ICT for Small-Scale Irrigation
A market study

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Digital applications in small-scale irrigation

Digital applications improving efficiency and monitoring agricultural water use play an increasing role in the debate on small-scale irrigation in international cooperation. Firstly, by supporting technical processes for minimizing water use and reducing fertilizer use, as well as saving energy in irrigation technology. Secondly, apps can often facilitate management processes and monitoring of irrigation and operating systems. However, up until now, digital applications specifically targeting small-scale irrigation have only been used sporadically and as pilots in many projects. As part of a market analysis, this report investigates the potential of digital applications for small-scale irrigation. The aim is to identify and structure existing experiences and, based on current developments and challenges, to define further requirements for digital applications in this field.

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Acronyms

AI	Artificial Intelligence
EO	Earth Observation
FAO	Food and Agricultural Organisation
GIAE	Green Innovation Centre for the Agriculture and Food Sector
GIS	Geographical Information System
GIZ	Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICT	Information and Communication Technologies
ICT4Ag	Information and Communication Technologies for Agriculture
IoT	Internet of Things
IT	Information Technologies
IVR	Interactive Voice Response
IWMI	International Water Management Institute
LORA-WAN	LoRaWAN is a cloud-based medium access control (MAC) layer protocol
LPWAN	Low-Power Wide-Area Network: a type of wireless telecommunication wide area network
LTE	Long-Term Evolution: a telephone and mobile broadband standard
NDVI	Normalized Difference Vegetation Index: The NDVI is a simple graphical indicator that can be used to analyse remote sensing measurements, assessing whether or not the target being observed contains live green vegetation.
PAYG	Pay-As-You-Go. Digitally-enabled business models in which services are paid for remotely with small, frequent payments such as daily or weekly instalments, and where the product (e.g., off-grid solar water irrigation pump) can be remotely deactivated or blocked in the case of non-payment.
RS	Remote Sensing
SMS	Short Message Service
SSA	Sub-Sahara Africa
SSAB	Sustainable Smallholder Agri-Business Programme / GIZ
SSI	Small-scale Irrigation
USSD	Unstructured Supplementary Service Data
WIFI	Wireless Fidelity: Family of wireless network technologies

Executive Summary

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Executive Summary

Information and Communication Technologies for Agriculture (ICT4Ag) is a rapidly developing field in which new technologies are integrated as soon as they emerge. At the same time smallholder agriculture remains greatly depended on traditional farming practices. While farmers in Europe and the US operate their own drones to monitor crop health, smallholders in Africa and Asia have limited access to seeds necessary for the next planting season.

With the emergence of phones and smartphones, access to technology has changed. Most farmers worldwide have nowadays at least access to a simple phone with smartphone access increasing rapidly. Smallholders worldwide use SMS services to get market prices, weather alerts or to share machinery and irrigation equipment. They use e-advisory services to get information about possible pests and diseases and they listen to community radio broadcasts and training videos to learn about better agricultural practices.

Very few of these applications target small-scale irrigation, and it is for this reason that this study has been executed and this report produced. The major issues for small-scale irrigation farmers are land degradation, water scarcity, market access and access to finance. This study particularly targets small-scale irrigation, the wide range of ICT4Ag solutions is discussed in various other papers and documents.

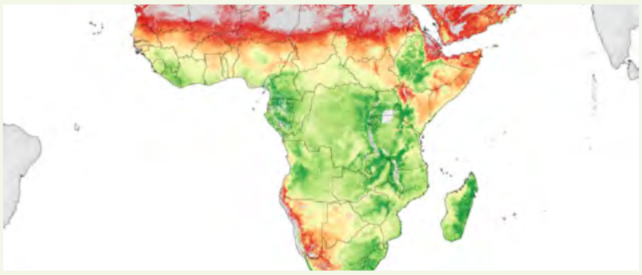
For this study, four fields of application have been identified where ICT can play a major role for small-scale irrigation farmers:

1. ICT-driven improvement of water use efficiency

ICTs help automating irrigation, reduce water consumption, reduce labor costs and enhance yields through sensors, controllers and transmission technologies. Machine learning and artificial intelligence help optimizing irrigation efficiency and apps allow monitoring and remote control.

2. ICT and innovative solutions for behavioural change

Serious games, e-learning and access to ICT based training material helps understanding the complex environment of irrigation and to protect resources, increase smallholders' incomes as well as enhancing environmental sustainability.



3. ICT and monitoring in irrigation

Spatial technologies help in assessing water resources, planning irrigation schemes, and monitoring water consumption and environment. Satellites, drones, sensors, remote sensing and GIS help to create a global picture for decision makers at a higher level.

4. ICT and smallholders' access to information

Farmers need access to localized, tailored information about weather, water consumption, diseases, yield and prices. ICT can channel this information to the smallholder through various technologies such as smartphones, Web-portals, IVR, SMS, USSD.

ICT offers a wide range of technologies from radio to artificial intelligence, from cell phone to satellite. It is not always the latest technology that is the most suitable, and the selection of the most appropriate technology in a given context depends on various factors: the availability of services such as Internet and electricity, the literacy of the target group, as well as their access to technology. A suitable business model is crucial for the sustainability of every ICT4Ag solution. The individual smallholder does not usually have high financial resources, but the number of users of a solution can be high; therefore certain business models can be suitable even if smallholders pay only a small amount. Other business models offer services for free and achieve profits through advertising and market linkages. There is no universal approach for the definition of a pertinent business model for a given solution. This economical aspect needs case-specific analysis and interactions with all stakeholders.

When introducing ICT based solutions, development professionals should always bear in mind to leave no one behind. The most marginalized people are often illiterate and lack access to technology. The successful setup of a project therefore needs to consider many factors, including the social context. This document identifies hurdles at an early stage and indicates appropriate measures to successfully overcome them.

Introduction: ICT4Ag and ICT for small-scale irrigation

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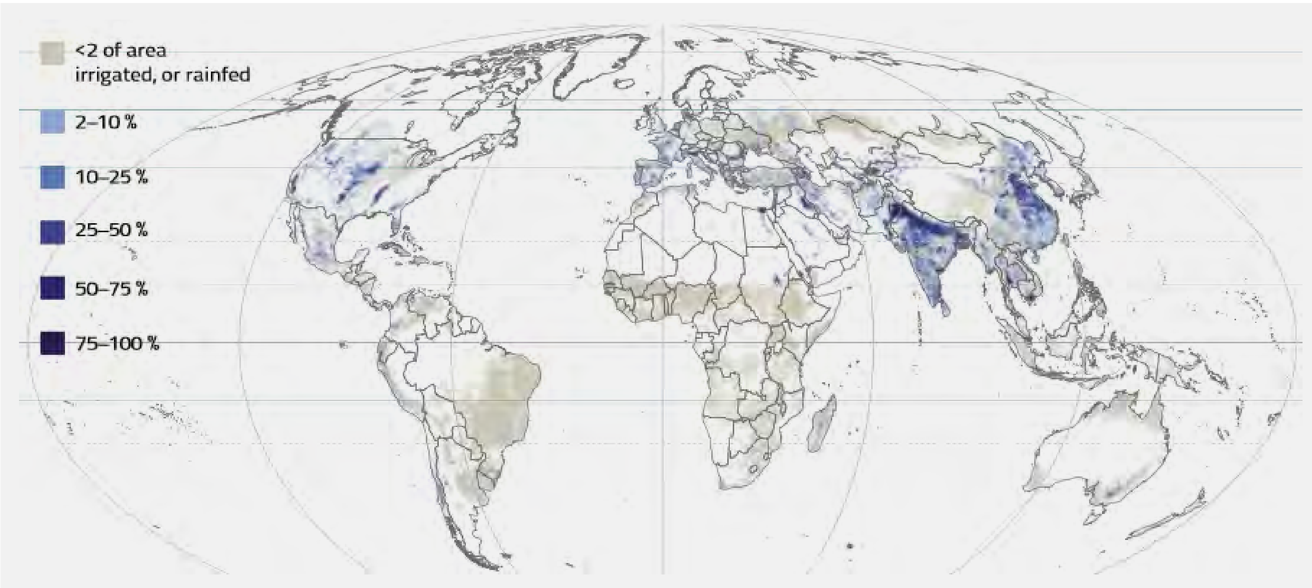
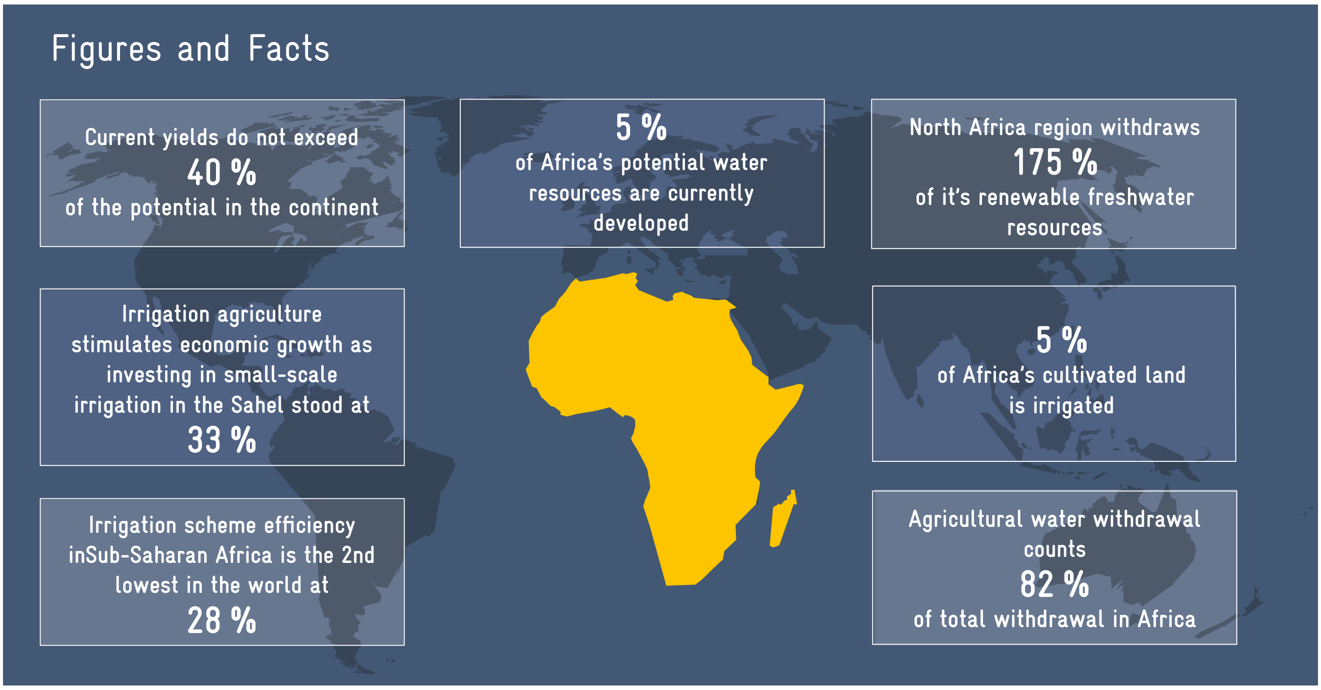
> "Across the developing world, the majority of the poor and most of the hungry live in rural areas, where family farming and smallholder agriculture is the main farming system. Family farming and smallholder agriculture's growth, through labor and land productivity increases, has significant positive effects on the livelihoods of the poor through increases in food availability and incomes."[1]

2.1 The role of Irrigation in Small-Scale Agriculture

Farms less than two hectares in size play a crucial role in global food security. Many regions of Africa and Asia can be defined by their poor access to water. Efficient use of precious water for irrigation is a significant priority for growing crops and enabling food security. In Africa, according to FAO, only 5% of these agricultural lands are under irrigation and the applied irrigation methods are of very low performance . In South America, the situation is not very different. Only in India and South-East Asia the percentage of irrigated agriculture is above average.



Area equipped for irrigation as percentage of land area.[2]



Africa irrigation facts according to the Food and Agriculture Organisation, Land and Water Division.[4]

Irrigation has never been common in most of Sub-Saharan Africa and South America. The climate has enabled farmers to grow their crops, quite successfully, under rainfed-only conditions. But in recent years precipitation patterns have changed and according to climate models they will become less predictable and less reliable[3]. Farmers who rely solely on rain to water their crops risk losing all their produce. Irrigation can improve the resilience of agricultural production and many farmers are actively looking for information on irrigation schemes, and how to get the best out of their farms under changing conditions.

In other regions of the world, irrigation has long been an important element of local agriculture. Irrigated agriculture in arid areas usually developed along perennial rivers. Relicts of first appearances of irrigation can be found in Egypt and Mesopotamia dating back to 5.000BC[5] . Most of these systems were, and still are, gravity-based.

If gravity is not an option, pumps have to be used. Today solar pumps are recommendable as they are emission-free in operation and the costs are lower in the long term. However, solar pumps systems bear the risk of encouraging over-exploitation of water resources because the operational costs for such systems are independent of the amount of water that they pump. At the same time, in combination with ICT equipment solar pumps can support taking account of water abstractions and in that sense support water resource management. In case water has to be pumped for irrigation, solar pumps are ideal for the automation of the systems. A rarely mentioned feature is that they can be easily started and stopped, even remotely. Estimation of pumped water volumes is also easier, and electromotors generally need less maintenance. Coupled with sensors and microcontrollers, they can provide the right amount of water at exactly the right time to the right root level of the plants.

Modern irrigation automation sends status information directly to computers and smartphones. There are examples from India and Kenia where automation of small-scale irrigation pays off economically, operated from just one hectare.

Soil moisture sensors, placed directly into the soil and connected to a controller, detect the soil moisture level, and when it gets too low – when the soil becomes too dry – they send a signal to the controller, which opens a valve to irrigate the soil. These soil sensor systems are becoming much cheaper, to the point that they are affordable for many small-scale farmers. The farmer uses less water per year and is able to recover the investment costs very quickly.

Spatial technologies such as Geographical Information Systems (GIS) and Remote Sensing are useful for finding suitable irrigable land, for identifying available water sources and for planning the technical layout of irrigation schemes. They are necessary for forecasting and monitoring natural hazards, water consumption and productivity. These technologies need a high level of expertise and they are not readily available for regular use by small-scale farmers. Smartphones and feature phones can help make this information accessible to the farmers. Technologies like Interactive Voice Response (IVR) can tackle illiteracy, Unstructured Supplementary Service Data (USSD)-technology can help in areas where Internet is not available.

ICTs help to connect farmers to other agricultural professionals, in their region and throughout the world. Connecting the various stakeholders enables them, through communication and learning, to improve crop production. Israel, for example, is probably the world leader in irrigation technology and understanding the innovations made there will help to better irrigation in other regions. The use of technology in agriculture will continue to increase in the future; gathering data, monitoring inputs and evaluating production helps to make efficient use of resources in an effort to produce better yields.

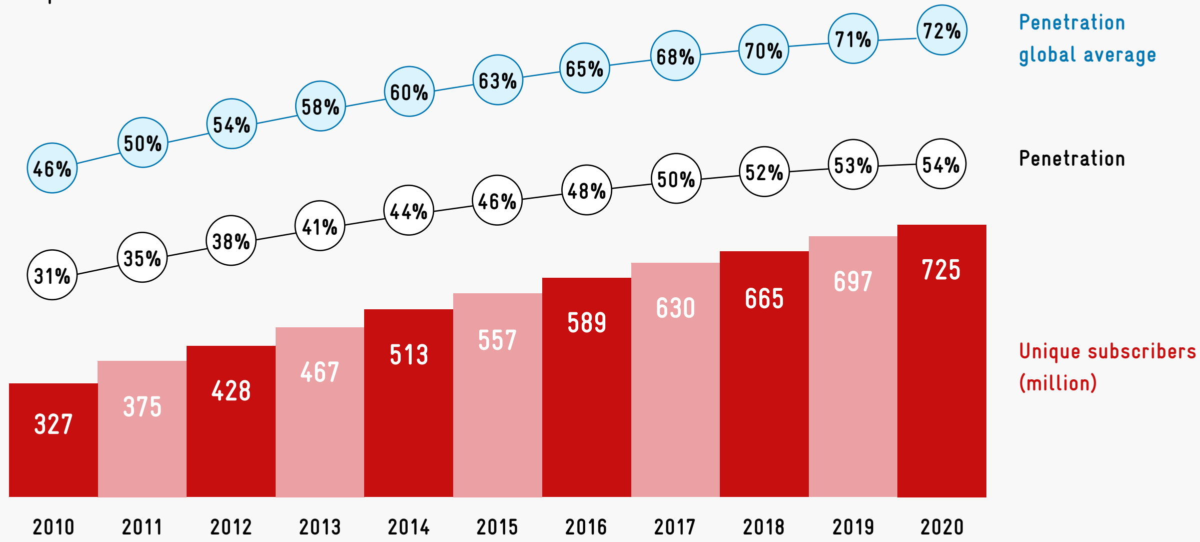
Farmers are normally not very receptive to change. Modern irrigation requires farmers to change their traditional agricultural practices. But sustainable changes in behaviour are only possible on the basis of understanding and communication. In Africa and Asia, the general approach in recent decades has been to introduce better practices through agricultural extension services. On the one hand, ICTs can help to strengthen these advisory services by offering various tools; on the other hand, e-Advisory services can also help streamlining processes and partially reduce the costs of the services. Better communication mechanisms (SMS, Smartphone apps), tools for early warning and pest detection (smartphone apps, drones, cameras), apps for farmer registration, supply chain management etc. are all helping to make agriculture more efficient at all levels. The prospect of higher returns attracts farmers two change their traditional agriculture towards modern technologies and sustainable practices.

Finally, it is the farmer who needs better information for his daily work and for planning his activities. Sophisticated technologies allow modelling hyper-localized and customized information for individual sites automatically. Farmers with cell phones can access this information, get custom-tailored advice on good agricultural practices and early warnings to avoid loss. These services can be offered by governmental advisory services or commercial service providers.

The following figure shows available ICT core technologies and their potentials in small-scale irrigation. Mobile technologies play a huge role, as they allow not only transmitting information to the farmers even out in the fields, but also bi-directional communication and data collection. Computers and servers play a background role in processing information for dissemination, whereas GPS, satellites, drones and sensors are useful for automation and monitoring.

Available ICT core technologies. Highlighted, the technologies suitable for small-scale irrigation.

Unique mobile subscribers in Africa



Source: GSMA Intelligence

The proliferation of mobile phone networks has transformed communication in remote areas worldwide. Cell phone ownership has grown fast and the smart phone market is emerging. Cell phones are most commonly used for making calls and sending text messages. Taking pictures and videos are also relatively common activities. Mobile banking is widely used in only a few countries in Africa, but it bears a high potential.

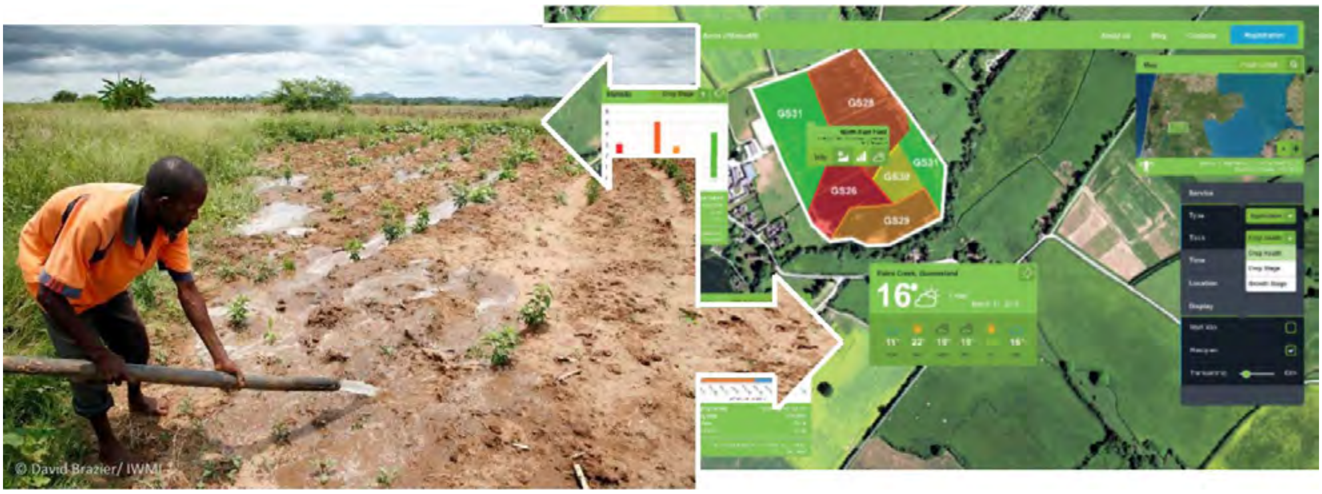
Africa is at the focus of GIZ's agricultural activities because there is a high potential for making agriculture more efficient through building capacities for a great number of small-scale farmers. ICT is a formidable means to address a high number of users because it fosters communication and offers custom-tailored information to the user.

2.2 Challenges and risks

Numerous technologies are available to solve the various problems of small-scale irrigation in Africa and Asia. In many cases ICT may offer a technical solution. Challenges are however, to develop suitable and scalable business models or to select the technology appropriate for the target group. It is not always the latest technology that leads to the desired goals. When developing an IT-based solution, many parameters must be considered. The technical solution has to fit into the social environment and adhere to the current technical conditions of the location where it is used. Further it should also respond to the expected technical development in the near future. Technological development is progressing rapidly, also in Africa.

Not every farmer has a cell phone or can read and understand messages in text-form. The poorest farmers usually have no access to digital technology; thus, the introduction of ICTs can lead to further marginalization. Face-to-face communication is therefore still very important, either in the field, or in formal sessions where farmers visit a local training centre, for example. Practical demonstrations are often the most important means of getting information across, especially when it comes to explaining complex systems such as drip or sprinkler irrigation systems.

A major obstacle for the introduction of ICTs is the related cost: costs to access technology such as smartphones, airtime and Internet, but also costs to finance the services which allow service providers to setup sustainable business models. Many donor-driven IT based services lack a functioning business model. Services have to be free or cheap enough so that smallholder farmers can benefit from them.



ICT offers various technologies – but for every specific case, the right technology level has to be identified.

