a reduction in irrigation time. They elaborated that their decision was based on the the activation of the yellow flag and the time it took to activate. They noted that if the soil was moist the activation time reduced. Some of the participants also noted that once the time is known for one furrow it is easy to apply those to the other furrows and hence further reduces the time to irrigate. Furthermore, some farmers trusted the amount of irrigation applied using the technologies in one irrigation event and sometimes jumped the next irrigation turn which saved both time and labor. However, arround 34% of the respondents stated they didn't observe a reduction in irrigation duration. The reasons mentioned by the respondents were: i) the irrigation time allocated by the WUG is fixed and hence farmers would not like to take the risk to apply less water than allocated by the WUG as there is insecurity about receiving water if needed earlier than allocated; ii) lack of trust with the technology as farmers assumed applying more water would translate in higher wheat yield; iii) unable to manage the other furrows based on the first furrow irrigation time as farmers did not have a watch or cellphone; and v) sometimes the activation of the yellow flag was not consistent across irrgation events which led to shorter as well as longer irrigation times throughout the season. Five out of six blocks, showed similar results whilst in Andinet block more than half of the respondants responded that they did not observe a reduction in irrigation time (36% observed a change and 64% observed no change).

Regarding the chameleon users, 68% of the observed a reduction in irrigation time either within one furrow or across the field. The other 32% of chameleon users did not reduce their irrigation because: i) they did not trust the color patterns for decision making; ii) sometimes the soil was "dry" but the chameleon reads "very wet" attributing it to a technical problem. However, as farmers trusted the amount of irrigation applied using technologies in one irrigation event, they sometimes skipped the next irrigation event resulting in water stress before they had access again in their water user group which reduced their interest in following the technology.

The irrigation interval for all farmers within one WUG is fixed and ranges from 8 to 14 days. Therefore, the project tried to understand whether farmers using the technology would want to irrigate in different time intervals and whether this resulted in additional conflicts or whether WUGs would allow a change in irrigation interval. Over 80% of the technology users responded that they tried to receive water outside their original schedule. Explanations provided were: i) during the first irrigation event farmers believed that they applied sufficient to jump one irrigation event which resulted in plant water stress as their were unable to irrigate before their next turn; ii) when irrigation access was provided in the evening or afternoon whilst water in the main, secondary or tertiary canals were reduced and hence insufficient water was applied prior to their next turn; and iii) in some cases the fixed irrigation schedule was shorter than the time needed to irrigate their entire field. Borrowing water from neighbor or appling more water during the next turn were mechanisms used by farmers to solve this problem. Only, 18% of the WFD and 14% of the chameleon respondents mentioned their received water as they needed and did not experience water shortage.

Overall, 62% of the WFD and 58% of the chameleon users mentioned times throughout the season where the time needed to irrigate their field was not followed. Some of the most frequently mentioned explanations were: i) the time allocated by the water user group doesn't consider the technologies advice; ii) the field was very dry and required more time than allocated by the WUGs; and iv) the discharge was low and hence more time would be required than allocated. Farmers, experiences these challenges mentioned that they had no other choice than wait till their next turn. On the other hand, about 38% of the WFD and 42% of the chameleon respondents said they did not face such challenges and strictly followed the technology advice which they believed helped avoid water shortages in their field and the water user group, and sometimes they borrowed water from their neighbour. There were some differences observed among the blocks as more than 70% of the respondents from Kudmi, Andinet and Teleta noted more challenges with water access influencing the duration of their irrigation events compared to the other blocks. Overall the results suggest that the governance by the WUG and the operation of the scheme continue to signficantly influence farmer's irrigation behaviour and that access to the technology does not necessarily influences water rotation or access within the WUG in the first year.

9.2 Accessibility and functioning of the information platforms

In the WFD and Chameleon platform, respectively 68% and 75 % of the technology users said they provided information (Figure 9.1). Type of information provided was similar for both type of plata forms and a combination of time to irrigate one furrow, furrow length, area of the field, and time taken to irrigate the entire field.