Contributions from development partners and other actors

The introduction of ICT in agriculture depends on an established regional IT sector. Smallholder farmers usually live far from the capital where IT capacities are centralized. This jeopardizes the successful introduction of ICT in remote areas. Additionally, IT professionals frequently do not know or do not understand the potentials of IT for agriculture. IT professionals often focus on employment opportunities in the financial sector and at communication service providers.

Awareness on the potentials of ICT within agriculture in general and small-scale irrigation in particular can be raised through conferences and workshops. Hackathons and accelerators facilitiate the match-making between challenges in the agricultural sector and IT solutions.

Synergies can be found with programmes developing basic services such as energy, financial services and Internet facilities, as well as with economic components promoting inclusive business models.

2.3 Methodology

The findings of this study are based on interviews and secondary sources. The interviews were mainly held between October and December 2019. The interview partners included experts from GIZ (project representatives as well as planning officers), representatives of projects from various other donors, research institutes and representatives from ICT4Ag solution providers from the private sector. Further-more, subject relevant reports were investigated and complemented through internet research. Finally, the report comprises the results of a workshop which took place in Eschborn, Germany in December 2019, where the findings were discussed among experts from the agricultural and water sectors. The mentioned reports and other sources are referenced in footnotes throughout the report. Links to the most valuable information sources are listed at the end of every chapter of the four application fields.

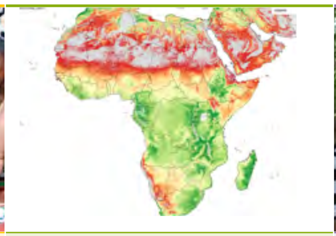
The selected showcases represent only a subset of the available solutions, and the selection is based on their suitability for the four identified fields of small-scale irrigation. Not all the presented showcases were tested and it was not possible to interview representatives from all presented ICT service and solution providers. The presentation of the showcases follows a common structure in order to make the data comparable. Where possible, information about business models, geographic reach, technology and platform is given, and the benefits for farmers are listed. Many links to additional material and information complete the catalogue of showcases.

2.4 Structure of this report

This study attempts to illuminate those sub-sectors of irrigated agriculture where the introduction of ICT can be useful and successful. It aims to shed light on the multitude of technologies available and what to consider when searching for the appropriate technology for a given context. The document lists already available solutions and ongoing projects where ICT for SSI plays a positive role.

This study seeks to identify and understand technologies developed specifically for irrigated smallholder agriculture or support the development of small-scale irrigation as such. It does not aim to cover the wide field of ICT solutions for agriculture in general.[6] For further analysis the study was structured into four different areas of application.

The following chapters present these areas of application. Each chapter includes objectives and potentials for the introduction of ICTs, lists available and suitable technologies and discusses possible challenges and risks. Selected showcases, projects or products complete each chapter. The selection of showcases is based on interviews with development professionals and research by the author. This list is neither complete, nor does it necessarily show the best products of the areas of application. For each chapter, an examplary implementation within a development project is explained in detail. Each chapter concludes with a list of additional resources. At the end of the document a concise list of the keys to success summarizes the obstacles of implementing ICT projects, as well as how to avoid or overcome them.

ICT-driven improvement of water use efficiency	ICT and innovative solutions for behavioural change	ICT and monitoring in irrigation	ICT and smallholders' access to information
			
Solar pumps, sensors, controllers and transmission.	Serious games, e-learning and access to training material.	Satellites, drones, sensors, remote sensing and GIS.	Smartphones, Web-portals, IVR, SMS, USSD.
ICTs help to automate irrigation, reduce water consumption, reduce labor costs and enhance yields.	Behavioural change needs communication, learning and understanding. ICT can channel content to users.	Spatial technologies help in assessing water resources, planning irrigation shemes, monitoring water consumption and environment.	Farmers can access information about weather, diseases, prices and irrigation-related advice through cell phone and Internet.

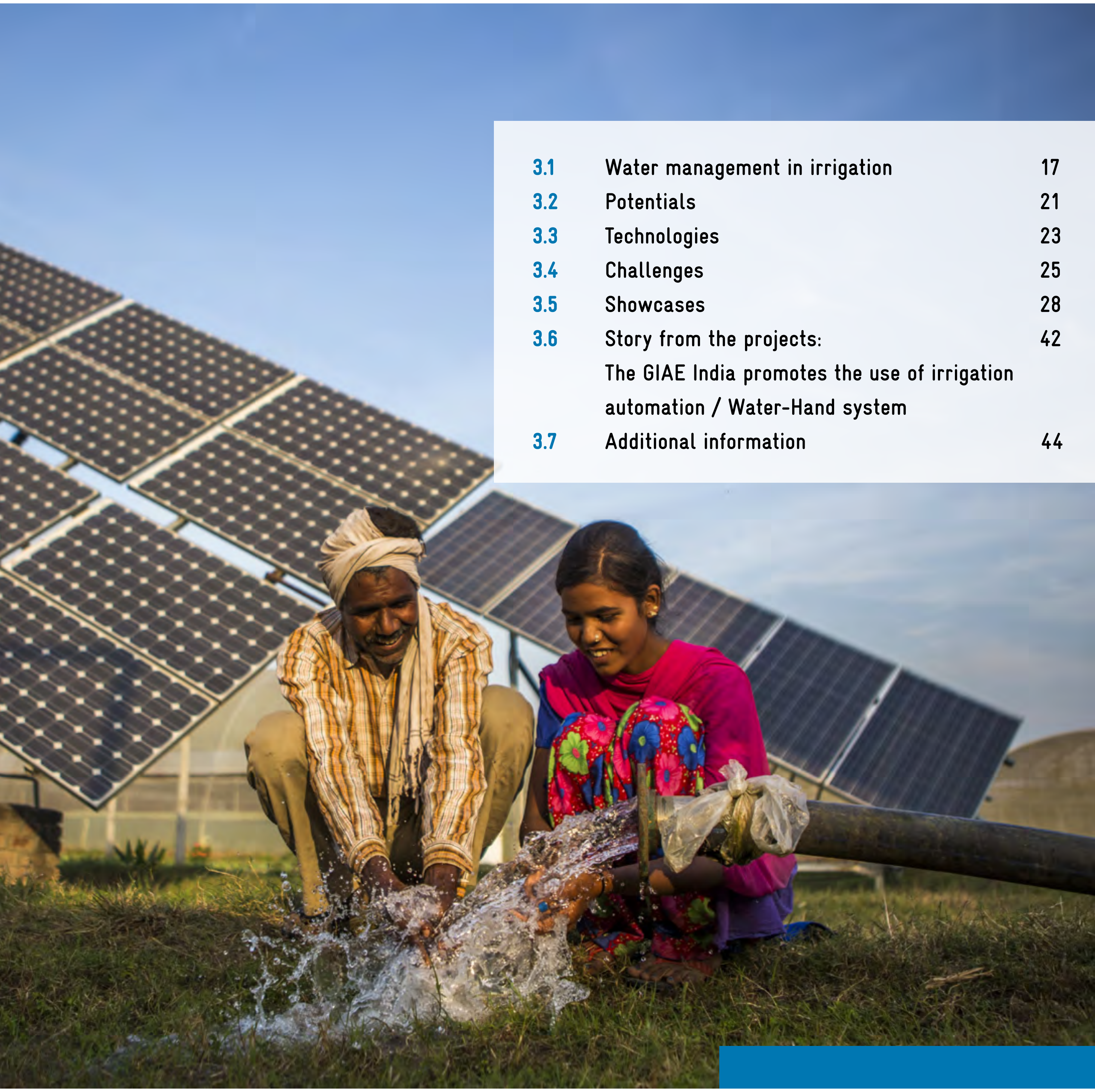
2.5 Key findings

Modern information technologies can help small-scale farmers in multiple ways. Whether it is to improve communication or the access to information, for viewing training videos or for gaining market access. Phones, apps, drones, sensors and computers are becoming more and more popular. Apps providing early warning services and weather data or support the identification of crop health show a similar increase as apps and programmes for financial management and mobile banking.

ICT specifically designed for small-scale irrigation, however, is rare. While it plays a major role for improving irrigation efficiency and for monitoring irrigation water use at regional and national scale, there are only a few apps specifically dedicated to small-scale irrigation. This should be seen as an investment opportunity. The number of farmers in small-scale irrigation in Africa and Asia is large, and their demand for technology is high.

The four areas of application described in this study deserve a closer look. The challenge is to select the most suitable technology for a given context, so that smallholder farmers can afford, understand and handle the solution. Only then does ICT support the farmers to make their businesses and their environment more sustainable.

By selecting the right target group and the right technology, ICT can be a strong means for the development of the SSI sector in general, and for increasing the sustainability of the smallholders' businesses in particular. It can help farmers understand and protect their environment, resolve and avoid conflicts over resources and manage the complex relation of different factors of irrigation better.



ICT-driven improvement of water use efficiency

3


Optimized water use can be achieved through better management practices and automation. The same applies to the use of other resources such as energy, fertilizer and labour. Irrigation is a complex activity for which many parameters need to be monitored to derive the right action at the best possible moment. Here ICT can help by delivering up-to date, localised and customised information for farmers. Weather forecasts, real-time updates on current crop and soil conditions, real-time information on water availability and consumption can offer support for real-time decision-making (e.g. when to irrigate). Equipment can then be controlled remotely in line with the provided information. Thus, irrigation can be automated harnessing all positive effects: It not only reduces costs for water, fertilizer and energy, but also helps to increase yields while reducing labour. All of which improves the sustainability of the farmers' livelihoods and protects the environment through a considerate management of water resources, reduced CO2 emissions and reduced pollution of water and soil.

At first glance, the materials needed for these ICT solutions might seem too expensive, especially given the difficult access of smallholders to financial resources. However, there are good examples for viable business models involving low or no up-front investments at low risk.

3.1 Water management in irrigation

In most parts of the world, water is a scarce resource and the limiting factor for agricultural development. On a global scale, agriculture is by far the largest water consumer, accounting for 70% of annual water withdrawals - in Asia and Africa even 80%[7]. This said, it is clear that water has to be used in the most efficient and sustainable way in order to allow more lands to be developed with irrigated agriculture and without over-exploiting water resources. Furthermore, efficient water use can improve yields and reduce soil deterioration; thus it can result in a more efficient use of land and other resources. A good irrigation management applies the optimal amount of water under given conditions, and these frame conditions are defined by the actual meteorological values, soil parameters, crop type, agricultural practices and other factors.

Without economic means to access advanced soil water probes, farmers are prone to over-irrigate which is often incorrectly seen as a way to ensure a successful crop. This reduces the overall amount of water available for other farmers, while at the same time reducing the yield of the own crop. Over-irrigation causes nutrient drain of the soil, water saturation at the plant's root system which in turn results in root diseases, such as rot and mould.

This chapter focuses on the ICT driven improvement of water use efficiency and, therefore, is purely technology-related. While automation of irrigation is already applied on larger farms in developed countries and is an important element of precision farming today, it is rather unknown among the poorer small-scale irrigation farmers of Africa and Asia. In India, where smallholders generally have better access to technology and finance, good examples exist for a first step in irrigation automation. In Africa, however, good examples of automated irrigation are usually hard to find, and the few examples rarely have business-models feasible for outscaling.

Internet of Things (IoT) describes the interconnection of physical objects like pumps, valves and other devices in which communication electronics can be embedded. This interconnection enables these devices to directly exchange data with each other and to connect to other networks. IoT devices use sensors to detect and translate the physical world into data and transmit this data in the form of a digital signal. IoT devices use sensors to sense the physical world and transmit this data in the form of a digital signal. IoT opens opportunities in many sectors such as production, household and traffic automation. Applied to agriculture, IoT can enable farmers to grow their crops or raise their animals using the precision of today's modern technologies, which can result in higher productivity and protection of the environment. On-farm monitoring of rainfall, temperature, humidity, soil moisture, soil nutrients and other parameters can help to make water usage more efficient and to mitigate risks related to climate change and pest infestations. The monitored data can be automatically analyzed and used to automatize the application of water and nutrients and thus optimize the use of the various resources. If used effectively, IoT solutions can emulate an ideal environment for agricultural production that is prone to the negative effects of external parameters. The automation can result in a more precise way of maintaining the aspects that positively affect the growth of plants, ultimately leading to an increase of yields.

However, most of the work being done in Smart Agriculture targets monitoring aspects, and there are only a few applications that are specifically designed for process automation. Few systems integrate both monitoring and process automation, and the ones that do usually only have limited automation features. Irrigation-agriculture, however, offers an interesting and realistic field for automation. Many examples exist where various sensors continually measure the necessary physical data for a server, which in turn analyzes this data and controls the irrigation equipment accordingly. In this chapter, we look at how an IoT system can be designed for both monitoring and automation. This will include analysing different aspects of an IoT system, including: which hardware to use; which software to run on the hardware; how data is measured, transmitted, stored and analysed; and how automation can be achieved using the results from the analysed data.

Predictions of soil moisture are a good tool for assessing the progress of the growing season and can provide early warning of natural hazards, including droughts and floods. A new generation of soil sensor technologies is currently being developed for the African market. Some companies have begun selling electronic soil sensor technologies equipped with GPS, micro-SD and Wi-Fi for use on smartphones or laptops. These technologies help to monitor data such as soil moisture and nutrients, pH and moisture levels, temperature and sunlight and help to increase knowledge of ongoing changes in the field and environment; they also provide real-time guidance, recommendations and notifications of rainfall and droughts. One sensor can cover up to three hectares of land, depending on environmental factors. The sensors currently cost between 150 and 500 €. Although the use of mobile technologies is growing rapidly in SSA, most smallholders do not have access to laptops or smartphones, and unless prices drop significantly, most smallholders will not be able to afford these soil sensors. For this reason, a project in Tanzania explored the potential for commercializing a very simple version of soil sensor technology, consisting of a sensor and a LED light that indicates irrigation needs (or no needs) and is capable of sending information to the cloud and of analyzing it in real time. The estimated cost is between 40-80€ (including the sensor, a data logger and a SIM card). The project estimated that the use of the simple soil sensor could be profitable for Tanzanian farmers, especially those growing tobacco, highland rice or maize - crops that are most likely to benefit from the use of a soil moisture sensor. While there may be a potential market for soil sensors, social habits and challenges still need to be addressed. Farmers frequently do not trust automatic systems as they are often competing with (the reality of) low labour costs.

With the technology of hyperspectral imaging, information on electromagnetic spectrums can be collected. African firms are making the first effort to distribute such cameras, which can analyse images and identify stressed crops, droughts, and outbreaks of pests and diseases. In combination with soil sensors, farmers can use this technology to evaluate the effectiveness of their irrigation and fertilizer application by correlating soil data with overall vegetative crop health. These cameras can be mounted on a stick or optimized to work with drones to monitor larger farms.

ICT can help introduce more efficient irrigation management, either directly, through sensors and automation, or indirectly, through making valuable information available and/or by training and educating decision makers. Making precise and up-to-date information for a better irrigation management available to the smallholder is part of chapter 5 “ICT and monitoring in irrigation“.

3.2 Potentials

A wide range of technology is available to measure all sorts of physical parameters, meteorological parameters as well as soil parameters and water availability. Even water quality and plant health nowadays can be assessed by sensors in the field, or remotely by drones and satellites. Various transmission technologies are available to send this data to the cloud for centralized analysis. Powerful computers are used for real-time analysis of this data and machine learning; devices such as solar pumps, weirs and valves are remotely controlled to automatize irrigation and optimize water use, energy consumption and yields. The use of sensor equipped solar pumps helps in measuring water consumption, reducing emissions and in saving energy. Automation targets highest yields by lowest costs for water, energy and labour. Sensors and pumps with IoT technology help in building up regional and global information bases.

- **Computer modeled hyper-localized surface weather forecasts**
  Predicting weather has a long history. Observation and statistics are at the basis, but today earth observation plays the major role. With the increasing computing power of servers and cutting-edge machine learning software, the models become more and more accurate and their spatial resolution higher. With this accuracy, the data can be an input to irrigation automation.

- **Improved irrigation management through sensors**
  The availability and affordability of sensors and transmission technologies nowadays allow dense measuring networks. Remotely controllable devices allow the setup of automated irrigation. Automated irrigation not only saves water and energy, it also helps deliver the best water volumes to the plant so that highest yields are achieved.

- **Water savings through efficient irrigation equipment**
  Solar pumps and drip irrigation allow precise irrigation both in terms of time and location. Solar pumps can be easily controlled remotely, and water consumption can also be derived more easily. A more precise irrigation helps save water per produced crop.

- **Saving labour time through automatized irrigation**
  Automation not only saves water and money, it also saves labour time, which can then be spent for other important activities on the farm. Education, health care and business activities are important operations which all require time. Traditionally, it is especially women and children who fetch water for irrigation; consequently, they are the ones who will most likely benefit.

- **Collection of water consumption data**
  The use of solar pumps enables a more accurate measurement of water consumption. This valuable data can be analysed centrally in order to get a better understanding of the status of water resources.

- **Affordability of solar pumps**
  Initial investments can be high for solar pumping and automation. Pay-as-you-go revenue models allow farmers to start with this technology without requiring them to have the financial means to buy the equipment. Small, monthly payments have to be made until farmers own their precision sensor-based irrigation system outright. This empowers even poorer smallholder farmers to take control of their farm environment.

3.3 Technologies

Hardware

- **Solar pumps**
  The market for solar pumps is evolving rapidly. The large companies are developing regional distribution networks and there are now also African manufacturers producing specifically for this market. Solar pumps in the long run are cheaper for the farmer and they are an important element for the automation of irrigation systems.

- **Earth Observation (EO) sensors (Optical/Infrared/Radar/Lidar/GPS)**
  Different wavelengths derive different physical parameters. Geo-positioning and laser distance measuring complete the range of technologies. With increasing development, sensors are becoming lighter and can be mounted on ever smaller aircrafts. Remote sensing leads to the development of products such as Digital Elevation Models, Digital Terrain Models, NDVI, and other tools for analysing weather forecast, soil moisture, plant health, water stress and others.

- **Satellites, airplanes, drones**
  With the emergence of drones, the spatial resolution of remotely sensed data experienced a quantum leap. The operation of drones is much cheaper and can be feasible for much smaller acreages of land. Drone based monitoring offers much higher resolutions and the products can be provided at any time and for any location.

- **Terrestrial sensors**
  Sensor technology is becoming much more affordable. Determining how much water plants need requires an understanding/analysis of the soil humidity at root level. Soil humidity sensors can derive this information both accurately and in real-time. These sensors are key to monitoring and automation.

- **Transmission (GSM, LTE, 5G, LPWAN, LORAWAN)**
  Automation requires data transmission between sensors, computers and remotely controllable devices. For each specific situation, numerous solutions are available to select from.

- **Modern irrigation equipment**
  For the automation of irrigation and for saving water, modern irrigation equipment is indispensable. Remotely controllable irrigation devices and microcontrollers are available at affordable prices. With integrated IoT technology, these devices help in collecting data and making it available for others.

- **Microcomputers and servers**
  Microcomputers help analysing the sensed data and translating it off-line into directives for operation. Larger solutions can analyse and process the sensed data on computers and servers. Machine learning and artificial intelligence need high-performance processors.

- **Cloud-based solutions**
  Other solutions operate with Internet connectivity and cloud-based services, and they remotely command the ground-based devices. Cloud-based solutions do not require the purchase of any computer hardware; they directly communicate with mobile end devices.

Software

- **Apps for remote control**
  The connectivity of IOT devices enables their remote control. In the simplest way, smartphones are used to open and close valves, to start and stop pumps.

- **Apps for monitoring**
  Connected sensors can transmit the measured values to smartphones and servers. Based on these parameters, energy and water consumption can be measured.

- **Software for automation**
  No automation can take place without software. Microcontrollers are the platform and the software brings them to life. Based on real time measurements received from sensors, the irrigation demand is calculated, and the necessary actions are taken by the software. The software starts the pumps and opens valves. This not only makes human interaction obsolete, but also helps to optimize irrigation. The human factor usually tends to over-irrigate in cases where water is easily available. Especially the availability of solar pumps, where energy is free, tempts farmers to over-irrigate their plots. Automation can be a remedy. Machine learning and artificial intelligence[8] help to optimize irrigation.

3.4 Challenges

By combining the different monitoring and automation techniques available today, cutting-edge IoT systems can be developed that can support sustainable development through smart agriculture. Such systems are able to monitor farming areas and react to the parameters being monitored on their own, without the presence of human beings. It is a legitimate question why the technology has not long since become much more widespread in African countries. The main reasons for this are the high cost of the systems, the unavailability of the necessary basic services such as mobile internet coverage, and a generally low level of literacy and technology adoption among most of Africa's smallholders. The small size of the plots and the low labour costs further lower the attractiveness. As a consequence, ICT services with feasible business models are usually only found in Africa's higher-income countries. However, there are many demonstration systems implemented, usually with donor funding, and these projects are developing strategies for financial sustainability of these solutions.

Scaling up ICT-driven improvement of water use efficiency will face a range of challenges that need to be addressed:

- **High costs for data acquisition**
  Regardless if systems use remotely sensed data or data from locally installed sensors, the related costs are high. With the exception of weather data, the freely available remote sensing data unfortunately is of a spatial resolution which is inadequate for small-scale irrigation. Drone-based high-resolution data can be a solution, but it is expensive, too. However, sensors are becoming more and more affordable[9] and, in the long run, optimized irrigation is increasing revenues.

- **Availability of basic services (power grid, Internet …)**
  Smallholder farmers often live in the most remote areas, which are the last areas to be reached by basic services. And even if the services are available, they are not always affordable for smallholders. The development of ICT4AG has to take this into account. Traditional technologies can be more suitable than the most modern solutions, but even remote areas will receive these services if they become attractive for the service providers. To provide a remote region with a mobile phone network is economically feasible once several thousand users can pay for this service. Development projects can streamline and accelerate these processes by addressing smallholders via cooperatives, associations or contract farming schemes.

- **Accessibility of technology for SSI farmers**
  Usually farmers are not the early adaptors of new technology. The high illiteracy rates among smallholders in many countries hinder or even prevent any technological development of the sector. The development of ICT4AG should be synchronized with the development of other sectors such as education and energy. Young farmers, however, are adopting technology much faster. That way, younger generations can be attracted to agriculture through ICT.

- **Finding a feasible business model**
  In order to develop the sector of small-scale irrigation automation, functioning business models need to be deployed (an overview of suitable business models for ICT4Ag solutions is given in the box on page 103). This is often impossible based on conventional financing as smallholder farmers do not have access to credit or investment assets. Pay-as-you-go models can be a solution. The incentives to invest in solar pumping have to be made clear to the farmers – solar pumping pays back in several ways[10].

- **Difficult outscaling**
  For the reasons given above, outscaling (increasing the number of users) frequently fails. On the other hand, ICT is a very good means for outscaling – this technology is able to reach millions at the same time. A "… small minority of companies (about 15, most of which focus on advisory services as their current primary focus) have begun to reach notable scale with 1 million plus registered farmers each"[11].

- **Solar pumping does not provide incentives for saving water.**
  Switching to solar pumping eliminates the costs for fuel. This often makes farmers over-irrigate, which not only affects the local water resources but also decreases yields. Automation of irrigation here can be a remedy. In India, energy not used can be fed into the public grid on a remunerated basis and provides therefore an incentive for the farmers to pump less water.

- **Collected data needs capacities for interpretation.**
  If only data is collected without any automation, capacities are needed for its interpretation in order to derive the correct decisions. The smallholder has to be appropriately trained, which may be difficult in case he/she is illiterate. Traditional methods such as lead farmers and advisory services have to train farmers in this respect.

- **Sometimes, ICT is seen as a remedy for all.**
  ICT can only be a complimentary approach. Mulching, collecting rainwater, reuse of treated waste water and greywater, as well as planting drought-resistant plants can help to reduce water consumption. The right amount of water depends on the plant variety, soil type and soil condition, the actual weather conditions and its development. It also depends on the time of day as evaporation is highest at noon. Traditional irrigation expertise thus is at the core of success; ICT can be a perfect tool to better observe and understand all parameters of irrigation, to precisely control the systems and to increase yield while optimizing water and energy consumption.

3.5 Showcases

	NAME	CATEGORY	SERVICES	MAIN USER GROUP	BUSINESS MODEL
3.5.1	**FERME DIGITAL ECO**	Automation of irrigation	Fully automatized irrigation system solutions	Individual Farmers, Farmer Communities / Cooperatives	Provision of hardware
3.5.2	**SASYA SYSTEMS**	Automation of irrigation	Fully automatized irrigation system solutions	Individual Farmers, Farmer Communities / Cooperatives	Provision of hardware
3.5.3	**SEABEX**	Automation of irrigation	Software for monitoring and automation of irrigation systems	Individual Farmers, Farmer Communities / Cooperatives, NGOs, Extension Service	Provision of software
3.5.4	**PHYT'EAU**	Automation of irrigation	Software for monitoring and automation of irrigation systems	Individual Farmers, Farmer Communities / Cooperatives, NGOs, Extension Service	Start-Up developing software solutions
3.5.5	**WATER-HAND**	Automation of irrigation	Fully automatized irrigation system solutions	Individual Farmers, Farmer Communities / Cooperatives, NGOs, Extension Service	Start-Up developing software solutions
3.5.6	**IRRIPORT IRRIGATION CONTROL**	Automation of irrigation	Consultancy specialized on automation of irrigation	Individual Farmers, Farmer Communities / Cooperatives, NGOs, Public Sector	Consulting service
3.5.7	**SIMUSOLAR**	Solar Powered Irrigation	Provision of Solar Powered Irrigation Systems	Individual Farmers, Farmer Communities / Cooperatives	Provision of hard- and software, PAYG
3.5.8	**SUNCULTURE**	Solar Powered Irrigation	Provision of Solar Powered Irrigation Systems	Individual Farmers, Farmer Communities / Cooperatives	Provision of hard- and software, PAYG
3.5.9	**CHAMELEON SOIL WATER SENSOR**	Sensor Technology	Visually informs about the soil moisture level at different depths	Individual Farmers, Farmer Communities / Cooperatives	Provision of hardware
3.5.10	**FARMSHIELD**	Sensor Technology	Remote control of farms based on real-time data	Individual Farmers, Farmer Communities / Cooperatives	Provision of hardware
3.5.11	**ZENVUS SMARTFARM**	Sensor Technology	Collection and evaluation of soil and environment parameters	Individual Farmers, Farmer Communities / Cooperatives, NGOs, Extension Service	Start-Up developing sensor hardware and services for dataevaluation.
3.5.12	**FARM BEATS**	Developer tools for IoT applications	Cloud based development environment for Farming IoT Solutions	IT Developers	Provision of software
3.5.13	**Fathym**	Developer tools for IoT applications	Cloud based development environment for Farming IoT Solutions	IT Developers	Provision of software

Individual Farmers · Farmer Communities / Cooperatives · NGOs · Extension Service · IT Developers · Public Sector

3.5.1

FERME DIGITALE ECO

CATEGORY: Automation of irrigation

IN A NUTSHELL: Tech-Innov is a Nigerian enterprise that develops and markets the “Ferme Digitale Ecologique” and the “Télé-Irrigation” system. All innovations are based on phones and solar energy. Tech-Innov provides the irrigation hardware incl. solar pumps, plus the telecommunication material and software needed for remote-control.

PRINCIPAL FUNCTIONALITIES:

- The “Télé-Irrigation” system allows the remote monitoring and control of irrigation devices.
- Option to fully automatize an irrigation system.
- The system can be extended and completed by automatic fertilization and an automatic cattle watering place.

BENEFIT: Automation of a farm saves labour time, water and fertilizer. Optimized irrigation practices also help to increase the yields.

PLATFORM(S) AND TECHNOLOGY: Hardware for irrigation and use of mobile devices for monitoring and control of the irrigation system

COMPANY: Tech-Innov SARL

BUSINESS MODEL:
Provision of hardware

REGION: Niger, West Africa

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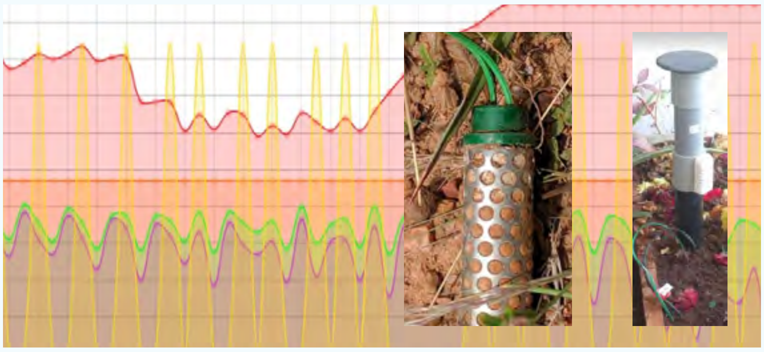
3.5.2

SASYA SYSTEMS



CATEGORY: Automation of irrigation

IN A NUTSHELL: Sasya Systems offers equipment for automation of irrigation. This includes for example different environmental sensors, irrigation controllers, wireless pump switches and solar powered wireless valves.

PRINCIPAL FUNCTIONALITIES:

- Soil moisture monitoring through sensors.
- Remote control of pumps and valves.
- Irrigation Scheduling
- Combination with fertigation control

BENEFIT: Automation of the farm saves labour time, water and fertilizer. Optimized irrigation practices also help increase yields.

PLATFORM(S) AND TECHNOLOGY: Sensors and Controllers together with mobile application for remote control

COMPANY: Sasya Systems

BUSINESS MODEL: Provision of hardware

REGION: India

SASYA SYSTEMS

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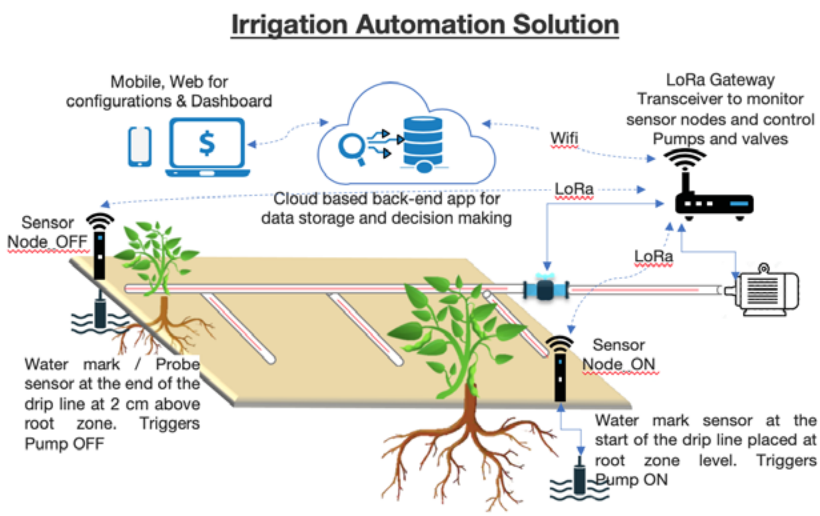

3.5.3

SEABEX

CATEGORY: Automation of irrigation

IN A NUTSHELL: SEABEX is able to monitor and control the key environmental parameters of a farm in real time, interacts and reacts autonomously and appropriately to any environmental parameter variation with minimum level of human intervention.

PRINCIPAL FUNCTIONALITIES:

- Automation of irrigation by composing scheduled plans
- Data is collected in real time from the in-field sensors
- Real-time dashboard shows the on/off status of the in-field equipment.
- Irrigation history and water consumption by sector at any time.

BENEFIT: Automation of a farm saves labour time, water and fertilizer. Optimized irrigation practices also help to increase the yields.

PLATFORM(S) AND TECHNOLOGY: Application / Software based on cloud services, web site and Android app

COMPANY: IT Grapes

BUSINESS MODEL: Provision of software, subscription packages per month and hectare.

REGION: Tunisia

FURTHER INFORMATION: SEABEX is a project of IT Grapes

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LANGUAGE

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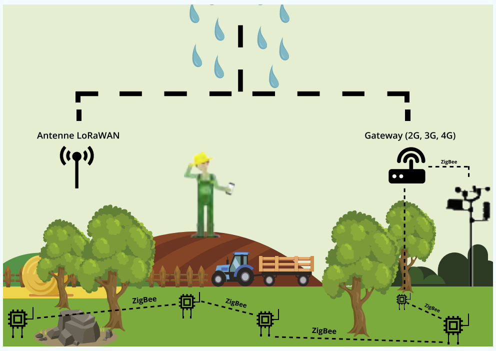
SOCIAL MEDIA

3.5.4

PHY'TEAU



CATEGORY: Automation of irrigation

IN A NUTSHELL: Phyt'Eau is a platform linking agriculture and the IoT (Internet of Things) for the management of real-time irrigation. It is a solution that allows the prediction of doses of irrigation based on sensor information. The platform connects intelligent sensors to a high-performance analytical system for monitoring the water status of crops and for real-time irrigation management.

PRINCIPAL FUNCTIONALITIES:

- Crop specific models simulate water requirements according to the stage of the crop's development and climatic conditions.
- Able to evaluate and process data sets from a range of sensors

BENEFIT: Automation of the farm saves labour time, water and fertilizer. Optimized irrigation practices also help increase yields.

PLATFORM(S) AND TECHNOLOGY: Application / Software based on cloud services, web site and Android app

COMPANY: Sofia-Technologies

BUSINESS MODEL: Start-Up developing software solutions

REGION: Tunisia

FURTHER INFORMATION:
Sofia-Technologies
ifarming Solutions
Phyt'Eau Application

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LANGUAGE

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SOCIAL MEDIA

3.5.5

WATER-HAND

CATEGORY: Automation of irrigation

IN A NUTSHELL: The automated irrigation system “Water-Hand” aims to deliver the right volume of water at the right time based on the life-cycle of the crops, the local weather and soil conditions. It allows to leave ultimate irrigation control with the farmer and does not use soil sensors.

PRINCIPAL FUNCTIONALITIES:
Irrigation according to schedules which are based on a water balance model that forecasts crop irrigation needs. To provide an estimate of the systems’ benefits, pilot trials use two different scheduling approaches:
(i) semi-automated schedules, operated by the farmer via a mobile application; and (ii) automated schedules computed by the Water-Hand dynamic scheduling platform.

BENEFIT: Automation of the farm saves labour time, water and fertilizer. Optimized irrigation practices also help increase yields. The technology is affordable for Indian farmers as it does not need soil sensors.

PLATFORM(S) AND TECHNOLOGY:
Set of different controllers together with mobile and web application for control and monitoring.

COMPANY: Farm-Hand

BUSINESS MODEL:
Start-Up developing software solutions

REGION: India

FURTHER INFORMATION:
Results from a pilot project can be found here

FARM HAND

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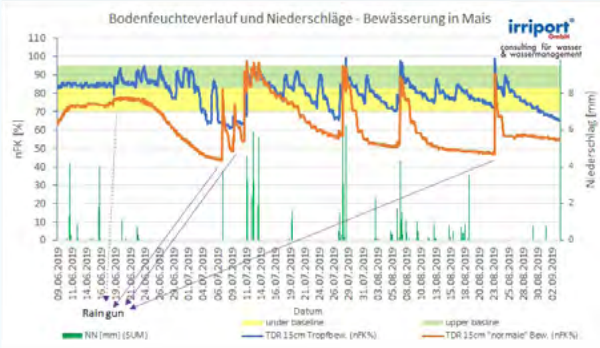
3.5.6

IRRIPORT IRRIGATION CONTROL



CATEGORY: Automation of irrigation

IN A NUTSHELL: Irriport is a consultancy specialized on automation of irrigation. The range of services includes advice, planning, training, market studies, project engineering and construction supervision. The entrepreneurial activities include the trade through import and export of technology for water pumping, hydraulics, application technology, control, monitoring, data generation and processing.

PRINCIPAL FUNCTIONALITIES:

- Consultancy for planning, designing & realization of irrigation automation.
- Use of platforms and technologies from different brands.

BENEFIT: Automation of a farm saves labour time, water and fertilizer. Optimized irrigation practices also help to increase the yields.

COMPANY: Irriport

BUSINESS MODEL: Consulting service

REGION: Germany, Pakistan

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LANGUAGE

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SOCIAL MEDIA

3.5.7

SIMUSOLAR

CATEGORY: Solar Powered Irrigation

IN A NUTSHELL: Simusolar offers clean energy solutions for agribusinesses including remote control and monitoring that ensure security and services beyond the grid and beyond the network. The service is offered as a pay-as-you-go system that enables and assures that customers make their equipment payments by phone during the loan-period.

PRINCIPAL FUNCTIONALITIES:
Provision of solar irrigation systems from design to installation and financing. The all services are enabled through smart apps and integrated workflows.

BENEFIT: The availability of a PAYG (Pay-As-You-Go) model allows even smaller farmers to start using this technology. Further, solar pumping is more affordable than the use of diesel pumps in the long run and leads to less pollution of the farmers environment.

PLATFORM(S) AND TECHNOLOGY:
Hard- and software solution for solar powered irrigation.

COMPANY: Simusolar

BUSINESS MODEL:
Provision of hard- and software, offering a Pay-As-You-Go payment model

REGION: Tanzania and Uganda / East Africa

FURTHER INFORMATION:
Customer Feedback can be found here

Simusolar

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LANGUAGE

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SOCIAL MEDIA

3.5.8

SUNCULTURE

CATEGORY: Solar Powered Irrigation

IN A NUTSHELL: By combining solar pumping technology with an Internet of Things (IoT) platform and advance machine learning algorithms, the system is able to predict trends and to optimize performance in real-time. That way, affordable easy-to-understand precision farming tools are available for a smallholder farmers.

PRINCIPAL FUNCTIONALITIES:
- Solar energy and lithium ion energy storage technology
- Integrated sensors (Groundwater level and pump performance)
- Optional wireless on-farm soil and weather sensors.
- Farmers can remotely monitor irrigation
- One system provides water for up to 2 acres

BENEFIT: The availability of a PAYG (Pay-As-You-Go) model allows even smaller farmers to start using this technology. Further, solar pumping is more affordable than the use of diesel pumps in the long run and leads to less pollution of the farmers environment.

PLATFORM(S) AND TECHNOLOGY:
Hard- and software solution for solar powered irrigation, IoT connectivity

COMPANY: SunCulture

BUSINESS MODEL:
Provision of hard- and software, offering a Pay-As-You-Go payment model

REGION: Kenya

SunCulture

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LANGUAGE

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SOCIAL MEDIA

3.5.9

CHAMELEON SOIL WATER SENSOR

CATEGORY: Sensor Technology

IN A NUTSHELL: Chameleon offers an inexpensive, easy to use and effective system to monitor soil water levels. The sensors provide farmers with an easily understood readout. The Chameleon soil water system has been designed to be inexpensively manufactured, simple to install, and easy to understand.

PRINCIPAL FUNCTIONALITIES:

- The system visually informs farmers about the soil moisture level at different depths:
  - blue light: no irrigation required for some time
  - red light: too little soil moisture – irrigation required
  - green light: adequate level – do not irrigate
- An additional suite of tools allows measuring salt and nitrate levels.
- Combined, the Chameleon soil water sensor system aims to help farmers make informed management decisions.

BENEFIT: Monitoring soil moisture at an affordable price with devices made in Africa. No specific capacities needed, neither for installation nor operation.

PLATFORM(S) AND TECHNOLOGY: Manually readable sensors, option to upgrade to wireless collection of data points.

COMPANY: CSIRO (Commonwealth Scientific and Research Organization)

BUSINESS MODEL: Provision of hardware

REGION: Chameleon sensors are currently servicing over 1,000 crops across 13 countries in four continents.

FURTHER INFORMATION:
Case Study on the CSIRO Website
Academic research articles can be found here

CSIRO

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SOCIAL MEDIA

3.5.10

FARMSHIELD

CATEGORY: Sensor Technology

IN A NUTSHELL: Farmshield enables remote control of farms from mobile phones and dashboards based on real-time information on fertigation and irrigation needs for the crop. Grid sensors measure different parameters and send this data to the cloud where it is analysed. Real-time alerts and advice is fed back to farmers via SMS, Email or App alerts.

PRINCIPAL FUNCTIONALITIES:

- Opening and closing of valves if the soil moisture sensors report low soil moisture levels.
- Activating greenhouse fans to control temperature and humidity of a greenhouse.

BENEFIT: Improved farm/greenhouse management through accurate and up-to-date information about soil moisture, humidity and nutrient availability.

PLATFORM(S) AND TECHNOLOGY: Wirelessly connected sensors to control irrigation systems, web-based and mobile applications

COMPANY: Illuminum Greenhouses

BUSINESS MODEL: Provision of Hardware, the product can be purchased in different configurations.

REGION: Kenia, East Africa

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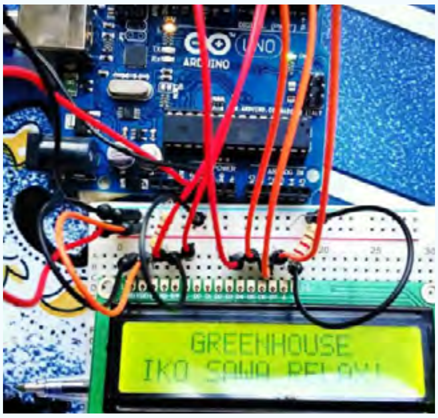
SOCIAL MEDIA



3.5.11

ZENVUS SMARTFARM

CATEGORY: Sensor Technology

IN A NUTSHELL: Zenvus Smartfarm are electronic sensors which, collect data and wirelessly transmit the data to a cloud server where computational models help to calculate the current crop situation. Powered by solar energy with a battery backup, a farmer interacts with the hardware data via a web interface.

PRINCIPAL FUNCTIONALITIES:

- Monitoring of humidity, temperature, pH, moisture, nutrients
- Evaluation of data through web interface which works on desktop and mobile devices
- Connectivity via WIFI, GSM and Satellite, manual data collection with microSD card is possible

BENEFIT: Automation of the farm saves labour time, water and fertilizer. Optimized irrigation practices also help increase yields. The whole system is solar-powered.

PLATFORM(S) AND TECHNOLOGY: Solar powered sensor together with web interface.

COMPANY: Fasmicro

BUSINESS MODEL: Start-Up developing sensor hardware and services for data evaluation.

REGION: Nigeria and West Africa

FURTHER INFORMATION:
Fasmicro Group
Zenvus Portal

zenvus

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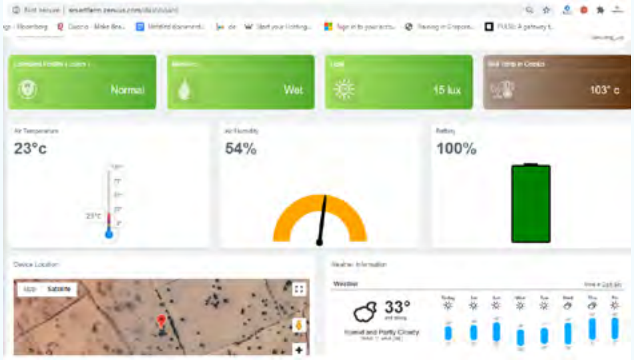

3.5.12

FARM BEATS

CATEGORY: Developer tools for IoT applications

IN A NUTSHELL: FarmBeats is an end-to-end IoT platform for agriculture that enables seamless data collection and processing from various sensors, cameras and drones. It enables building artificial intelligence (AI) and machine learning (ML) models based on data sets.

PRINCIPAL FUNCTIONALITIES:
Programming platform for
- Aggregation of agricultural data from different sources.
- Integration of different agricultural datasets from sensors, drones & satellites.
- Tools to build customized digital agriculture solutions.

BENEFIT: FarmBeats is often featured together with sensors which use TV white space, the unused spectrum of TV broadcast bands, to transmit data. This is an advantage in remote rural areas where network coverage is usually low.

PLATFORM(S) AND TECHNOLOGY:
Microsoft Azure cloud-based service

COMPANY: Microsoft

BUSINESS MODEL:
Provision of software. Cost for Azure Cloud resources additional.