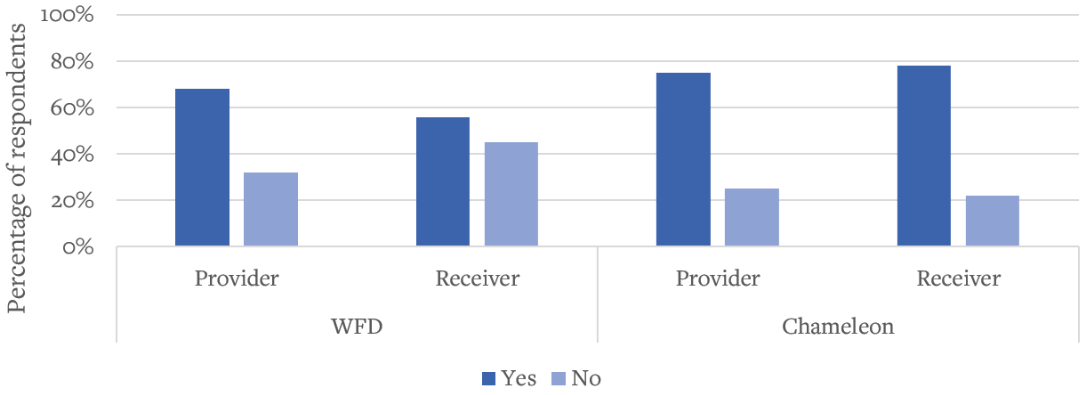


Figure 9.1 Percentage of respondents who provided and received information within the WFD and Chameleon platform respectively.

The WFD users who responded they did not provide information (i.e. 32%) elaborated that: i) they did not understand the technology in the beginning and only started to provide information after sometime when they “mastered” the technology, ii) the information receiver was not present in the field; and iii) the detector did not activate and hence no information was transfered. In the chameleon platform, 25% of the technology users responded they were not providing information in the begining because: i) they did not trust the technology; ii) the information receiver did not trust the information and; iii) information receiver was not present to receive the information.

For the WFD platform, 56% of information receivers mentioned they received information on furrow length, area of the field, time taken to irrigate one furrow, and time taken to irrigate the whole field. Respondents, when asked about why they received the area of the field and furrow length, responded that it enabled them to convert the information to their plot size and furrow length. The remaining information receivers responded they did not receive information as: i) at the beginning the technology farmer was not confident with the technology; ii) the furrow preparation was different and the farmer did not trust the information or didn’t know how to convert and iii) lack of trust in the technology. In the chameleon platform, the explanation for not receiving the information were: i) lack of trust between information provider and receivers, ii) one of the family members who didn’t know how to transfer inormation was irrigating the field and it was difficult to get the information, and iii) lack of communication system as the fields were far from eachother.

9.3 Farmers' perception on using the information and its impact on irrigation practices

In the WFD based platforms, 20%, 39%, 41% of the information receivers classified the information as not bad, easy and very easy to use, respectively. Reponses were relatively uniform across the blocks. Some farmers explained sometimes the information provider did not give "clear" or "useful" information and hence categorized the information as "not bad". Around 80% of the respondents said the information they received was easy because: i) they visited the information providers which helped them to trust the technology and the information they received, ii) they were willing to learn and apply the information they got; iii) the information on time taken to irrigate one furrow and/or the entire field was easy to apply and iv) project provided support when needed between the information receivers and providers (Table 9.2).

Table 9.2 Perception of farmers who received information (values are average percentages of the respondents across the respective blocks).