REGION: Worldwide

FURTHER INFORMATION:
Piloting FarmBeats in Africa:
Data-driven agriculture
Find here a publication on FarmBeats

Microsoft

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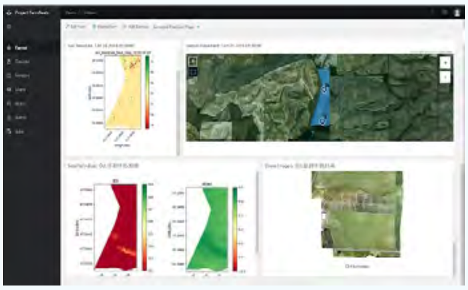

3.5.13

FATHYM

CATEGORY: Developer tools for IoT applications

IN A NUTSHELL: Fathym is a development framework based on so called Low-Code Units. These Units are modular and reusable building blocks of code which enable developers to use workflows to rapidly create IoT and data-driven applications that are agnostic to tools, platforms and clouds.

PRINCIPAL FUNCTIONALITIES:
Developer tools for:
- Provision and monitoring of IoT infrastructure.
- Managing of flow of IoT device data with drag/drop editors.
- Building data dashboards and web applications.

BENEFIT: The modular Low-Code framework reduces time and work for developers.

PLATFORM(S) AND TECHNOLOGY: Microsoft Azure as cloud-based service

COMPANY: Fathym

BUSINESS MODEL:
Provision of software, offered in two different subscription packages. Cost for Azure Cloud resources additional.

REGION: Worldwide

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LANGUAGE

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VIDEO

SOCIAL MEDIA

3.6 Story from the projects: The Green Innovation Centre for the agriculture and food sector (GIAE) India promotes the use of irrigation automation by use of the Water-Hand system[12]

On a 10-acre mixed vegetable farm in Tamil Nadu, India, the Water-Hand system has been controlling crop irrigation since September 2017. This resulted in a significantly higher productivity compared to the average for the Indian Agricultural Sector. The pilot trial aims to quantify the improvement provided by the Water-Hand system when compared to manual micro-irrigation (both drip irrigation).

Method

A water balance model forecasts crop irrigation needs based on data that local sensors are providing. Compared to manual practices, this causes a significantly lower water use and higher yields compared to traditional practices. To estimate the benefits, the trial compared the automatically derived water volumes computed by the Water-Hand dynamic scheduling platform with pre-determined schedules devised by the farmer. Likewise, crop yields are compared.

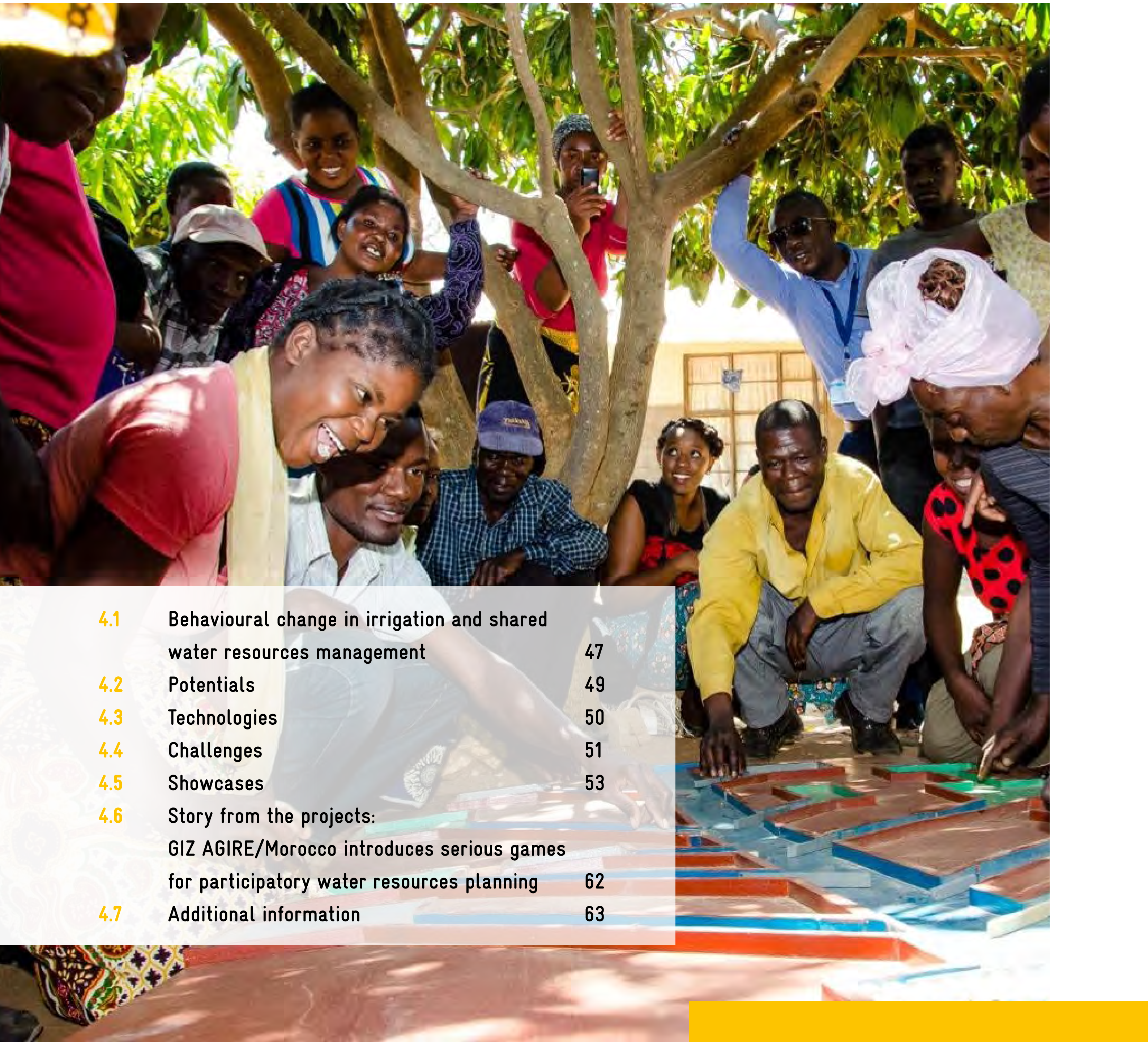
The Farm Hand Team calculated a 30% increase in yield, 60% water and energy consumption decrease and 10% decrease in fertilizer and 10% decrease in labour when looking at the efficiency increases of using Water-Hand. An additional benefit is the fact that crop irrigated by Water Hand systems reached harvest earlier, e.g. 12 days in the case of okra crop. Apart from the fact that farmers directly benefit from increase in yields and decrease in water and energy consumption and fertilizers, there are many other benefits for the environment and the social community.

Co-benefits of the Water-Hand system:

- Reduced energy consumption will lead to reduced CO2 emissions up to 2.7 TCO2 per acre per year.
- Water consumption savings between 39 and 69% allow expansion of agriculture and food production in areas where water is scarce.
- The emergence of remote, automated irrigation systems largely eliminates any requirement for visits to the farm at night. This increases safety and women start being responsible for day-to-day management of farms.
- The labour reduction frees up time, which could be used for other economically productive activities.
- By significantly improving water efficiency, Farm-Hand, along with other resource saving techniques and strategies, helps reduce conflicts over limited resources.
- The application of automated irrigation helps target the SDGs, i.e. strengthening resilience and response to crises, lowering energy consumption, reducing CO2 emissions, promoting global prosperity, and tackling extreme poverty and helping vulnerable citizens.

3.7 Additional information

- CLASP Water Pump Outlook 2019 (Global Trends and Market Opportunities)
- Towards low-cost soil sensing
- Low-Cost Aerial Imaging for Small Holder Farmers
- Solar pump selector app
- CCAFS / GIZ Brochures : Evaluating diverse solar irrigation systems for their scalability in India
- Feed The Future: Agricultural Technology Assessment for Smallholder Farms in Developing Countries: An Analysis using a Farm Simulation Model (FARMSIM)
- EEW Council on Energy, Environment and Water: Solar for Irrigation. A Comparative Assessment of Deployment Strategies



ICT and innovative solutions for behavioural change

4


A change in behaviour is a consequence of communication, sharing information and negotiation. ICT can help to facilitate these processes and provide information to people.

ICT supported learning can help farmers to understand how to protect shared resources and the ways inappropriate management practices harm the sustainability of their business. If streamlined via appropriate channels, ICT-based solutions can target a large number of users without high costs of dissemination. Gamification of irrigation issues is relatively unknown but has high potentials at low cost, enabling farmers to better understand the conflicts between the different uses in a shared water basin. This understanding might also mitigate conflicts between the water users, between environmental needs and farmers' economical demands. A better understanding can also result in a more considerate use of resources, which can help to protect the environment and can consequently improve the sustainability of farmers' livelihoods.

ICT can therefore be a means to foster a change in behaviour of water users towards more favourable management practices.

4.1 Behavioural change in irrigation and shared water resources management

Water is not only a limited, but also a shared resource. In most cases, neighbouring farmers cultivate their fields from the same water resources. Frequently, they neither know nor understand that their irrigation behaviour affects the water availability for neighbouring, and especially downstream, farmers. And they do not only influence their neighbours' water availability but also the quality of the water which is available for the other users. It is even more difficult to understand that all different water users of the same basin use the same resource, but with different interests. Thus, industrial water use, urban wastewater disposal, touristic water demand, and the agricultural water needs are heavily interrelated. In addition, there is an ecological demand for water that is not easy to understand and which, if it is neglected, can cause irreparable environmental damage.

Water management is an important element of national and regional politics, but often the water users at local levels do not know much about it. It is therefore of high importance for all different water users of a shared resource to understand the limited water resources and the interrelation between the behaviour of all stakeholders. Good irrigation practices do not mean irrigating as much as possible. Over-irrigation causes erosion, soil deterioration and lower yields. To change existing mismanagement, to fill knowledge gaps and to achieve a better understanding, the water users need information and training.

Behavioural change is generally not easy to achieve. Shared resources need the behavioural change of all users without exception. Existing social traditions and the individual benefit often restrict those changes. With a shared resource it is difficult to define collective opportunities by offering enough individual freedom. Behavioural change functions best if people see the changes as beneficial by themselves.

ICT-supported learning

ICT can help enhance the understanding of the complex water use situation through sophisticated training materials. Training videos, audios, posters and documents can all be considered as ICT-supported learning tools. This technology is not specifically related to agriculture and less so to small-scale irrigation. Hence, it is discussed only briefly. There are, however, a few web portals which are specifically dedicated to the dissemination of agricultural advice through videos, and they have irrigation as a sub topic or search filter and thus they are part of this chapter.

Gamifying irrigation

There are many games, both board games as well as computer-based games, in which water plays a central role, and many of them are well suited for raising awareness at different levels. One example is the World Water Game, in which the player decides on measures to prevent water shortages in different regions of the world. In another game, developed by the Swiss Federal Office for the Environment (FOEN), the player can select various water management measures for a city and for rural areas along a stream. Another web-based multiplayer game, called Irrigania, demonstrates current water conflicts by using several players, which represent the stakeholders. This simple form of role-play allows a easier understanding of a complex issue. While this game is simple in its rules, it illustrates in various theoretical game situations typical water-related conflicts illustrating the tragedy of the commons problem and other failures. Other types of games are board games such as the “River Basin Game” and “Globalization of Water Management” (developed by Arjen Hoekstra), which aim to illustrate issues related to the sharing of a common resource in an upstream and downstream environment, including the concepts of a water footprint and virtual water trading.

Games, aimed at the behavioural change of smallholder farmers, need to be free of high technology. The smallholder farmer will not be able to play a web-based multi-player game that needs a high performance graphic card. These games need to be traditional board games so that they can be played without any costs. Nevertheless, the idea of gamification can be included into the programming of computer or smartphone-based ICT solutions to increase interest among younger generations and people within the farming community interested in technology.

4.2 Potentials

ICT offers various technologies to support knowledge transfer and learning. Traditional channels such as radio or television are widely used to disseminate knowledge on good agricultural practices but also to inform farmers of weather events and pest incidents and how to prepare for them. A relatively new field is the gamification of learning. While this sector rapidly develops in industrialized countries, it is relatively unknown in poorer countries. Learning through games does not necessarily need ICTs, but if ICTs play a role, the target group understandably needs to have access to the necessary technologies.

- **Videos can easily be created.**
  Every modern smartphone comes with the equipment and performance to record videos in sufficient quality for dissemination over the Internet, allowing an interactive community. The creation of professional training videos, of course, needs a certain experience and expertise.

- **Videos and tutorials can easily be spread by Facebook and other social media.**
  Uploading a new video to a well-known Facebook site can disseminate the information to thousands of Internet users of the target group within a few days at relatively low cost. ICT therefore enables access to more people within the target group while lowering costs.

- **Audio sequences can be broadcasted by community radio AND social media.**
  In many African countries, the community radio is still the number-one choice to channel information to the rural population. However, the nearer people live to the capitals and big cities, the more they adapt to newer technologies. Farmers should receive the same information no matter where they live. Therefore, information should be broadcasted through multiple channels.

- **Complex relationships can be understood through serious games, both board games and apps.**
  In order to make the complex interrelationships between the various users and user groups of a common resource (usually a water basin) understandable, games can be developed which simulate the behaviour of the environment. Through serious games, certain development goals can be addressed: such as a common understanding of water users for environmental effects and impacts, and what actions can reduce this impact. Recognizing local expertise and getting feedback on public policies can be another outcome.

- **Crowd-sourcing information in combination with machine-learning.**
  There are farmers who understand their environment much better than any decision maker at a ministry far away. The knowledge of the best performing farmers should be made accessible so that others can learn from it. This can be realized through more traditional technologies such as radio and television but also through modern technologies such as apps. If the number of farmers providing information is high enough, modern machine learning algorithms can learn from it and use this data to make future decisions more precise.

4.3 Technologies

- **Videos for download and streaming**
  The videos should be short enough to allow downloading and streaming. They should be produced on specific topics and should not be too general. They should be broadcasted using local idioms and showing local settings. Specific web platforms exist with agricultural focus for the exchange of such videos. Usually it is a lead farmer downloading the video, showing this saved video on his device to interested colleagues.

- **Audios for broadcasting via Facebook and other platforms**
  The number of community radios sending out farming-specific information in rural areas is high. Audios produced on specific agricultural topics should be made available for other radio stations in order to reach the highest possible number of interested listeners.

- **E-Learning via web and app**
  Learning via apps, web sites and video channels is very common in developed countries, but it does require certain computer skills. Logically, it is usually not the smallholder farmer himself who digests this training material but rather the extension worker, lead farmer or association employee who will use this technology.

- **Serious games both offered as traditional game and app**
  Complex relationships can be made understandable in a playful way through serious games. Such games allow the simulation of complex environmental behaviours such as the management of a shared water basin. The different players can play roles of different water users and learn how different behaviour affects nature and economy in different ways. These games can be made available not only as board games (which makes sense as most of the target group has no access to Information Technology) but also as apps to increase interest for agriculture among younger generations.

4.4 Challenges

- **Achieving behavioural change**
  In order to achieve behavioural change of users of a shared resource, all individuals have to understand the collective opportunities and benefits of the change. If a few users do not change their behaviour, the whole project is likely to fail.

- **Dealing with high illiteracy rates**
  Illiteracy rates among smallholders are usually above country average - especially in those countries with a generally elevated illiteracy rate. ICT here cannot help through Web sites and apps. But radio, Interactive Voice Response (IVR) and videos still can play their role. Frequently, lead farmers, association leaders or other local leaders act as multipliers. Likewise, children and young adults can help their parents in reading and understanding the message.

- **Learning material has to be available in local idioms.**
  The learning material not only has to be translated to the local idioms, but photos and images have to be adopted and/or replaced.

- **Learning material has to be adopted to the local setting.**
  Every river basin reacts differently. Problems of tropical river basin management are different from problems in the Sahel or even the desert. Likewise, rice agriculture in India is different from the way, West-Africans cultivate their rice. Thus, it is not always possible to make use of existing videos by only translating them to the local idioms. Sometimes, the video content is not transferrable to other countries/regions. Animated videos, for instance, can be adopted more easily, including content, language and look.

- **Interested users and appropriate content**
  ICT can offer channels for capacity building and behavioural change. Without suitable contents and interested users, however, the technology is useless. Irrigation farmers need to be animated and attracted in order to be open to the content and, finally, to change. Successful programmes usually address the farmers through associations and cooperatives.

- **Video streaming needs good internet.**
  Watching videos over the Internet needs a good Internet connection, which results in costs. The provided videos should be short, precise in topic and available in different resolution. Animated videos are usually lower in size than reality videos.

- **How to tackle high costs for streaming?**
  Videos have to be made available for download. This enables owners of a smartphone to download the videos and later show them to others. Once downloaded, they can be watched for no additional cost. That way, the videos will be watched by a higher number of users.

- **What if basic services and access to technology are not available for all (grid, Internet …)?**
  It is the objective of any development effort to support the poorest and most marginalized people and to minimize the difference of living standards within the community and throughout the countries. By choosing ICT for this task, there is a high risk of increasing this difference. When using modern technologies in development cooperation, great care must be taken to ensure that the poorest of the poor can also participate.

4.5 Showcases

	NAME	CATEGORY	SERVICES	MAIN USER GROUP	BUSINESS MODEL
4.5.1	3D ANIMATION	Educative videos	Animated training videos on good agricultural practices		Non commercial
4.5.2	ACCESS AGRICULTURE	Educative videos	Animated training videos on good agricultural practices		Non commercial
4.5.3	SAWBO DEPLOYER	Educative videos	Animated training videos on different agricultural extension topics		Non commercial
4.5.4	AFRICAN FARMER	Role playing game	Simulation game on small-scale farming		Non commercial
4.5.5	IRRIGANIA	Role playing game	Simulation game on water use conflicts (focus on irrigation)		Non commercial
4.5.6	RUN THE RIVER	Role playing game	Simulation game on water use conflicts		Non commercial
4.5.7	RIVER BASIN GAME	Role playing game	Simulation game on river water management and related conflicts		Non commercial
4.5.8	LET IT RAIN	Crowdsourcing agronomic data	Provision of free and accurate weather data via SMS or call		Non commercial

Individual Farmers Farmer Communities / Cooperatives NGOs Extension Service IT Developers Public Sector

4.5.1

3D ANIMATION

CATEGORY: Educative videos

IN A NUTSHELL: The GIZ Sustainable Smallholder Agri-Business Programme (SSAB) used well-proven and research-based analogue training material to develop 3D animated training videos. The videos are produced with a modular principle, making it easy to adapt to different languages and recent developments of innovative strate-gies to bring the message to the farmer. SSAB produced five 3D animation films: on good agricultural practices for cocoa, cassava and maize, on good practices for a healthy diet and on safe pesticide use and management. All videos are available in English and French.

BENEFIT:

- The farmer recognizes well-known details of his usual environment and can relate to the characters on the video.
- Reduced data needs (animated video) result in lower data costs.
- Animated videos can easily be adopted to new environments (language/culture/topics). Small-scale irrigation specific materials could be integrated into the tool.

PLATFORM(S) AND TECHNOLOGY: Animated 3D videos (available in the project website)

DEVELOPER: GIZ – Sustainable Smallholder Agri-Business Programme (SSAB)

BUSINESS MODEL: Non commercial

REGION: Tailored for West Africa (available worldwide)

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

EN FR

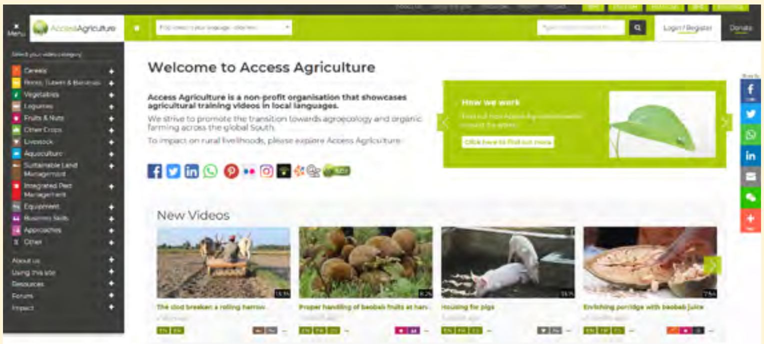
LANGUAGE

WEB

VIDEO

4.5.2

ACCESS AGRI- CULTURE



CATEGORY: Educative videos

IN A NUTSHELL: Access Agriculture is a non-profit organisation that hosts and produces agricultural training videos in local languages. It promotes the transition towards agroecology and organic farming across the global South. To develop local language versions, mass multiply and disseminate agricultural training videos, Access Agriculture collaborates with more than 200 communication professionals across the globe.

BENEFIT:

- Learning by watching training videos, often available in local languages (suitable for low literacy contexts).
- Watching videos as a social event.
- Additional videos can easily be integrated. Farmers can participate by recording and uploading their own videos which will be reviewed before publishing.
- Smallholder irrigation is already a sub-entry below Sustainable Land management which offers access to four different videos

PLATFORM(S) AND TECHNOLOGY: Online video streaming platform

DEVELOPER: Non commercial

BUSINESS MODEL: Open source, community-driven; supported by EU and others

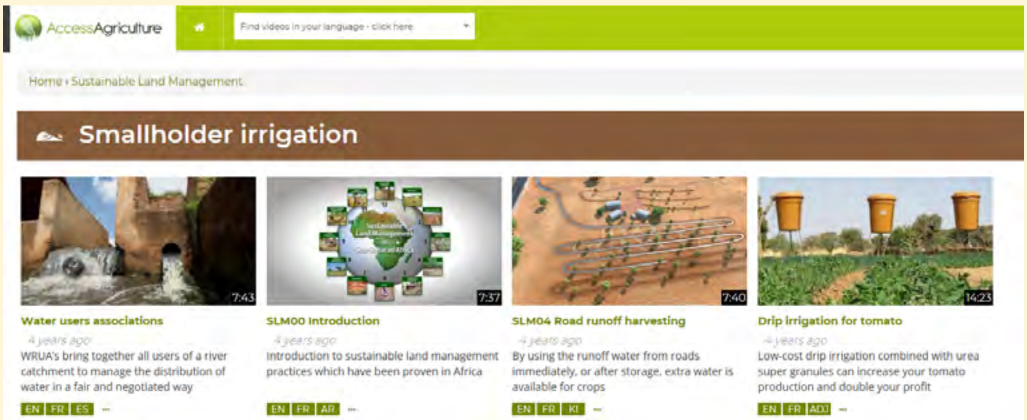
REGION: Worldwide

EN FR ES BN HI

LANGUAGE
videos in dozens of local languages

WEB

VIDEO



4.5.3

SAWBO DEPLOYER

SAWBO
Scientific Animations Without Borders

CATEGORY: Educative videos

IN A NUTSHELL: Scientific Animations Without Borders (SAWBO) is a university-based program. SAWBO transforms extension information on relevant topics (such as agriculture, disease and women's empowerment) into animated videos, which are then voice overlaid into different languages from around the world. The material can be downloaded to mobile devices for sharing. Its target group are educators from the global South working with low literacy learners.

PRINCIPAL SERVICES:

- Free access and download of animations for educational purposes.
- For TV broadcast and sharing on computers, smartphones and cell phones.

BENEFIT:

- Learning by watching training videos, often available in local languages (suitable for low literacy contexts).
- Watching videos as a social event.

PLATFORM(S) AND TECHNOLOGY: Animated videos (available in the project website and in an Android app)

COMPANY: Scientific Animations Without Borders (SAWBO) – Michigan State University (MSU) Technologies

BUSINESS MODEL: Non commercial

REGION: Worldwide

EN
LANGUAGE

WEB

VIDEO

4.5.4

AFRICAN FARMER

CATEGORY: Role playing game

IN A NUTSHELL: African Farmer is a free, open source game that simulates the complex decisions and uncertainties faced by small-scale farmers living in Sub-Saharan Africa. The challenge is to manage a farming household in a small village, to make decisions on what crops to grow, when to plant them and respond to crop pests and changeable weather. Management of labour and provision of nutritious diets are important parts of the simulation.

BENEFIT:

- Learning by multi-role play.
- Knowledge building as a social event.
- Multi-player mode available, for 12–36 players (ideal for trainings and classroom settings)

PLATFORM(S) AND TECHNOLOGY: Single-player game: Adobe Air Application for Windows desktop
Multi-player game: free online game

DEVELOPER: University of Sussex and FutureFarmers

BUSINESS MODEL: Non commercial

REGION: Worldwide

FURTHER INFORMATION: Irrigation is only a small part of the game. This topic could be emphasized in a similar irrigation game.

Other similar simulation games:

- 3rd World Farmer
- African Highland Farmer

EN

LANGUAGE

WEB

VIDEO

SOCIAL MEDIA

4.5.5

IRRIGANIA

CATEGORY: Role playing game

IN A NUTSHELL: Irrigania simulates irrigation conflict issues among farmers and villages. Irrigania's parameters are simplified compared to reality, but they are well chosen and accurately modelled. The game authentically illustrates the issues typical in conflict situations in an understandable way. Players take the role of farmers who must irrigate up to ten fields, and decide whether to use rain, river, or ground water. Each has different costs, revenues, and recharge parameters. For instance, use of river water leads to quick depletion, yet this source has no yearly memory; groundwater overuse will not be apparent for some time, but aquifers take several years to recharge. The winner is the player who can make the highest profit; to achieve it they must work cooperatively, as other farmers in the same village draw from common resources. The main teaching issue is achieving the collective optimum and showing that this may be different from the preferred solution for any individual player.

BENEFIT:
Learning by multi-role play

PLATFORM(S) AND TECHNOLOGY:
Multi-player online game about sharing water resources
The authors recommend running game sessions in a computer laboratory where participants can communicate. They also suggest playing several rounds, exploring the game's settings and possibilities. Irrigania can be played with any number of players, but four to six per village yields the most interesting outcomes and discussions.

DEVELOPER: University of Zurich

BUSINESS MODEL: Non commercial, but needs accounts

REGION: Worldwide

FURTHER INFORMATION:
[Blog of the European Geosciences Union]

Universität Zürich[UZH]

EN
LANGUAGE

WEB

4.5.6

RUN THE RIVER

CATEGORY: Role playing game

IN A NUTSHELL: The Game combines elements of the natural water cycle with the challenges of balancing water use between various water consumers, including the environment, agriculture, and cities. Running from 1905 to 2006, real historic and modelled data from the Murray–Darling Basin (Australia) is used to show the challenges faced during different periods of the Basin's history.

BENEFIT:

The game is based on the physical behaviour of the Murray-Darling basin and thus does not reflect the realities of the global South. Although it is not tailored for smallholders, it can be used to illustrate water management concepts or as an orientation to develop a context-adapted game.

PLATFORM(S) AND TECHNOLOGY: Android and iOS Apps, Online game, Windows desktop game

- Native app for Android devices.
- Online game
- Windows desktop

DEVELOPER: Australian Government – Murray-Darling Basin Authority

BUSINESS MODEL: Non commercial

REGION: Murray-Darling Basin – Australia

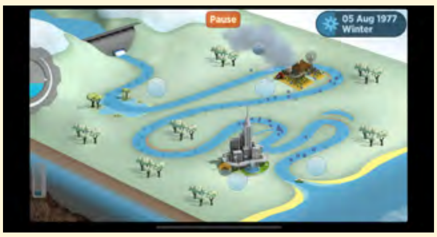
FURTHER INFORMATION:

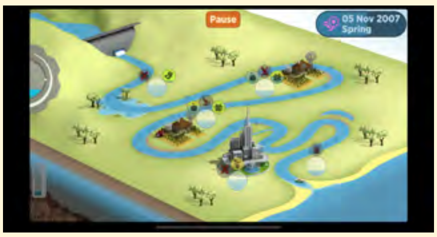
Teacher Guide

EN

LANGUAGE

WEB





4.5.7

RIVER BASIN GAME

CATEGORY: Role playing game

IN A NUTSHELL: A two-day workshop designed around a board game to help resolve conflicts over water. As a role-playing tool, it promotes dialogue and decision-making over water resources where irrigation is present. The board represents a catchment and reflects upstream-downstream flows of water, highlighting the difficulties of managing a common resource and inequality in water access. The tool can be used with local resources users, high-level decision-makers, both together or in academia with students and researchers.

BENEFIT:

- Players discover the natural dynamics of water flow in a river basin.
- The game creates a 'space' that utilizes serious play to demonstrate various dimensions of irrigation, water-based livelihoods and river basin management at the local level.
- Players learn about possible solutions and consensus-building.

PLATFORM(S) AND TECHNOLOGY: Game board and materials (construction details available on provided website).

DEVELOPER: Bruce Lankford, University of East Anglia, UK

BUSINESS MODEL: Non commercial

REGION: Worldwide

FURTHER INFORMATION:
[Another river basin game by University of Twente (Netherlands)]

UEA University of East Anglia

EN
LANGUAGE

WEB

VIDEO

4.5.8

LET IT RAIN

CATEGORY: Crowd sourcing of rainfall information

IN A NUTSHELL: "Let it rain" is a marketing campaign about gamifing weather prediction with the aim to incentivize farmers' uptake of localized agro-advisories. Furthermore, crowd-sourced weather information, shall be analised through machine learning to further improve weather forecasts. Through farmers participating in the competition ("Guess the start of the rain!") the organizers are able to build farmer profiles for the purpose of then providing customized weather information.

BENEFIT:

- Using Mediae's popular farm make-over TV show Shamba Shape Up, the campaign will stir up a national discussion on the relevance of weather forecast.
- Farmers have better access to extension services by joining the platform iShamba.

PLATFORM(S) AND TECHNOLOGY: Integrated into Shamba Shape Up television show (weather forecast) and the iShamba platform (multiple extension services).

DEVELOPER: International Center for Tropical Agriculture (CIAT), Kenya Agricultural & Livestock Research Organization (KALRO), International Potato Center (CIP), Mediae Company, iShamba

BUSINESS MODEL: Participation in the competition is free. (iShamba offers free and premium plans)

REGION: Kenya

FURTHER INFORMATION:
Farm Show "Shamba Shape Up"
Farmer information service "iShamba"

EN
LANGUAGE

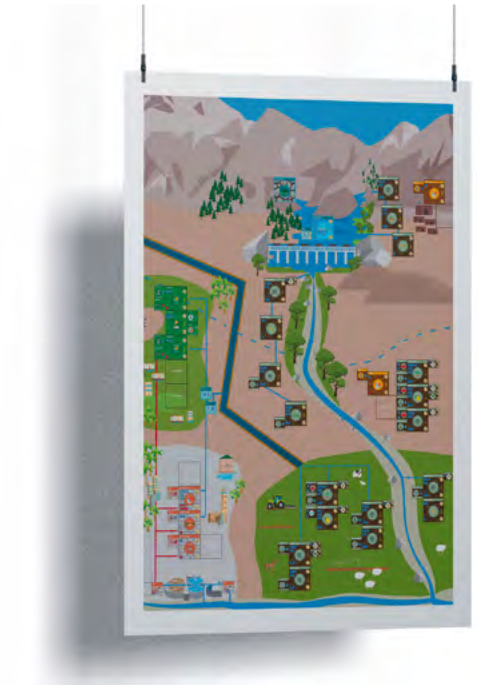
WEB

VIDEO

SOCIAL MEDIA

4.6 Story from the projects: GIZ AGIRE/Morocco introduces serious games for participatory planning and management of water resources[13]

In Morocco, the overexploitation of groundwater threatens socio-economic development and increases social disparities between user groups. The Moroccan water law 36-15 introduces a new approach through participatory management contracts. This need for innovative participatory tools initiated the idea for this game, which allows both knowledge transfer to stakeholders and involvement in decision-making processes. The approach also enables a understanding of the whole system by recognizing the expertise of each stakeholder. The serious game aims to combine modelling with participation. It seeks to improve knowledge and aid decision making.



Preview of the Wadi Naffis Basin Water Game (GIZ/IRSTEA).

PRO

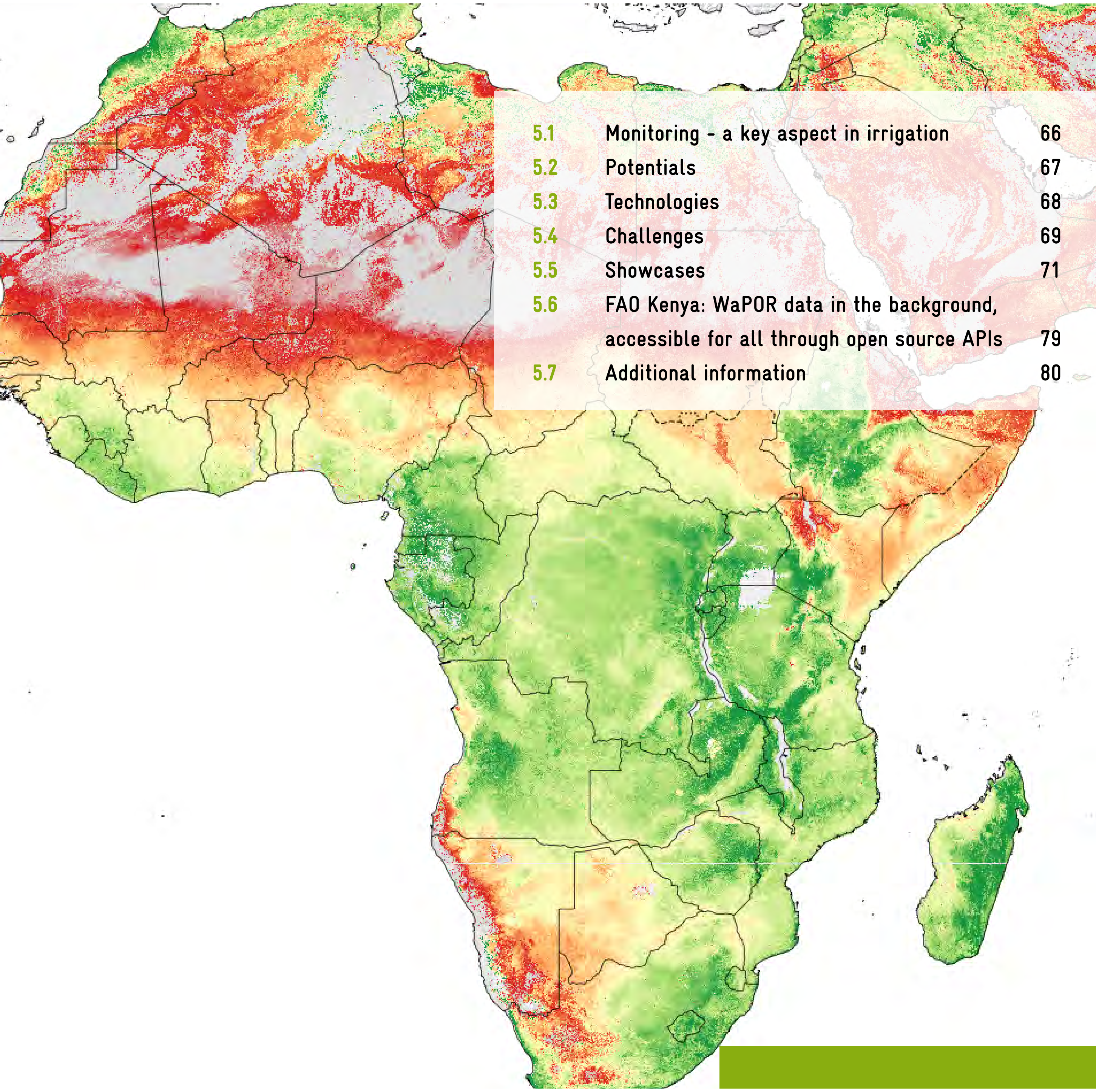
- Distance from personal situations.
- Motivation / pleasure / fun
- Actively involve the participants.
- Measure the interest of cooperating with others
- Support mutual understanding, transparency of process.
- Bridge the gap between the local users, “experts” and decision-makers.
- Define acceptable and inclusive solutions.

CONS

- Time
- Means
- Need for physical presence.
- Need to have an external facilitator.
- Some may not take it seriously.
- Some will fear that their strategy / hidden information will be revealed.

4.7 Additional information

- Malabo Montpellier Panel – Smart Irrigation Strategies for Africa
- Water Games
- Links to a wide variety of serious online games, from space engineering to farming simulations.
- Gaming for smallholder participation in the design of more sustainable agricultural landscapes
- Using serious games to facilitate collaborative water management planning under climate extremes
- The Irrigation Management Game: A role playing exercise for training in irrigation management
- Learning about water resource sharing through game play
- Irrigania – a web-based game about sharing water resources
- How a tangible user interface contributes to desired learning outcomes of the virtual river serious game
- eLEarning Africa portal



ICT and monitoring in irrigation

5

ICT supports monitoring activities in irrigation with a variety of techno logies. Monitoring in irrigation has many aspects. Sensors can be installed on-site, or on drones, airplanes and satellites. They measure various physical parameters such as water consumption, water quality, soil humidity, biomass, temperature or solar radiation. There are many technologies available which allow sensors to send the continuously recorded data to computers and servers for processing and analysis. Final products such as maps of yield, plant health, water consumption or erosion risk help decision makers to find appropriate solutions. ICT enables real time monitoring and can give access to this data to various users at the same time.

5.1 Monitoring – a key aspect in irrigation

Irrigation can be improved in many ways through monitoring. The first consideration is of course water availability and water use. Today, satellite-based meteorological forecasts allow relatively precise predictions about precipitations even in regions without rain gauging stations installed. For accurate local water resources management, however, a network of level sensors is indispensable.

Irrigated agriculture also influences other environmental areas, such as soil fertility (salination, water logging) and erosion and residuals in the final products. Monitoring therefore plays a far greater role than just in connection with water resources and their use. To simplify matters, the monitoring topic can be divided into the following four groups:

- **Water resources monitoring & management**
  This includes climatological, meteorological, hydrological, hydro-geological, water uses and water quality monitoring. It is clear that sensors, drones, satellites, remote sensing, GIS, modelling and databases are important elements.

- **Soil parameter monitoring**
  There are two aspects of soil parameter monitoring: Real-time monitoring of soil is part of automatic irrigation systems; long-term monitoring of other parameters such as soil salinity helps in identifying and mitigating irrigation-induced soil deterioration. There are now new apps which allow measuring soil characteristics.

- **Vegetation monitoring**
  Plant health (water stress, pests) and weed can be monitored by airborne sensors.

- **Erosion monitoring**
  Water erosion is primarily the wearing-away of soil by water from rain, runoff, snowmelt, but it can also be caused by irrigation. A prerequisite for successful agricultural activities is, to not lose fertile soils through erosion. Both erosion control inspection apps, as well as LIDAR[14]-based air-borne erosion monitoring applications, exist. All of this data needs to be spatially processed within GIS for further analysis.

5.2 Potentials

Accurate and up-to-date (sometimes real-time) data is a precondition for informed decisions. Decision makers are often located far from the places where the need for action occurs. Therefore, remote sensing plays a role, as does automatization and transmission of information by digital means. Communication tools are inevitable, as are auxiliary means such as charts, maps and animations for making problems understandable. A major goal of monitoring is to increase the availability of valuable information for example to government departments and extension services but also to the public through sharing the information online for anyone to use. Finally, it is the smallholder farmer who should benefit from the information and who should be guided in deriving suitable solutions out of it. Chapter 6 presents ideas for linking this information to the grassroot level.

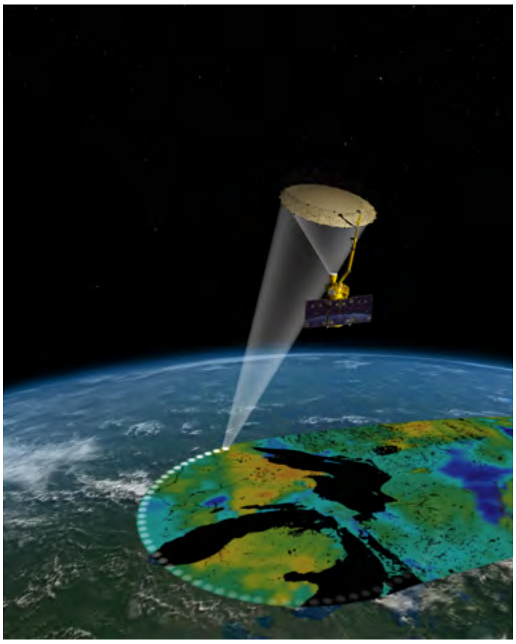
Technology and procedures are available for measuring, monitoring and deriving a number of SSI-relevant parameters and for supporting several irrigation-related activities.

- **Identification of irrigable lands and design of irrigation systems**
  For the identification of additional irrigable lands, data from satellites can be combined with hydro-geological data of ground water or hydrological data of rivers and lakes. ICT helps not only through the acquisition of the appropriate data but also through spatial evaluation procedures facilitated by geographical information systems. The use of detailed Digital Surface Models (DSM) and Digital Elevation Models (DEM) derived from satellite, airborne or drone-based sensors allows specifying the layout of functioning irrigation schemes. Terrain data and vegetation data is further relevant for modelling erosion risk.

- **Monitoring of environmental parameters for irrigation**
  It is indispensable to have accurate information about the weather and its forecast. Parameters such as temperature, humidity, wind and solar radiation allow the calculation of the water balance and thus the irrigation water demand of plants. It is also indispensable to know details about water availability and its quality. Sensors can automatically collect the necessary data for computer models, which calculate the water balance and plant water demands. Monitoring plant health and other important environmental parameters is another crucial element, and it is here that ICT can help through sensors such as soil moisture sensors and refractometers.

- **Monitoring the impact of irrigation**
  The Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). This helps identify biomass, water stress, pest infestations and thus the health of the crop. LIDAR can help monitor the crop height and the Leaf Area Index. On a larger scale, monitoring technologies help evaluate the impact on the environment. Water use and resulting resource depletion can be monitored remotely, as can other impacts on the environment such as erosion or loss of biodiversity.

5.3 Technologies



In order to fully exploit the above-mentioned monitoring potentials, a wide range of technologies can be used:

- **Earth observation (satellite, airborne, drones)**
With satellite imagery becoming more and more affordable and drone technology more accessible, these technologies gain importance for agriculture.

- **Earth Observation (EO) sensors**
(Optical/Infrared/Radar/Lidar/GPS).
The number of available sensors is high and new technologies are developed every few years. LIDAR, for instance, can penetrate the canopy and allows to measure plant height.

- **Remote Sensing software, GIS, modelling**
Powerful GIS and RS software nowadays is available for free.

- **EO Data**
Many valuable satellite-sensed data sources are for free today. The national and multi-national space agencies offer web portals and APIs for comfortable download and integration.

- **Terrestrial sensors**
Likewise, terrestrial sensors such as soil humidity sensors are becoming more affordable. This will also make the automation of irrigation cheaper and thus more attractive.

- **Data transmission (GSM, LTE, 5G, LPWAN, LORAWAN)**
Mobile radio coverage is spreading at breakneck speed in Africa. This makes transferring data from sensors to servers less expensive. Above all, it allows access to centralized information for everyone who owns a mobile phone. Materials for learning and training can easily be shared with a high number of interested parties.

- **Computers, servers, databases**
No modelling without computers, no mobile technology without servers and no information management without databases.