	WFD	**Chameleon**
How do you rate the use of the information?		
Very difficult	0%	0%
Difficult	0%	0%
Not bad	20%	43%
Easy	39%	50%
Very easy	41%	7%
Did you reduce the time to irrigate one furrow or the entire field per event using the information?		
Yes	63%	47%
No	37%	53%
Were there times that you wanted to irrigate based information received but you couldn't due to water access?		
Yes	93%	60%
No	7%	40%
Were there times that you couldn't follow the duration of irrigation based on the information received due to water restrictions in your water user group?		
Yes	73%	55%
No	27%	45%

Similarly, for the chameleon network, 43%, 50%, 7% of the respondents classified the information received as not bad, easy, and very easy, respectively. The reason categorizing the information as "not bad" was explained by the respondents as follows: i) it took the information providers some time to provide "clear" information; ii) not using the chameleon sensor as the colour pattern remained blue whilst the soil resembled a drier status. The majority of the chameleon information users (57% of the respondents) said the information obtained was easy because i) information providers who provided information were clear on the type of information provided, iii) they were committed to learning from the technology, and iii) they trusted the technology as they went and observed the color pattern when receiving the information.

Information receivers in the WFD-platform tend to reduce the time to irrigate their field (Table 3). The exception was Taleta, which is likely related to general water shortages as it is situated at the tail end of the scheme. The information receivers who did reduce their irrigation practices explained: i) they received the area of the field and the furrow length and hence were able to convert the information to their field situation; and ii) they visited the technology periodically and hence gained trust in both the technology and information shared. For the chameleon platform, the information receivers who reduced the duration of their irrigation events were slightly below 50%. Whilst 47% of the receivers claimed that they trusted the technology, information and where appreciative of the additional support the project provided, there was a significant number of information receivers who did not trust the technology. Additional reasons for not following the information were: i) the information providers took time to adopt the technology; ii) irrigation time within the WUG is fixed and hence if the advice resulted in a longer irrigation requirement it was not feasible and; iii) whilst the technology indicated "sufficient" water availability the information receivers classified the information providers land as "dry".

Information receivers in both platforms (i.e. WFD and chameleon), were asked whether there were times that they wanted to irrigate based on the information but did not receive water access. The majority of respondents answered positively (Table 3). Causes for changing their irrigation request were mainly related to the actual scheme operation as farmers mentioned low discharge in the canals and at their farm inlet, or even not receiving water during their allocated time slot. This meant that they would not necessarily trust the "time" they were told by the information providers. Overall the farmers did mention that this was not a continuous challenge but rather occurred a few times a season. Within the WUG they would, in those cases, try to negotiate and change water allocation schedules or irrigate more than needed to compensate for the earlier shortage.

Furthermore, there were times the information receivers felt that other factors influenced the irrigation duration and that they could not follow the information they received (Table 9.2). Explanations provided by the respondents were: i) the time allocation is area based and fixed within the WUGs and sometimes does not fit with the information received, ii) the field was very dry and required more water than allowed by the WUGs; and iii) the crop was at development stage and requires more water than indicated by the information. This shows that on several occasions aside from scheme operation, rules and regulations of the WUGs, past farmer experience and knowledge does "overwrite" the information received as in the case of the crop stages and the observation of "top soil dryness".

The explanations of both the information receivers and providers show the complexity of setting up information platforms in irrigation schemes as they might in some cases interfere with the defined rotation, is dependent on sufficient water availability and perceptions of a "similar context". Based on the focus group discussions, both technology users and information receivers tend to trust the technology to a certain degree though in specific crop stages or when the scheme environment deviates from a "business as usual" (i.e. sufficient discharge, water allocation schedule) tend to fall back on their own knowledge. Additionally, for the information receivers if they perceive their field condition as "different" from the technology users would opt to not "trust" the information and fall back to their own practices.

9.4 Farmer participation of the information platform and the links to wheat yield

Within the information sharing platforms the majority of providers and receivers observed an increase in yield (Table 9.3). The main reason given was the water application whilst some also added they used a better seed quality and changed the amount of fertilizer compared to other years. Farmers who claimed they did not observe a difference elaborated that either the yield was the same or they could not recall a difference compared to other years.

Table 9.3 Farmers' perception on their participation in the platform and the impact on wheat yield.