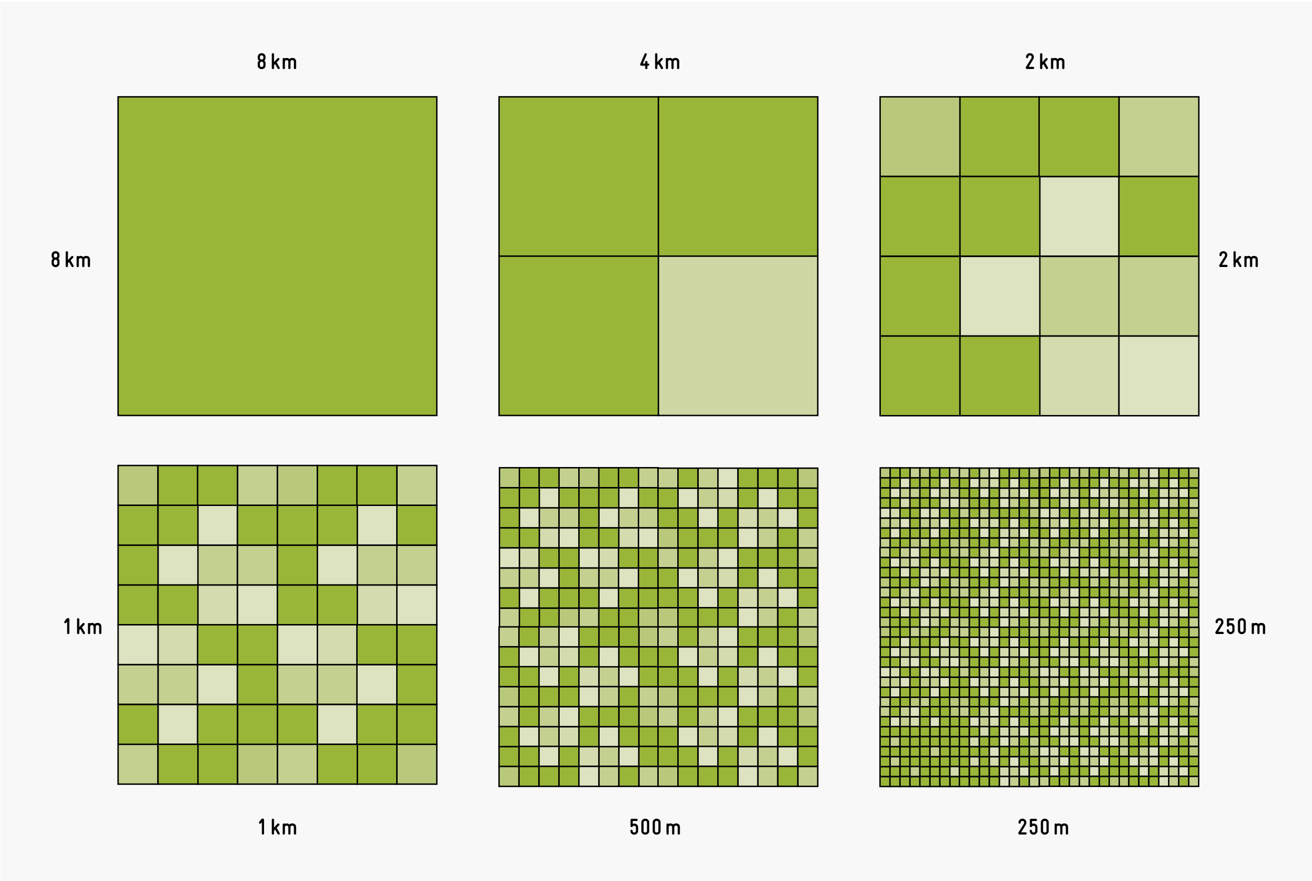
5.4 Challenges

- **Missing standards, missing regulation**
  In many countries no data privacy standards exist and no regulations for drones etc. While Rwanda, Namibia or South Africa have developed robust laws for the operation of drones, other countries still lack drone laws or have banned drones altogether (e.g. Algeria[15]). For countries lacking laws and guidelines for data principles, GIZ developed what is called Responsible Data Principles[16], Responsible Data Guidelines[17], and a corresponding toolbox[18] to fill these gaps.

- **High costs prevent outscaling.**
  Especially for small-scale irrigation, high-tech solutions are rarely suitable. High investment and operating costs cannot be financed by individual farmers. In addition, usually specialist knowledge is required that is not available locally and cannot be financed. Nevertheless, the technologies are available on larger scales. The collected data can be processed centrally and the results of the analysis can be shared with farmers using different channels such as smartphones or simple feature phones (see chapter 6 for examples). The potential customer base for these services is large, which is a good precondition for a variety of feasible business models.

- **Capacities for data processing and interpretation**
  Sensors can provide data automatically and in short intervals. But the data usually has to be interpreted before decisions can be derived. This can be done automatically (see chapter 3.3), but for many purposes interpretation of the data requires human expertise which is beyond what local farmers can provide. Therefore, governments have to invest in capacities to make this information accessible and comparable on a national scale.

- **How can decisions be derived from analysis and how can they be implemented?**
  Knowing about the scarcity of water resources does not automatically mean that farmers are more careful with it. This calls for behavioural change (see chapter 4), which requires assistance and time.



- **Low resolution of EO imagery for SSI**
  A lot of the freely available information has a spatial resolution which does not meet the needs of small-scale irrigation. While it is suitable for large-scale agriculture, the irrigated plots of the smallholders are simply too small to allow the application of (free) remote-sensing technologies. Drone-based information could collect this valuable information even though this kind of data collection is not for free.

- **Availability of basic services**
  ICT-based monitoring technology needs basic services such as a connection to the electricity grid and internet connection. Examples exist where solar panels make systems self-sustaining (see chapters 3.5.10 or 3.5.11 for example) and data collection apps usually store the data in offline mode on the device and synchronize the data later when Internet is available.

- **Vandalism**
  Theft of solar panels and destruction of river gauging stations are common problems in remote areas. Many counter-measures are available but none of them can ensure 100% safety.

- **How can SSI farmers access the information?**
  Monitoring data is valuable for all levels, the farmer himself should also have access to this important information. Chapters 6.3 – 6.6 describe how information, derived from satellite, sensors and surveys can be made accessible for the smallholder farmer.

5.5 Showcases

	NAME	CATEGORY	SERVICES	MAIN USER GROUP	BUSINESS MODEL
5.5.1	**ASTRAL AERIAL**	Data for precision farming	Drone services and provision very-high resolution data		Provision of imagery and data
5.5.2	**FAO WAPOR**	Data for water management	Near real-time database for the monitoring of water productivity		Non-commercial
5.5.3	**GGIS**	Data for water management	Web-based portal and GIS tool on groundwater		Non-commercial
5.5.4	**REAL-GUD**	Data for water management	Database and IoT application on groundwater		In development, provision of data services
5.5.5	**SAT-IRR & FIELDLOOK**	Irrigation monitoring	Real-time monitoring of water consumption and crop-water requirements		Provision of software
5.5.6	**MIKE OPERATIONS & MIKE SHE**	Automation of Irrigation & Water Management	Model-based forecast services and for online operational control of water distribution systems		Provision of Software
5.5.7	**SEBA-RIBEKA**	Monitoring of irrigation systems	Information, monitoring and management system for water distribution systems		Provision of Software and Hardware

Individual Farmers   Farmer Communities / Cooperatives   NGOs   Extension Service   IT Developers   Public Sector

5.5.1

ASTRAL AERIAL

CATEGORY: Data for precision farming

IN A NUTSHELL: Astral Aerial offers flexible and cost-effective Unmanned Aerial Vehicle (UAV)[19] and UAS[20] integrated solutions. They operate drones in different sizes, from small quattro-copters to huge fix-wing airplanes. The drones can be equipped thermal, multispectral and infra-red sensors which allow for the modelling of transpiration rates, crop health, soil quality and other.

PRINCIPAL FUNCTIONALITIES:

- Mapping of farms
- Crop spraying
- Crop health monitoring
- Data and images for Precision farming (on transpiration rates, sunlight absorption, soil quality)

BENEFIT: Farmers receive very high-resolution maps that are often not available with commercial satellite services at a comparable price.

In addition, other non-water related services are available (e.g. pesticide application or continous crop health monitoring). The services are usually not affordable for individual small-holders; financing could be provided by development partners or larger associations.

PLATFORM(S) AND TECHNOLOGY:
On-board Infra-Red, thermal and multispectral sensors.
Image processing for the creation of maps showing the health of the investigated field and data on sunlight absorption rates, transpiration rates, crop health and soil quality.

COMPANY: Astra Aerial

BUSINESS MODEL:
Production/Sale of very high-resolution images and other drone-related services.

REGION: Kenya

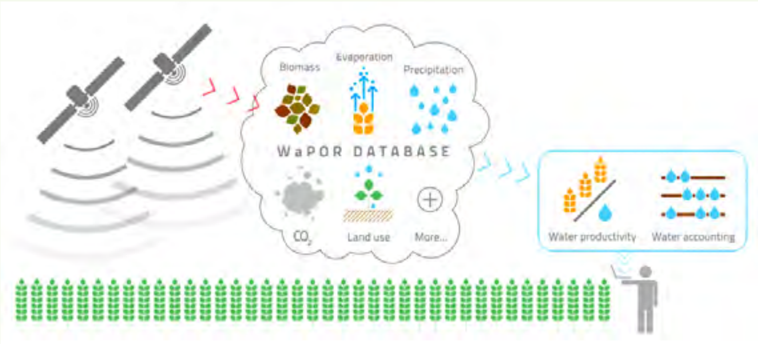
EN

LANGUAGE

WEB

5.5.2

FAO WAPOR



CATEGORY: Data for water management

IN A NUTSHELL: FAO WaPOR is a publicly accessible near real time database for monitoring of key variables associated with water and agriculture. By using and processing Sentinel satellite data, maps of different resolution are offered showing water productivity through NDVI-based biomass.

PRINCIPAL FUNCTIONALITIES:
The platforms allows for direct data queries, time series analyses, area statistics and data download of key variables associated to water and land productivity assessments, such as evapotranspiration, precipitation, NDVI and biomass productivity that provide an input for the monitoring of water productivity and water accounting.

BENEFIT:
By providing near real time pixel information, WaPOR opens the door for service-providers to assist farmers in obtaining more reliable yields and improving their livelihoods. At the same time, irrigation authorities have access to information to modernize their irrigation schemes and government agencies are able to use this information to promote and increase the efficient use of their natural resources.

PLATFORM(S) AND TECHNOLOGY:
Database, Web GIS

DEVELOPER: FAO, Land and Water Division, IHE Delft Institute for Water Education, International Water Management Institute (IWMI)

BUSINESS MODEL:
Services for free. Multilaterally funded.

REGION: Worldwide but focus on Africa and Near East

FURTHER INFORMATION
Lebanon: Water Accounting in the Litani River Basin
Koga, Ethiopia: Stakeholder mapping and needs assessment

EN
LANGUAGE

WEB

VIDEO

5.5.3

GGIS

Global Groundwater Information System

CATEGORY: Data for water management

IN A NUTSHELL: The interactive, web-based portal provides information and knowledge on groundwater. The GGIS consists of a number of thematic modules providing each the data in its own map-based viewer.

PRINCIPAL FUNCTIONALITIES:
The portal provides data time series on aquifers and thematic maps. Data can be visualized in a map viewer. External map layers can be integrated via a Web-map service. Time series analysis can be performed for each point measurement location to better understand temporal changes of groundwater levels.

BENEFIT: Groundwater professionals in public administration and research can share and analyze groundwater monitoring information. Based on the analysis, the allocation of groundwater resources can be planned and areas with potential for irrigation can be identified.

PLATFORM(S) AND TECHNOLOGY:
Database and GIS tool

DEVELOPER: International Groundwater Resources Assessment Center

BUSINESS MODEL:
Services for free. Multilaterally funded.

REGION: Worldwide

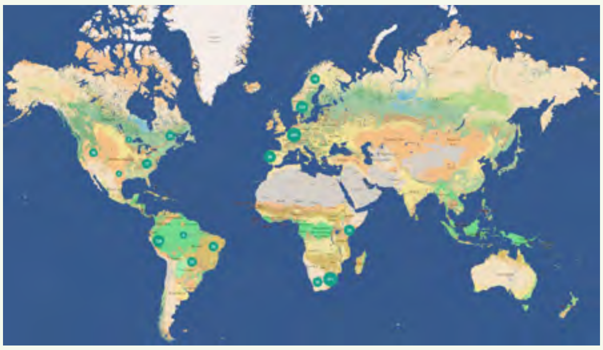
FURTHER INFORMATION
Information Brochure on igrac

igrac
International Groundwater Resources Assessment Centre

EN
LANGUAGE

WEB

SOCIAL MEDIA



5.5.4

REAL-GUD

Real-time East Africa live groundwater use database

CATEGORY: Data for water management

IN A NUTSHELL: The Real-time East Africa live groundwater use database aims to reduce groundwater information gaps by turning the network of solar pumps into IoT devices. These devices send the collected information to cloud servers for further processing and integration. The results should be made accessible via an open, online water information platform at IWMI.

PRINCIPAL FUNCTIONALITIES:
The system would be able to provide real-time information on water withdrawal, area irrigated, and energy use. REAL-GUD is a public-private partnership approach to use IoT to provide accessible, consistent data on shallow groundwater availability and use across multiple SSA countries.

BENEFIT: On the basis of real time information on groundwater abstraction, water users and water authorities can organizie the sustainable use and equitable allocation of groundwater resources. Thus the risk of overabstraction through the increasing distribution of solar irrigation systems can be mitigated.

PLATFORM(S) AND TECHNOLOGY:
FuturePump Solar Pumps, transmission technology, servers and databases

DEVELOPER: International Water Management Institute (IWMI), Future pump

BUSINESS MODEL:
In development,provision of data services

REGION: East Africa

Futurepump

IWMI International Water Management Institute

EN

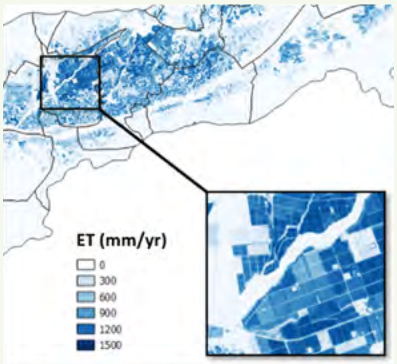
LANGUAGE

WEB

VIDEO

5.5.5

SAT-IRR & FIELDLOOK



CATEGORY: Irrigation monitoring

IN A NUTSHELL: eLEAF uses satellite-based data and provides a web-based application to optimise crop production, water management and the monitoring of water consumption.

PRINCIPAL FUNCTIONALITIES:
eLEAF's irrigation management application detects on-farm water needs days in advance. Using satellite imagery, the actual crop water requirements are monitored in real-time. This allows irrigation authorities to anticipate their expected irrigation requests. Individual farms or command areas can be compared and prioritised. Irrigation schedules can be matched to actual crop water requirements.

BENEFIT: Water allocation becomes more efficient and uniform across the system, resulting in higher crop production and increased local food security. Water Management Authorities can use data for water auditing and accounting, compare the actual water consumption with water use permits and thereby identify illegal water abstractions.

PLATFORM(S) AND TECHNOLOGY:
Satellite data, web-based application

COMPANY: eLeaf

BUSINESS MODEL:
Provision of software

REGION: Worldwide

FURTHER INFORMATION:
ICT Update, issue 86: "Precision agriculture for smallholder farmers", page 6: Transforming satellite data for smallholders
The sky is not the limit: Satellites in support of smallholder farming

eleaf

EN FR
LANGUAGE

WEB

5.5.6

MIKE OPERATIONS & MIKESHE

CATEGORY: Automation of Irrigation & Water Management

IN A NUTSHELL: MIKE OPERATIONS is a software product series designed for model-based forecast services and for online operational control for water resource management. MIKE SHE covers integrated modelling of groundwater, surface water, recharge and evapotranspiration. It includes all important aspects of hydrology and that way offers the creation of integrated models.

PRINCIPAL FUNCTIONALITIES:

- Forecasting and early warning
- Real-time system optimisation and control
- Automated processes and alerts
- Spatial and temporal data processing capabilities
- Software support and access to training courses

BENEFIT: Regulating bodies for water and irrigation can benefit from improved water resource monitoring and management, leading to an increased irrigation efficiency. The information generated can improve the water allocation in community-based irrigation systems.

PLATFORM(S) AND TECHNOLOGY:
Windows, GIS-based system

COMPANY: DHI

BUSINESS MODEL:
Provision of Software

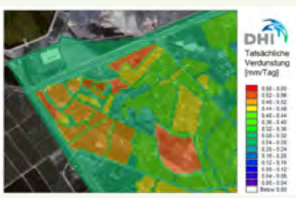
REGION: Worldwide

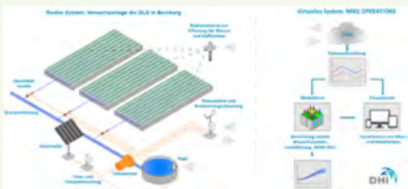
FURTHER INFORMATION:
MIKE OPERATIONS
MIKE SHE

VARIOUS
LANGUAGE

WEB

VIDEO

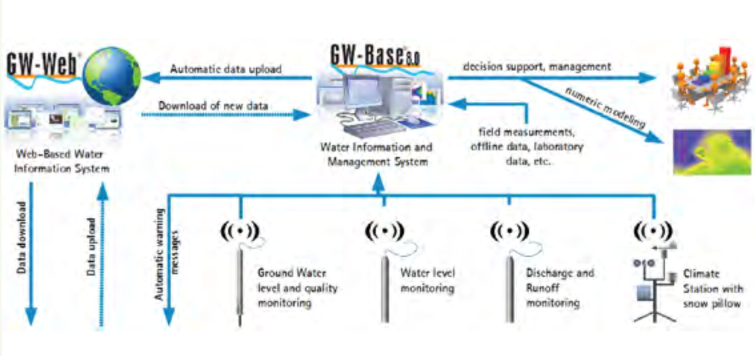




5.5.7

SEBA-RIBEKA

Part of the WEIN Project



CATEGORY: Monitoring of irrigation systems

IN A NUTSHELL: The SEBA-ribeka system is a technical solution which has been developed as part of the WINE Project on Water use efficiency in Northern Central Chile. It is an end-to-end solution for different kinds of actors from regulating bodies to water users, comprising an integrated information system for water resources management.

PRINCIPAL FUNCTIONALITIES:

- Measuring reservoir water levels.
- Measuring runoff, discharge, and water levels of rivers and channels.
- Calculating water losses (e.g. channel leakage, evaporation, calculation errors).
- Accessing water right account information.
- Specify irrigation water orders and deliveries in real time.

BENEFIT: Water and Irrigation authorities benefit from an improved water management and an increased irrigation efficiency. Community-based irrigation can benefit from a more transparent management.

PLATFORM(S) AND TECHNOLOGY:

- Water level, water velocity, discharge and water quality runoff sensors
- Data logging and data transmission via GSM/General Packet Radio Service (GPRS)
- Integrated, modular software system for data management and evaluation
- Software for servers, web interfaces and mobile applications

COMPANY: SEBA, ribeka

BUSINESS MODEL:
Presented solution is part of a research project. The companies provide software and hardware solutions.

REGION: Example is from Chile, the companies operate worldwide.

FURTHER INFORMATION:
SEBA
ribeka
Documentation on the WINE Project Solution

EN FR ES

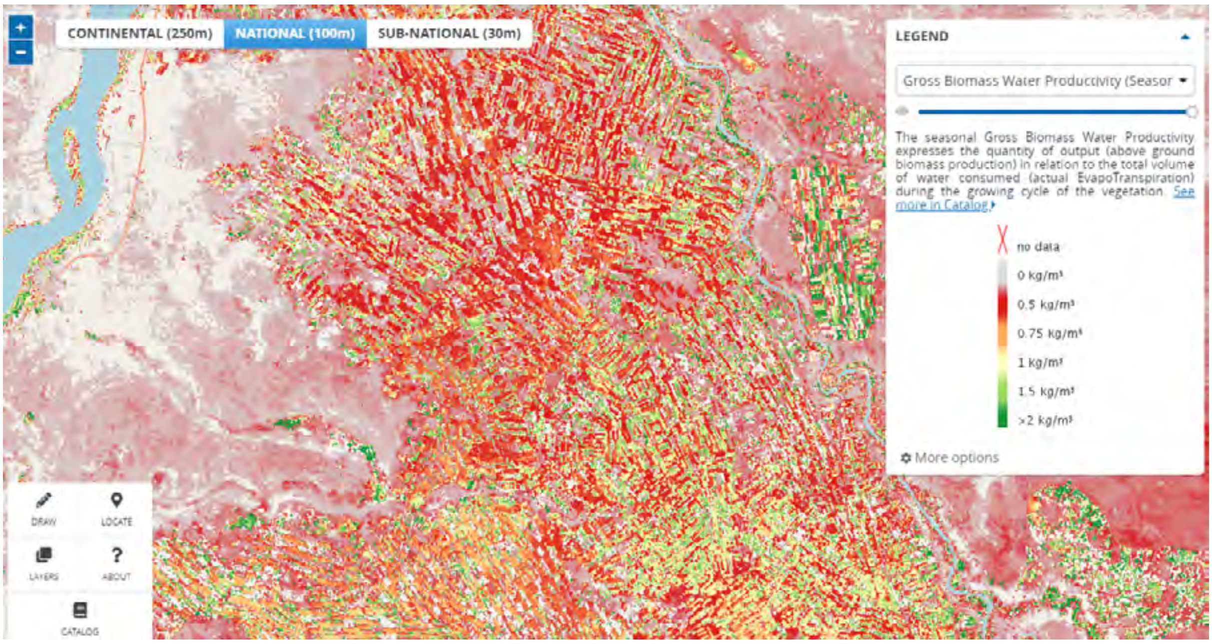
LANGUAGE

WEB

5.6 FAO Kenya: WaPOR data in the background, accessible for all through open source APIs[21]

The WaPOR Database[22] is a FAO portal that provides a publicly accessible near real-time database using satellite data to monitor agriculture water productivity. The existing database provides maps on various biophysical parameters like ET, precipitation, biomass, landcover etc., for Africa and the Middle East at a 250m resolution, at national level for selected countries and river basins with a resolution of 100m per pixel, and for some selected irrigation schemes at sub-national level at 30m per pixel. This data is generally interesting to understand and monitor water use in agriculture[23]. For small-scale irrigation with its small plot sizes, only the highest available resolution of 30m is of interest. This data, however, exists only for a few project sites and is not available nationwide for any country.

Data availability from various remote sensing sources is improving and even 30m meter resolution nowadays can be free of charge[24]. However, processing the data requires resources, such as time, technical capacities, computing power and storage, so that data suitable for small-scale irrigation is not readily available for free. Base data, however, can be downloaded for free, and further processing for small-scale irrigation can be done with free software.



The WaPOR database is interesting for water management on a national scale. How can smallholders benefit? FAO WaPOR provides an API[25] which allows integration of the data and maps into other computer software such as apps. On this basis, **Plant Village**[26] created the **Nuru**-app[27], which gives smallholder farmers of Busia/Western Kenya access to this data. By combining it with other parameters like weather & soil data, farmers receive advice for climate adaptation practices (see chapter 6.6).