	WFD		Chameleon	
Information type	**Provider**	**Receiver**	**Provider**	**Receiver**
Do you think, you obtained a higher yield this year compared to previous years?				
Yes	88%	67%	89%	78%
No	12%	33%	11%	22%
How do you rate the "usefulness" of the technology/information in relation to yield and water consumption?				
Very useful	77%	50%	42%	47%
Useful	18%	32%	52%	31%
Not useful	5%	18%	2%	22%
Bad	0%	0%	4%	0%

After one season, the majority of farmers linked the obtained wheat yield with adjustments in their irrigation practices. When asked to elaborate, the technology users (i.e. information providers) explained: i) the technology responds to the water needed so the crop grows well, ii) by following the time to irrigate one furrow throughout the field, a uniform amount is applied and wheat growth was more uniform. Additionally, farmers explained that it saved labour and helped strengthen the social interaction between farmers in the WUG. Farmers explained that this season, as they reduced their irrigation and hence saved time, the water saved could be used to expand the irrigable land within the WUG or supported a "quicker" rotation and hence reduced water shortages between head and tail users within the WUG. However, not all farmers agreed and explained that the fixed rotation schedule limited the flexibility to follow the technology or the information in their day to day practices. Trusting the technology or information requires time which continues to surface in the discussion with the farmers. Those who classified the technology as not useful were mainly information receivers who wanted to follow the technology for several seasons, some even indicating 2 to 4 years, before deciding on the usefulness of the technology. Hence, establishing successful platforms take time in terms of familiarization with the technology, building trust within the platform and optimizing information flows.

9.5 General farmer feedback on the information platform and water governance

When farmers where asked about the lessons they learned over the past season and their recommendations. Respondents mentioned the project created awareness about on-farm water management and the use of technology/information to guide their irrigation practices. They noticed a more uniform distribution between head and tail users and a reduction in water related conflicts within the WUG. That there are a number of water related conflicts in the WUG was mentioned by the control WUGs: i) “frequently the water allocated to the WUGs is not sufficient and there are issues of water theft”, ii) “farmers allocated at the head of the outlet use more water and hence create shortages for the tail farmers”. Farmers in the control group further explained that they follow the water allocation schedule and hence when they receive water they use the water until the irrigator, they have to hand over to, is present in the field. They noticed that sometimes water logging does occur in their field and related that to a potential reduction in wheat yield.

Whilst several technology users requested additional sensors to support irrigation decision making for other crops, the information users preferred to receive the technology. Further research is needed to understand what the main drivers (e.g. trust, social status in the village) are for the information users to prefer the technology and whether the technology is changing power relations in the WUG. Hence, recommendations from the technology users and the information receivers were slightly different. The technology users mainly focused on receiving multiple technologies and asked the project to create awareness beyond the current 90 WUG to further improve water allocation. The information receivers suggested that the project should: i) increase the monitoring of the technology farmers to ensure that “clear” and “correct” information was shared, ii) work with scheme management to develop a flexible schedule that would fit with the crop water demand and the information received, iii) install both the WFD and chameleon sensors in the same field so that farmers could “choose” what worked best, iv) change the technology users if they were unable to provide information or use the technology, and v) ensure that the information providers and receivers were adjacent as several farmers do not have mobile phones and hence were unable to share or receive information. Despite the challenges observed in the first year, the farmers participating in the focus group discussions unanimously agreed to continue testing the technology and be part of the information platforms in the WUGs.

10. Recommendations for improving crop and water productivity in irrigation schemes

This study piloted an approach to identify water productivity gaps within the Koga irrigation scheme and improve water productivity at the Water User Group (WUG) level by combining the analysis of remote sensing-based water productivity indicators available in the WaPOR database with the application of in situ technologies., The approach can be readily upscaled to target larger interventions within the Koga irrigation scheme or to replicate in other irrigation schemes across Ethiopia and elsewhere.

The case study in Koga provided valuable lessons in improving water productivity:

- **Target intervention zones through remote sensing and in-field measurements:** the potential use of the WaPOR database in understanding productivity challenges in the scheme as a result of poor water supply performance has been demonstrated. The various parameters (ET and GBWP), as well as calculated indicators (the beneficial fraction), in combination with discharge based performance indicators, have provided valuable insights to design interventions to improve water and crop productivity in an irrigation scheme.
- **Co-design interventions locally with water-users and scheme managers:** implementation design allowed water user group leaders to determine with their farmers who would receive the technologies and who would receive the information. Whilst one could argue that this would lead to a self-selection bias and complicates the impact assessment, it is a crucial step in the adaptive learning process and strengthening the functioning in the water user group. The farmers feedback confirmed the importance of trust and communication contributing to the success of this project. This can only be achieved by respecting the social networks and the intrinsic water schedule. One could explore a few seasons after implementation whether the use of the technologies has further improved confidence and would have in the long term potentially altered the rotation schedule. This would require a longer impact assessment.
- **Information access can be as transformative as accessing technologies:** farmers access to contextually relevant information can be as transformative in adjusting irrigation practices as access to the technologies which provide this information. To what extent this relates to crop and therefore water productivity will depend on the interaction of the practices with the affordability and ability to supply fertilizer and the reliability of the water access.
- **Improving water productivity requires the water and the fertilizer interventions to be staggered:** the project decided consciously to not tackle both the water and the fertilizer application in the same season. Understanding the interaction of water and fertilizer is key for farmers to adapt both practices in a

staggered program. Tackling both at the same time would undermine trust and complicate the levels of innovations the project aims to convince. It is important to understand where the largest gains are to be made by using RS data at scheme level and a needs assessment at household level. Depending on these results and the objective of the program one can decide to first tackle the fertilizer or first the water objective.

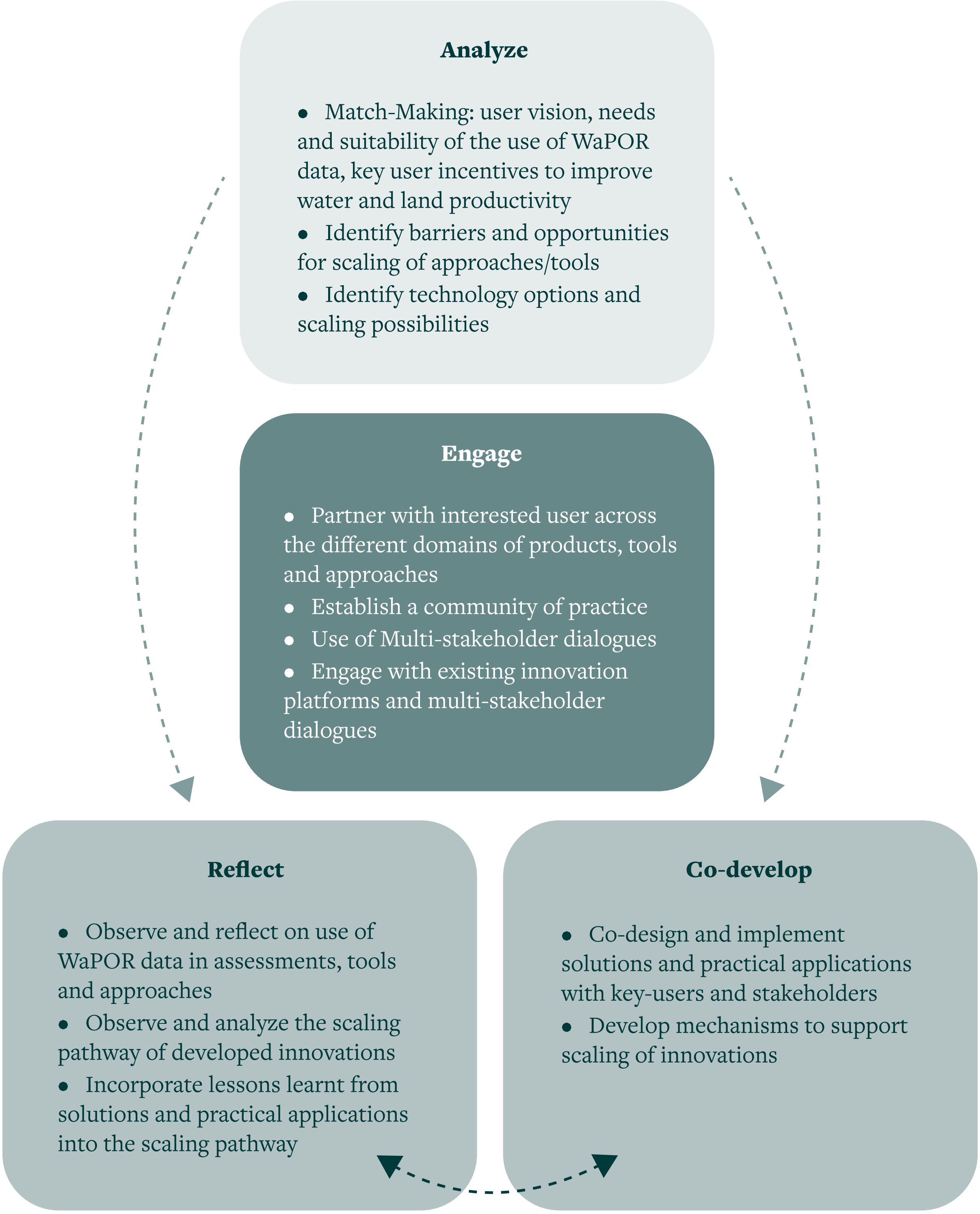
- **Smallholder schemes with diverse cropping patterns require higher resolution RS products to assess intervention impacts:** the ET, B-ET and respective CWPIrr were derived from the WaPOR database for each of the farmer fields. The ET showed less sensitivity across the treatments than expected based on the yield data collected. This could be related to the fact that farmers in Koga further sub-divide their already small plots to enable crop diversification within the irrigation season resulting in field sizes smaller than the 30*30m resolution. Further analysis is needed to understand whether the resolution of the L3 level ET products remains too coarse for smallholder irrigation schemes, as in the case of Koga, to support impact assessments of interventions in the future.