5.7 Additional information

- EU Science Hub / JRC: « Agricultural Monitoring”
- Sentinel Hub: « Agriculture monitoring based on continuous satellite imagery”
- CTA: ICT Update, issue 86: “Precision agriculture for smallholder farmers”
- CTA: ICT Update, issue 56: “Irrigation”.
- CTA: ICT Update, issue 82, 2016: “Drones for agriculture”.
- CTA: ICT Update, issue 87, 2018: “Weather data for agriculture”.
- Weather data community of practice
- African Minds: “Open Data in Developing Economies”

ICT and smallholders' access to information

6

ICT can facilitate access for smalholders to data that is relevant for small-scale irrigation. This includes the provision of localized weather forecasts, water resources related data, customized early warning information, pest and disease alerts as well as mitigation measures and appropriate management support. Based on all this information, farmers can improve their irrigation practices. Better agricultural practices will achieve higher yields and help reduce water and energy consumption; in that way it will contribute to the protection of the resources and ultimately improve the sustainability of farmers' livelihoods. The technical solutions to realize this potentials range from well-known radio transmissions to state-of-the-art mobile applications.

6.1 The knowledge gap

Chapter 3 described the role of ICT for environmental monitoring in general and for measuring parameters relevant to irrigation in particular. This entails the collection of data with satellite-, airborne- and drone-based sensors, complementing them with terrestrial sensors as well as processing and analysing the data to derive accurate and real-time information which supports decisionmaking in water management. Smallholder farmers are managing water resources directly. Their livelihoods depend on water availability to a great extend and at the same time it is often their activities which affect the quantity and quality of water resources. Eventhough there might already be laws and regulations to protect those resources, the probability of water users sticking to those rules is higher if they comprehend the underlying principles. Therefore access for smallholder farmers to the above mentioned information is crucial.

This is where ICT can play an important role. For example smartphone-based services can be set up in a way that they deliver custom-tailored and localized information. A poultry farmer might need information about chicken pests, while the horticulturalist needs a localized weather forecast. The information can be collected, analysed and synthesized in maps, diagrams and tables at management level, but in the end it is the smallholder farmer themselves who should get access to this information, and this information needs to be translated into the language the smallholder understands. In order to reach out to a high number of users, ICT is indispensable. This is understood by most actors, and there are new apps appearing every other day. But very few smallholder farmers in African countries have smartphones, and there is a shortage of available software that can directly help small-scale farmers with simple phones to manage their irrigation activities. Technologies are available to deliver information in a structured and even custom-tailored way: USSD (Unstructured Service Data, see chapter 6.3), IVR (Interactive Voice Response, see chapter 6.3), voicemail or SMS, all allow user demand driven information supply. These technologies are expensive for both service providers and farmers, and the information delivered via these technologies is not very detailed due to the given limits.

Most of the available software for small-scale irrigation is thus smartphone software (Apps), which provides farmers of cooperatives with access to information. Although the smallholder farmer might not have a smartphone, or might not be able to read, the lead farmer, farmer trainer, agent or similar can operate their smartphone and transmit this information to the smallholders. The smartphone will be the future instrument for all sorts of information-related services and, thus, future projects should not invest too much in the above-mentioned phone technologies. The most appropriate solution might be to deliver information via two or more technological channels. That way, this information can reach the largest number of users.

Some of the software presented here is web based and requires a browser and Internet- connectivity. Consequently it might be difficult for certain smallholders to access this software and information. Nevertheless, these solutions are noteworthy because they offer localized and customized information for single fields and plots - information which is particularly interesting for small-scale irrigation. In case smallholders lack the devices or resources to access this data, the provision of this information could be a service offered through multipliers such as agents, lead farmers or even commercially operating individuals.

Many types of software (apps, desktop and web) support the management of cooperatives or associations. This software, known under the term "Farmer Management System", is not presented within this study. Other ICT-related studies exist that target cooperatives and associations in a broader sense. Well-known examples of this type of software are GreenFingerMobile[28], eprod[29], or Esoko[30].

Another market segment is software for the design of irrigation systems. Almost every irrigation hardware manufacturer provides an app and/or a web site for the design of small, medium and large irrigation systems. They are usually provided by manufacturers for free and intend to attach the user to the products[31]. This is not part of the study, as becoming dependent on single manufacturers should be avoided and also because smallholders usually cannot invest in the expensive equipment these apps are suggesting.

6.2 Potentials

- **Modern mobile technologies enable the provision of localized and customized information.**
  Information relevant to agriculture has in most cases a spatial component. Weather and soil conditions differ from one place to another and so do water availability and quality. A plot has its boundaries, a farm its location, and water follows the slopes of the hills. If sufficient information is collected and/or modelled, smartphone technology, with its on-board GPS, can make this information available for specific locations through apps.

- **Modern mobile technology can be used to collect data.**
  Smartphones nowadays are frequently used for data collection. Survey sheets are translated into apps and guide the users in collecting all the data with the quality needed. If smallholders collect information and send this data to servers, it can be processed and made available for other users. In modern precision farming satellites, drones and tractors are permanently collecting data; however, smartphones also have on-board sensors and can be used for agricultural data collection as well.

- **Modern mobile technology can be used to remotely control and monitor.**
  Smartphones already come with a number of sensors onboard, but they can still connect to external sensors such as humidity or temperature sensors through Bluetooth or WIFI. That way, a farmer can control the physical parameters of his plots remotely and can send his management decisions to remote devices.

- **Providing low-technology farmers with latest state-of the-art-information**
  Information acquired with most modern technology can still be transported to the smallholder farmer through various low-level technologies such as SMS, Voice Mail, television or radio.

- **Combination of SSI-related services with other services of interest for the smallholders**
  This study particularly presents ICT-based solutions for small-scale irrigation. There are, however, numerous solutions on the market which are of interest to all smallholder farmers: Apps for access to market information, for mobile money, e-advice, and farm-management software etc. By combining the presented solutions for small-scale-irrigation farmers, the apps would receive an added value and a higher attractiveness.

- **Attracting youth to agriculture**
  Young people in most parts of the world consider agriculture to be old-fashioned and uninteresting. Modern technologies, above all smartphone-technologies, can be used to increase the attractiveness of agriculture among younger people.

6.3 Technologies

Many technologies are available for the dissemination of information. Smartphones are the best means to make localized and personalized information available to a large audience, but this technology is not yet affordable for the poorest, and data networks are not yet available everywhere. There is no universal recipe, no panacea, and the appropriate technology must be assessed on a case by case basis. It can be helpful to offer the same information through several channels. In this way, for example, older farmers in remote areas can receive information via radio broadcasts, while younger IT-savvy farmers near bigger cities already receive the same information via smartphones. The promotion of ICT4Ag usually targets the younger generation as they are more receptive to innovative technologies.

- **Smartphones for the reception of custom-tailored, localized information**
  A hyper-localized weather forecast, giving even information about the status of the soil can be helpful for farmers and their irrigation practices. Early warning systems and marker information systems all rely on this technology to link farmers to the system.

- **Smartphone apps for data collection and transmission**
  A very common application of smartphones is the collection of information and its transmission to cloud-servers. This is not directly related to small-scale irrigation, but this data, when crowd-sourced by many users, can be processed and made available to all participating users in a localized, custom-tailored form. Information about pest infestations, for instance, that is reported to a server can be made available for early warning of owners of neighbouring parcels.

- **Simple (GSM) feature phones and SMS**
  In many countries most farmers have access to a simple phone. Information can be sent to these farmers by bulk SMS. Software allows customized messages to be sent via a server of a phone service provider. With Push SMS technology, a bi-directional SMS technology, one can send an SMS to a user that includes a specific question that the user can respond to via a pre-paid SMS. There are no costs for the responding user.

- **Simple (GSM) feature phones and USSD**
  Another technology for bi-directional communication is the Unstructured Supplementary Service Data (USSD), sometimes referred to as "Quick Codes" or "Feature codes". It is a communications protocol used by GSM cellular telephones to communicate with the mobile network operator's computers. With this technology, specific information can be made available, and the user is guided to the information by menus. USSD messages are up to 182 alphanumeric characters long. Unlike Short Message Service (SMS) messages, USSD messages create a real-time connection during a USSD session. The connection remains open, allowing a two-way exchange of a sequence of data. This makes USSD more responsive than services that use SMS.

- **Phones and IVR technology**
  Many countries have very high illiteracy rates among smallholder farmers. The Interactive Voice Response Technology IVR can help solve this problem. IVR allows customers to interact with a server system via a telephone keypad or by speech recognition, after which services can be inquired about through the IVR dialogue. IVR systems can respond with pre-recorded or dynamically generated audio to provide the requested information or to further direct users on how to proceed.

- **Radio and television**
  Community radio stations are still the number one source for information in many countries. Several new radio and TV show formats attract both young and old farmers, and interactive shows allow farmers to participate with questions and content. Various Web portals provide platforms for sharing videos and audios, thus allowing for higher numbers of consumers to be reached. These videos can also be provided for streaming on smartphones or download so that farmers can share these videos off-line with other farmers.

6.4 Challenges

It is not always easy to select the appropriate technology for a given setting. The development of information technologies is advancing rapidly and the risk of a lack of sustainability is high. SMS technology, for instance, is a rather expensive way for sending information to a high number of users and might be abandoned in the near future.

Smartphones are the best means to make localized and personalized information available to a large audience; however, this technology is not yet affordable for the poorest, and data networks are not yet available everywhere. There is therefore no universal recipe, no panacea, and the technology must be assessed on a case by case basis. It can be helpful to offer the same information through several channels. In this way, for example, older farmers in remote areas can receive information via radio broadcasts, while younger, IT-savvy farmers near bigger cities already receive the same information via smartphones.

- **How to deal with illiteracy?**
  Illiteracy rates among smallholders is usually above average. In this case ICT cannot focus on web sites or apps. Here radio, Interactive Voice Response (IVR) and videos are the technology of choice.Frequently, lead farmers, association leaders or other leadership personalities act as multipliers. Likewise, children and young adults can help their parents understanding the message. Smartphones, with their colour-screens, allow the use of pictograms to make menus understandable even for illiterates.

- **Information provision in local idioms!**
  For the dissemination of information to the smallholders, local idioms have to be used, no matter which channel. Given the high number of languages in African countries, apps should be available in multiple languages. Modern programming environments for mobile apps take this into account.

- **Non-availability of basic services in remote areas (grid, Internet …)**
  The poorest smallholder farmers usually live in the most remote areas. These are the areas where basic services are least developed, thus promoting ICT is often difficult and has to be based on offline-technologies. However, by targeting large numbers of farmers, projects can attract phone companies to invest in extending their networks to these areas. This also applies to other fields, such as financial services and power grid.

- **Affordability of technology and services**
  It is the objective of any development effort to support the poorest and most marginalized people and to minimize the difference of living standards within the community and throughout the countries. By choosing ICT for this task, there is a high risk of even increasing this difference. Projects have to be carefully designed to mitigate this effect and not to increase it.

- **How to reconcile "leaving no one behind" and the introduction of ICT?**
  The preceding two bullet points already summarize the problem: The poorest have the highest illiteracy rate, the lowest technology literacy, no financial resources for technology and the weakest service networks.
  In Mozambique, the cotton company JFC handed over 10,000 simple phones to farmers. Twice a week, information about cotton price, weather, etc. is transferred via SMS. Farmers can also send information and receive custom-tailored data about their deliveries. Such actions develop technology literacy among smallholders and pay back in the long run.

- **Difficulty to find sustainable business models**
  There are costs related to the introduction of ICT for small-scale irrigation. These include hardware and software costs, but also costs for maintenance and/or licenses which have to be paid continually. A sustainable business model needs to consider the added value for the farmer. If a farmer can mitigate risks through the use of an early warning app, he might be convinced to pay for it.

- **Lack of ICT expertise**
  The introduction of ICT needs local expertise. The availability of these capacities varies among countries, but it can usually be found at least in the capitals. However, ICT experts primarily work for banks, phone providers and industry – agriculture is not often the focus. Attempts have to be made to connect the agriculturalists with their demands to the local IT sector so that the opportunities become visible for all stakeholders. Another opportunity are Hackathons, with the purpose of attracting young innovative people of the IT sector to think about applications for agriculture.

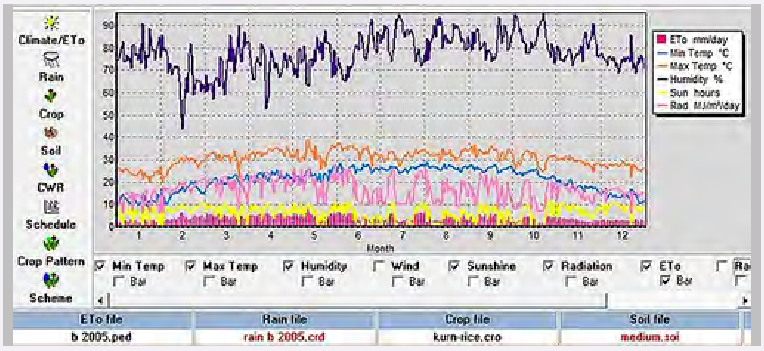
6.5 Showcases

	NAME	CATEGORY	SERVICES	MAIN USER GROUP	BUSINESS MODEL
6.5.1	**CROPWAT**	Irrigation management app	Calculation of crop water requirements		Non-commercial
6.5.2	**SEBA DISCHARGE**	Data collection app	Acquisition of flow velocity profiles, irrigation canals / furrows and waste water channels		Provision of Software
6.5.3	**UJUZIKILIMO**	Data collection app / Access to remotely sensed data for smallholders	Weather forecast & updates; measurement of soil and farm characteristics		Provision of weather data
6.5.4	**IRRISAT**	Access to remotely sensed data for smallholders	Irrigation scheduling advice		Provision of irrigation advice
6.5.5	**VILLAGELINK**	Access to remotely sensed data for smallholders	Weather updates and crop advice; flood monitoring		Provision of weather data
6.5.6	**PLANTVILLAGE**	Access to agronomic information for smallholders	Q&A forum and library on diseases and pests		Non-commercial

Individual Farmers   Farmer Communities / Cooperatives   NGOs   Extension Service   IT Developers   Public Sector

6.5.1

CROPWAT



CATEGORY: Irrigation management app

IN A NUTSHELL: CropWat is a computer programme which calculates the water and irrigation requirements of a crop. It can be used to work out irrigation and water balance schedules depending on the climate and soil type.

PRINCIPAL FUNCTIONALITIES:

- Monthly, decade and daily input of climatic data for calculation of reference evapotranspiration,
- calculation of crop water requirements and irrigation scheduling
- interactive user adjustable irrigation schedules,
- daily soil water balance output tables

BENEFIT: Free programme to calculate crop water demands.

PLATFORM(S) AND TECHNOLOGY: Application running on Windows

COMPANY: Food and Agricultural Organization FAO

BUSINESS MODEL: Non-commercial free download from FAO servers.

REGION: Worldwide

EN ES FR RS

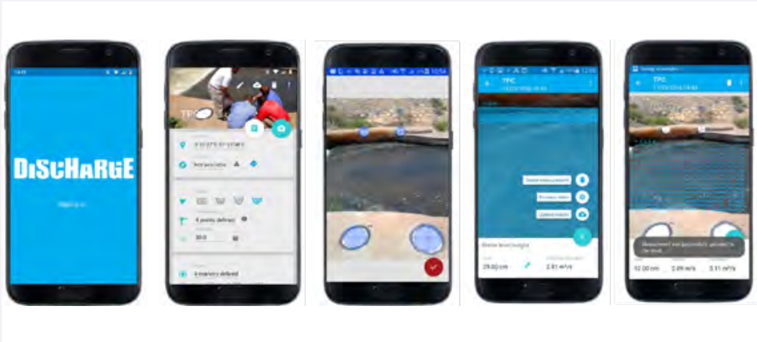
LANGUAGE

WEB

VIDEO

6.5.2

SEBA-DISCHARGE



CATEGORY: Data collection app

IN A NUTSHELL: SEBA Discharge offers a non-intrusive approach to measure discharges Surface Structure Image Velocimetry at pre-defined sites. A patented algorithm provides the velocity profile at the surface of the water body. The vertical velocity distribution is calculated from the surface velocity field using a physical model, which uses the roughness of the bed as a boundary condition.

PRINCIPAL FUNCTIONALITIES:

- The DischargeApp is a smartphone-based method for acquisition of flow velocity profiles, water levels and flow rates in natural water streams, irrigation canals / furrows and waste water channels.
- After interactive level detection and fully automatic velocity measurement the app computes the discharge value.
- Once a measurement is performed, it can be uploaded to the Discharge-Web platform

BENEFIT: No direct benefit for the smallholder. Community-based irrigation management can benefit from a more transparent data collection and provision.

PLATFORM(S) AND TECHNOLOGY: DischargeApp for smartphones and web portal for analysis and visualization.

COMPANY: SEBA

BUSINESS MODEL: Provision of Software, available in different plans, also freeware

REGION: Worldwide

SEBA HYDROMETRIE

NGO

EN FR ES

LANGUAGE

WEB

VIDEO

6.5.3

UJUZIKILIMO

CATEGORY: Data collection app & Access to remotely sensed data for smallholders

IN A NUTSHELL: UjuziKilimo offers timely weather updates, and predictive insights on the weather expectations through SMS for registered customers. To receive the weather updates, UjuziKilimo must have conducted a farm analysis first in order to custom-tailor the information to the farmers' needs.

PRINCIPAL FUNCTIONALITIES:

- Weather forecast via SMS
- Cloud connected sensor device to measure soil characteristics

BENEFIT: Making farmers more resilient through timely weather updates and predictive insights on weather expectations. The user can receive custom-tailored weather forecasts for his farm by SMS.

PLATFORM(S) AND TECHNOLOGY: Satellites, Ujuzi sensors, local weather forecasts. Machine learning & SMS dissemination.

COMPANY: UJUZI KILIMO

BUSINESS MODEL: Provision of weather data

REGION: Kenya, East Africa

UjuziKilimo

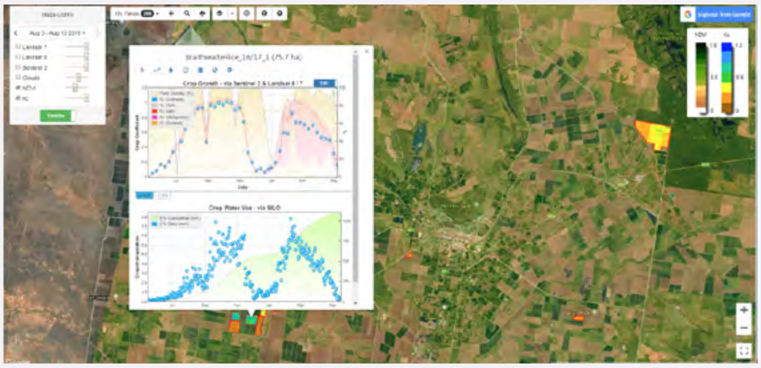
EN

LANGUAGE

WEB

6.5.4

IRRISAT



CATEGORY: Access to remotely sensed data for smallholders

IN A NUTSHELL: IrriSAT combines satellite data and information from local weather stations to generate daily, detailed irrigation advice to Australian farmers. Up to date satellite images are used to determine individual crop coefficients. These images then determine the canopy of the crop, and then the specific crop coefficient, which is combined with local data from on-ground weather stations. This parameters are then used to calculate the amount of irrigation to be applied.

PRINCIPAL FUNCTIONALITIES: Provision of weather based irrigation scheduling advice. Information is produced custom-tailored, daily, and can work across large spatial scales.

BENEFIT: Informs farmers how much water their crop has used and how much how much irrigation they need to apply.

PLATFORM(S) AND TECHNOLOGY: Satellite imagery, weather stations, central server, mobile application

COMPANY: CSIRO (Commonwealth Scientific and Research Organization)

REGION: Australia, Worldwide

FURTHER INFORMATION

Putting satellite data into the hands of farmers

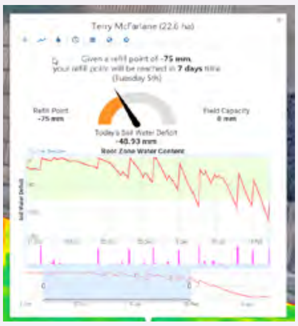
CSIRO

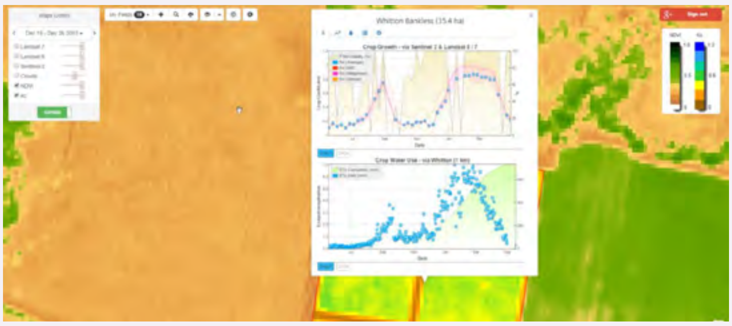
EN

LANGUAGE

WEB

VIDEO





6.5.5

VILLAGELINK

CATEGORY: Access to remotely sensed data for smallholders

IN A NUTSHELL: VillageLink Satellite Services (VLSS) is a platform that aggregates satellite data related to agriculture and transforms them into key information which businesses and organizations can use to improve their operations and decision making.

PRINCIPAL FUNCTIONALITIES:

- Localized weather forecast and updates, crop classification, crop extent measure, crop performance tracking, crop growth stage tracking and flood monitoring
- Yield estimations accessible by smartphone
- Connects farmers to agricultural professionals and service
  - Daily weather and crop guidelines

BENEFIT: The farmer can receive custom-tailored weather forecasts, yield estimations and advice for his farm.