We show, through the case study in Koga, the need for a multi-scale and multi-actor adaptive approach to translate scientific knowledge into actionable and transformational learning. The combination of remote sensing technologies and derived databases such as WaPOR provide a unique insight into determining entry points for tailored and contextually relevant interventions targeted at driving a change in water use in irrigation from farm to scheme level.

Learnings from the adaptive approach have resulted in the development of an analyse-codevelop-reflect-engage framework to support similar projects aimed at using WaPOR to identify opportunities and target interventions to improve water and crop productivity in irrigation schemes (Figure 10.1).

The activities planned from national to field level can be organised in a four-step approach in selected countries in an iterative process:

- **Analyze:** Identify user interest and needs in using WaPOR data to support irrigation interventions and strengthen user-engagement from field to national level
- **Co-develop:** Co-design and implement solutions/innovations/tools with identified users and stakeholder; co-develop mechanisms to support scaling of solutions and tools;
- **Reflect:** Observe and reflect on the use of WaPOR data in assessments, tools and solutions; observe and analyze the scaling pathway of developed innovations; and incorporate lessons learnt from solutions and tools into the scaling pathway;
- **Engage:** Partner with interested users across the different domains of solutions and tools; establish a community of Practice; use of Multi-stakeholder dialogues; and engage with existing innovation platforms and multi-stakeholder dialogues.



Analyze

- Match-Making: user vision, needs and suitability of the use of WaPOR data, key user incentives to improve water and land productivity
- Identify barriers and opportunities for scaling of approaches/tools
- Identify technology options and scaling possibilities

Engage

- Partner with interested user across the different domains of products, tools and approaches
- Establish a community of practice
- Use of Multi-stakeholder dialogues
- Engage with existing innovation platforms and multi-stakeholder dialogues

Reflect

- Observe and reflect on use of WaPOR data in assessments, tools and approaches
- Observe and analyze the scaling pathway of developed innovations
- Incorporate lessons learnt from solutions and practical applications into the scaling pathway

Co-develop

- Co-design and implement solutions and practical applications with key-users and stakeholders
- Develop mechanisms to support scaling of innovations

Figure 10.1 Action research end-user oriented process (adapted from T. Minh *et al.*, forthcoming)

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Annex I Discharge measurements for performance calculation

Measurements taken at different quaternary outlets along six blocks. A total of 453 discharge measurements were collected from 18 quaternary canal outlets (i.e. 3 per tertiary canal) spread over 6 tertiary canals (i.e. 1 per block) (see Demtie, 2020 for dETiled explanation of the methodology). Data collected on a weekly basis were used to calculate the adequacy (P_a), reliability (P_r) and equity (P_e) performance indicators for each of the blocks. A short description is given below whilst the full methodology is described in Damtie (2020).

- **Adequacy Performance Indicator (P_a):** The adequacy indicator or delivery performance ratio is the ratio of the actual discharge at the quaternary canal and the design discharge. A result <1, =1 or >1 implies an under, efficient or over supply, respectively.

- **Equity Performance Indicator (P_e)**: The indicator captures the uniformity of the supply across the different quaternary outlets. The performance indicator defines the variability over time using the coefficient of variation (CV). A value close to zero reflects a relative uniform water delivery among the tertiary canal in the block.

- **Reliability performance indicator (P_r)**: The reliability performance indicator represents the temporal variability at any location. As with P_e, a value close to zero reflects a relative reliable supply over time at the same location.

Annex II: Data collection sheets

Table 1 Data collection sheet used for recording geocoordinates of the field locations

Farmer ID	Block Name	Tc No	Qc No	GPS location of the field X	GPS location of the field Y	Elevation of the field	UTM GPS location of the field X	UTM GPS location of the field Y	UTM elevation of the field

Table 2 Data collection sheet for recording irrigation practices in the selected fields

Block Name	Tc No	Qc No	Treatment	Farmer ID	Area of the field (m^2)	Seed rate used for the field (kg)	Furrow length (m)	Furrow width (m)	Number of furrows	Bed width (m)	Number of beds	Number of furrows irrigated per time

Table 3 Datasheet for plant density Measurement

Block Name	Tc No	Qc No	Treatment	Farmer ID	Date of measurement	Number of plants at quadrant 1	Number of plants at quadrant 2	Number of plants at quadrant 3

Table 4 Datasheet for collecting yield information from the selected fields

Block Name	Tc No	Qc No	Treatment	Farmer ID	What method used to separate the grain yield from biomass (ox, stick, or others mention)	Yield measurement bag size (kg)	Number of bags used

Table 5 Datasheet for collecting information on irrigation water application

Farmer ID	Block Name	Tc No	Qc No	Irrigation event	Date of irrigation	Irrigation time started	Irrigation time ended for one furrow	Irrigation time stopped for the total area	Yellow 1=pop up, 0= pop down	Red 1=pop up, 0= pop down	Chameleon colour of deep	Chameleon colour of middle	Chameleon colour of shallow	Number of furrows irrigated per time

Table 6 Datasheet for recording fertilizer application in the selected fields

No	Block Name	TC No	Qc No	Stage	Date of fertilizer application	Farmer ID	Treatment	crop type	Type of fertilizer applied	Quantity DAP applied in kg	Quantity of urea in kg

Table 7 Datasheet for recording pesticide application in the selected fields

No	Block Name	Tc No	Stage	Date of pesticide application	Farmer Name	Treatment	crop type	Type of pesticide applied	Quantity of pesticide applied in litter

Implementation of on-farm water management solutions to increase water productivity in Ethiopia

This technical report focuses on Koga, in Ethiopia, and describes the process of developing, designing, piloting and evaluating potential solutions to increase water productivity sustainably, which is the third objective of component 4 of the project on WaPOR (Using Remote Sensing in support of solutions to reduce agricultural water productivity gaps). As irrigated areas expand, more attention must be paid to on-farm water management so as to allow for optimal use and distribution of water resources. Using WaPOR data, that is, remote-sensing based water productivity parameters, this report characterises the status of water use and productivity in the Koga irrigation scheme. It also uses the data to measure the changes occuring after the implementation of low-cost tools and irrigation practices so as to: increase yield and to reduce the water consumed or applied during the irrigation season.

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