PLATFORM(S) AND TECHNOLOGY: Sattelite data, native Android app

COMPANY: Villagelink

BUSINESS MODEL: Provision of weather data

REGION: Myanmar

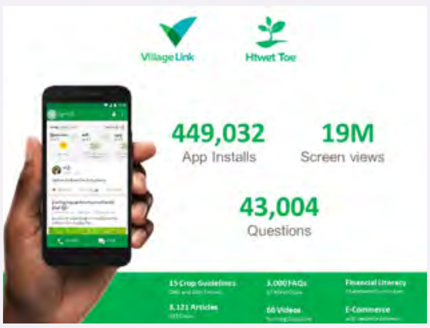
Village Link

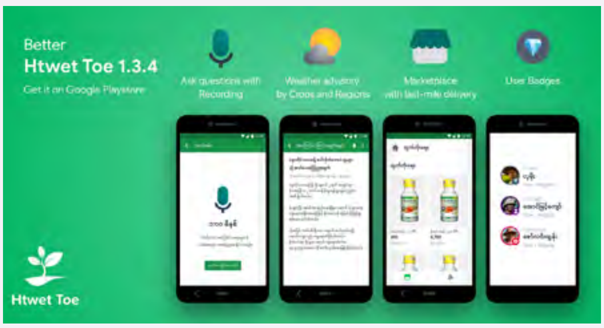
EN

LANGUAGE

WEB

VIDEO





6.5.6

PLANT-VILLAGE

CATEGORY: Access to agronomic information for smallholders

IN A NUTSHELL: PlantVillage is a user moderated Q&A forum dedicated to the goal of helping people grow their own food. It is an open, freely available resource that helps solving all plant related questions. Besides the Q&A forum PlantVillage provides an open-access library and contributes to improve solutions for farmers and extension workers by leveraging advances in AI, mobile phones, drones, satellites and nanotechnology.

PRINCIPAL FUNCTIONALITIES:

- User moderated Q&A
- Open-access library on diseases and pests, crops

BENEFIT: Farmers can access information about pests and diseases and profit from individual advisory services based on remotely sensed data

PLATFORM(S) AND TECHNOLOGY: Website including the Q&A Forum, AI based mobile applications

COMPANY: Huck Institute of Life Sciences at the Pennsylvania State University

BUSINESS MODEL: Freeware

REGION: Worldwide

FURTHER INFORMATION:
This App Lets Kenya's Farmers Monitor Crops From Eyes in the Sky
FAO Factsheet on Plant Village
Plant Village Nuru App working with WaPOR

PlantVillage

EN
LANGUAGE

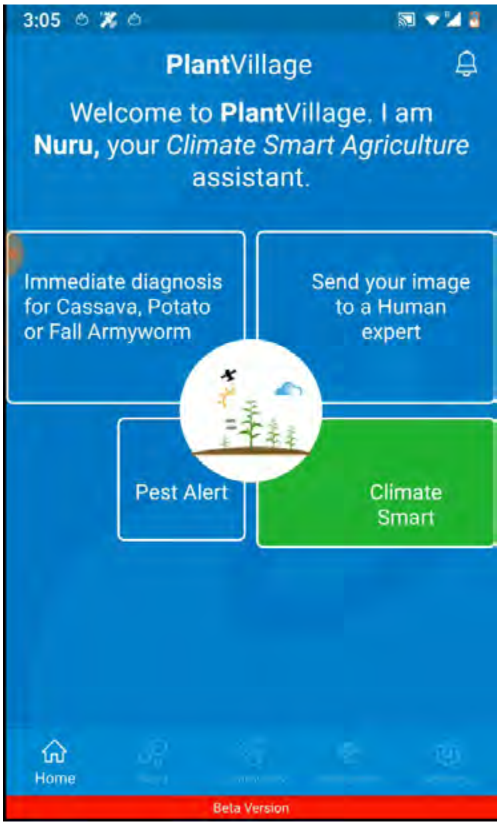
WEB

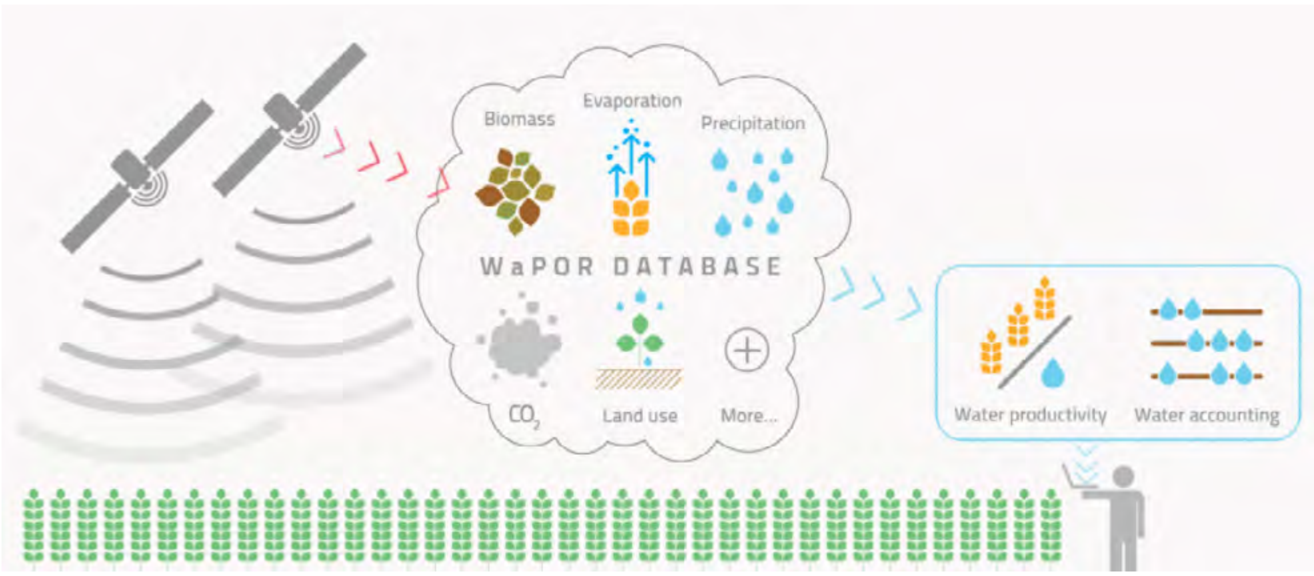
VIDEO

SOCIAL MEDIA

6.6 Plant Village: Nuru app gives smallholder farmers access to remotely sensed data[32]

PlantVillage Nuru is an existing AI assistant, similar to Plantix[33], that is being used across Africa to help diagnose crop diseases. The performance of underlying machine learning models of the app was tested using locally sourced smartphones under typical light and temperature conditions. These tests revealed a precision twice as good as human experts at making accurate diagnoses. **Plant Village**, a user moderated Q&A forum, developed this Android **Nuru**-app[34], which also provides smallholder farmers with local information on crop-productivity, weather and soil data for free. The most recent version of the app links this data with the FAO **WaPOR database** (see chapter 5.6) to advise farmers on climate adaptation practices. The Nuru app is a complete instrument for better farming at smallholder level and a good example of how smallholders can benefit from sophisticated remote sensing products.





PlantVilage is piloting this information system in Busia, Western Kenya.

6.7 Additional information

- Dalberg Advisors/CTA, 2019: "The Digitalisation of African Agriculture Report, 2018-2019" Comprehensive study on the ICT4AG development in Africa.
- WaterWatch Cooperative: "Global Data Ecosystem"
- "What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania"
- International Water Management Institute : "Climate Atlas Web Query".
- Feed The Future: Innovation Lab For Small Scale Irrigation
- CTA: ICT Update, issue 86: "Precision agriculture for smallholder farmers".
- The Worldbank: "ICT IN AGRICULTURE, Connecting Smallholders to Knowledge, Networks, and Institutions"

Keys to success

7

To find applicable solutions it is important to differentiate among countries, regions and social structures. ICT offers a wide range of technologies and there is always an appropriate technical solution for a given situation. To find the most suitable technology, many factors have to be considered: access to basic services, technology and financial services is one aspect. Literacy, as well as IT knowledge of the target groups, is another. Business models here are mostly direct-to-farmer based. Financial sustainability can be achieved because of the large potential customer base and pay-as-you-go models (see box on page 103).

General keys to success are given on the following pages. They apply to the introduction of ICT-based solutions not only related to small-scale irrigation but also for all other fields of smallholder agriculture. Taking these keys to success into account will increase the probability that project implementation will be successful and indicators are met. These keys are derived from a large number of individual projects, from documents and reports from other organizations, and from personal experience of the interviewed experts and the author himself.

Keep it simple for the end user![35]

ICT solutions have to be as simple and user-friendly as possible. The most successful ICT solutions are those that anybody understands. No user will read a multi-page tutorial before using an app. User Experience is a new field of science which discusses intuitive user design of applications.

Select the appropriate technology!

ICT is a means of providing better services and streamlining existing processes. ICT offers a wide range of technologies and usually there are several approaches that lead to the same goal. Selecting the state-of-the-art technology is not always the most effective option. Agriculture frequently takes place in remote areas where the service coverage for mobile phones is not complete or the literacy of the farmers is not high enough.

Create sustainable and affordable solutions!

Services that take a significant share of the farmers' incomes are likely not to be adopted by farmers. Free information services, however, frequently do not receive full appreciation. Wherever possible, create free basic services with additional paid advanced service levels. ICT is a perfect means to reach a high number of users/beneficiaries – this can lower the cost for the individual.

Gender

With an increasing variability of rainfalls due to climate change, access to small-scale irrigation systems is becoming an increasingly important risk mitigation tool for small-scale farmers. But not all farmers are able to access the benefits these systems provide—women in particular are often left out of the picture. Innovation in small-scale irrigation are far from gender-neutral and inequalities in access to irrigation water, accessing credit to implement an innovation and in active participation in decision-making around irrigation are well known.

At the same time, the digital gender gap in the use of ICT is comprehensively documented. Gender differences in opportunities and resources for access to and effective use of information and communication technology are commonly expressed through the term Digital Gender Gap.

›

Consider the local setting!

Consider access to basic services, consider literacy and local idioms. If farmers have to interact with the ICT solution (SMS, SMS polls, USSD, apps, training videos, etc.), it is essential that local idioms are considered. If literacy is low among the farmers, try to make use of voice mail, pictograms, and photos.

Attract youth to modern farming!

Modern technologies can be an incentive for young people to stay in rural areas and to engage in farming. Literacy rates and technical affinity are higher among the younger generations. Access to information can trigger the transformation of the local communities into a modern society.

Mobilize local ICT capacities!

ICT capacity can be found, developed and mobilized in all capitals and larger cities world-wide. Globalization gives access to state-of-the-art ICT know-how which stimulates the emergence of local IT ecosystems. Through hackathons, boot camps and programming competitions, these processes can be initiated and accelerated. GIZ made good experiences, e.g. in Tunisia.

The reasons for the unequal distribution of ICT participation are complex, and include socio-cultural backgrounds that prevent women from accessing computers or courses; technological innovations that do not address the needs of all genders; financial barriers that reduce the ownership of computers or mobile phone contracts; or low levels of education that prevent the use of digital technologies and reduce self-confidence.

When promoting innovation in small-scale irrigation, the differences in women's and men's agricultural roles, aspects influencing women's digital inclusion and context-appropriate channels for reaching women farmers have to be taken into consideration.

Further Information:

Considering gender when promoting small-scale irrigation technologies: Guidance for inclusive irrigation interventions

BUSINESS MODELS SUITABLE FOR ICT4AG SOLUTIONS

Business models for ICTs specifically targeting smallholders range from pay-as-you-go revenue models (e.g. SunCulture, see chapter 3.5.8) over transaction-based payments (e.g. SEBA Discharge, see chapter 6.5.2), to Freemium models where a product or service is offered for free but money (a premium) is charged for additional features or services. PAYG-models can be designed as rent-models or pay-to-own models, where the smallholder finally owns the system. There are other ICT solutions, where a governmental structure is offering the services for free, such as advisory services or weather forecasts. E-Krishok, an e-advisory service in Bangladesh, has a participatory funding approach including the government, private sector, universities and development organizations. A software can also attract an audience for free by creating content or attracting interaction and engagement, and then sell access to advertisers. This can be a win-win situation: users receive free or highly subsidized content and advertisers find their exact customer with the benefit of improved data-driven targeting. This is particularly applicable for marketing platforms. Some mobile network operators invest in ICT4Ag solutions in order to find and bind clients to the brand.

According to a study of the AGRA financial inclusion team[36], in its partnership with The MasterCard Foundation, the most successful business models for ICT4Ag have revenue models where agribusinesses or institutions pay for smallholder farmers to access the service. Hence the paying client differs from the user. Or they have diversified sources of income: subscription and usage fees combined with advertisements and commissions.

OTHER VALUABLE SOURCES OF INFORMATION FOR ICT4AG BUSINESS MODELS:

CTA Update, Issue 80, p7 "Sustainable and scalable business models" by Michael Elliott, TechnoServe regional programme director of the Connected Farmer Alliance.

CTA: Six business model recommendations for ACP digital agribusiness entrepreneurs

Conclusions and recommendations

8

Technology landscape

ICT offers a wide range of technologies. However, not all of them are suitable for small-scale irrigation, and there are usually different approaches to address a given problem. The decision should not be in favour of the most modern technology, but rather the most suitable technology responding to the carefully examined needs and framework conditions.

Smallholder agriculture, due to the fact that the target group lives in the most remote parts of a country, has the highest illiteracy-rates and low rates of access to technology. Consequently, the latest state-of-the-art ICT solution is not always the most suitable instrument to improve farm management. Limitations such as lack of Internet or poor Internet performance in the target areas make any web-based solution difficult to access. If literacy rates are low, ICT offers technologies to tackle these problems: Interactive Voice Response (IVR), which uses human voice for navigating menus and delivers information by pre-recorded messages, for instance, might be used, as well as videos, television or radio.

It is advisable, to disseminate the same information through two or more channels: Those who already have access to appropriate technology might digest this information through modern smartphones and apps, while the poorer and older still receive the information via community radio. By providing apps as a tool for small-scale irrigation younger people who have more interest in modern technology can be attracted to agriculture.

Based on the related costs and the context, it is understandable that precision farming using drones, satellites, tractors, apps, GIS and multi-band imagery is in most cases not applicable for smallholders in Africa. The technology should, nevertheless, be supported and further developed in pilot projects or through hackathons and accelerators. This would give young technology-savvy people of the major African cities an opportunity for development.

Business models and sustainability

In most cases ICT can come up with an appropriate solution for a given problem in a given environment. The difficulty, is usually to find a business model that works in the long term. Technology is not cheap and normally entails permanent costs such as data costs or costs for a cloud server. ICT solutions normally have a team behind them permanently working to collect the necessary data, to fix bugs, to operate the hardware and to manage customer relations. If small-scale farmers already lack money for seeds, they will not be willing to spend money on ICT services. To reach small-holders with ICT services, it might be a good option to approach them through cooperatives or contract farming. Furthermore, a range of business models are available to select from: freemium packages, a pricing strategy by which a product or service is provided free of charge, but where money (a premium) is charged for additional features or services; transaction-based fee models where money is only charged for services which create income for the user; traditional monthly flat fees, or software, offered for free to all by the government. For further information on business models, see the box on page 103.

There are very few ICT solutions specifically designed for small-scale irrigation. The automation of irrigation in Africa takes place only sporadically and only either in test projects or in larger irrigation systems. However, the spread of solar pumps is currently taking place because it is simply cheaper in the long run than using generators and fossil fuels. And with the use of solar pumps comes the possibility of collecting and sharing data on water volumes. Automation of irrigation agriculture will take place also in Africa, and this development should be supported where applicable.

Knowledge and access to it

Water is a limited and shared resource. It is shared between different users and also between different usages. Monitoring therefore is crucial, and this applies not only to water quantity but also to water quality, soil parameters, plant health and the quality of the products grown. Monitoring requires technology such as sensors, satellite or airborne sensing, drones, data transmission, computers and servers. It also requires specialist knowledge and, therefore is usually done by governmental institutions, multi-national organisations or on large farms which are capable of providing both the financial capacity and the necessary human resources. Ultimately, however, it is the small farmers who should develop an understanding of how irrigation can be improved in the future. And here is a gap ICT can bridge: ICT can make the smallholder farmer be part of the monitoring process and thus raise awareness for sustainable usage of water. ICT can provide valuable information to the farmer, such as early warning, weather forecast and market information. ICT can help to connect farmers with each other. ICT can also connect the smallholder with other professionals of the sector, with the market, with knowledge and with financial institutions.

Changing behaviour is information-driven. Without a thorough understanding of the problems and the appropriate solution approaches, people will not be able to change their habits. ICT technology makes it possible, to reach a high number of people at the same time. Radio, television, Internet, SMA and smartphone apps are all means of disseminating information to the people. It must be decided anew, for each individual case, which of these technologies is the most suitable.

ICT for small-scale-irrigation in a wider scope

When introducing ICT in development projects it should not be forgotten that the successful development of local ICT service providers has an important positive effect on the economic development of a society. Through hackathons, bootcamps and accelerators, talents can be identified, and the creation of start-ups stimulated. The agricultural sector, with all its requirements for high-tech solutions, is often overlooked by IT professionals. Match-making between agriculturalists and the local IT sector can bring the two sides together and create business opportunities. Workshops, conferences and papers can promote this process.

Likewise, the promotion of ICT for small-scale irrigation can be approached in tandem with the development of other sectors: Energy, education, financial services, inclusive business models – all of which are at the interface of small-scale irrigation and ICT. Therefore, sectors should not be considered individually or in isolation, synergies should be created between projects of different sectors.

Several chapters of this study point out that it is often difficult to find a suitable business model for ICT solutions in small-scale irrigation, since the target group cannot afford the required products or services. As an interim solution governmental structures could subsidise projects for a predifined period of time. This is for example already the case for large-scale governmental run farmer information services. Aiming for a sustainable operation of the respective ICT solution, the long-term objective should be that farmers can finance the product or service themselves, ideally with the additional income generated by making use of the ICT solution.

Footnotes

1 FAO, IFAD and WFP. 2015., The State of Food Insecurity in the World in Brief. 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome 2015.

2 FAO: http://www.fao.org/fileadmin/user_upload/faowater/images/graphs_maps/irrigation_area.jpg and http://www.fao.org/3/a-i4591e.pdf p.3.

3 IPCC, 2014, Climate Change, Fifth Assessment Report, Synthesis Report p.48.

4 FAO Land and water division / Maher Salman: "Diagnosis and Challenges of Agricultural Water Management in smallholders' traditional irrigation systems in Africa", 2017, http://www.fao.org/fileadmin/user_upload/faowater/docs/saskatoon/2_ICID_FAO_WUE_AWM_EP.pdf

5 Overview of the history of Water Resources and Irrigation Management in the Near East Region, 2006, Mohamed Bazza, PhD. http://www.fao.org/tempref/GI/Reserved/FTP_FaoRne/morelinks/Publications/English/HYSTORY-OF-WATER-RESOURCES.pdf

6 One comprehensive recent study on the ICT4AG development in Africa is the CTA Dalberg study "The Digitalisation of African Agriculture Report, 2018-2019" https://www.cta.int/en/digitalisation-agriculture-africa

7 FAO: http://www.fao.org/aquastat/en/overview/methodology/water-use

8 According to the author, the use of the terminology „artificial intelligence" should be treated with caution. In most cases, the term „machine learning" should rather be used in the context of automation. The journal "Artificial Intelligence in Agriculture" gives insights: https://www.sciencedirect.com/journal/artificial-intelligence-in-agriculture

9 The appearance of African sensor manufacturers is a positive sign. GIAE India tests the calibration of inexpensive sensor technology with the help of technically higher-quality hardware: "Calibration of WaterMark soil moisture sensor with Delta-T's Equitensiometer", see chapter 3.5.5 or www.freedesign.co.in

10 According to the Dalberg Study "The Digitalisation of African Agriculture Report, 2018-2019", "… a handful of players are beginning to develop viable businesses with attractive financial models." (p. 18). https://www.cta.int/en/digitalisation-agriculture-africa

11 Dalberg (2019) p. 18.). https://www.cta.int/en/digitalisation-agriculture-africa

12 The text is an extract from a report "Farm-Hand pilot results" for Innovate UK which financially supported the project during the start up phase.

13 The text is an extract from the GIZ/AGIRE presentation "Serious games for participatory planning and management of water resources", Marc Haering, Programme AGIRE Morocco.

14 LIDAR: Light Detection and Ranging: A laser technology which can penetrate the canopy and thus allow for precise modelling of terrain and measuring of plant heights.

15 The global drone regulation database: https://www.droneregulations.info/

16 Download poster from http://star-www.giz.de

17 Download document from http://star-www.giz.de

18 Download toolbox from http://star-www.giz.de

19 Unmanned Aerial Vehicle.

20 Unmanned Aerial Systems.

21 The text is an extract from the GIZ presentation "Digital applications in small-scale irrigation",
Lucie Pia Pluschke, Hub Manager, Powering Agriculture, GIZ Kenya

22 https://wapor.apps.fao.org/home/WAPOR_2/1

23 For different user cases, see
http://www.fao.org/in-action/remote-sensing-for-water-productivity/wlpa-introduction/wapor-applications/en/

24 ESA Sentinel, download e.g. via simple self-registration at
https://scihub.copernicus.eu/dhus/#/home

25 An Application Programming Interface is a computing interface to data or services. An API comes with clear definitions on how other components or systems can have access to the data or services.

26 PlantVillage (https://plantvillage.psu.edu/) is a user moderated Q & A forum dedicated to the goal of helping people grow their own food. It is an open, freely available resource that helps Kenyan farmers solve diverse plant related questions.

27 https://plantvillage.psu.edu/solutions

28 https://greenfingersmobile.com/ .

29 https://www.eprod-solutions.com/ .

30 https://esoko.com/servicedelivery/

31 Hunter, Netafim, Spruce, Niagara to name a few.

32 The text is an extract from the GIZ presentation "Digital applications in small-scale irrigation", (Lucie Pia Pluschke, Hub Manager, Powering Agriculture, GIZ Kenya) completed with information of the PlantVillage web site.

33 https://plantix.net/en/

34 https://plantvillage.psu.edu/solutions

35 There are many resources on the Internet, for example:
- itCraft (2019): 10 awesome tips for developing user friendly app
https://itcraftapps.com/blog/10-awesome-tips-to-developing-user-friendly-apps/
DesignKit: The field guide to human centered design:
https://www.designkit.org/resources/1

36 "ICT4Ag business models: How to sustain and grow the Digital Harvest" (2016)
https://www.raflearning.org/post/ict4ag-business-models-how-sustain-and-grow-digital-harvest

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On behalf of

Federal Ministry
for Economic Cooperation
and Development