Final report

# SMART-WADI: SMART WAter Decisions for Iran

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# 1 General introduction

The SMART-WADI project is a feasibility study in Iran to assess a three-source information service for irrigators derived from drones, satellites and crop growth models. The main aim is to deliver irrigators a solution providing up-to-date information on water productivity and *near-real time advice* on their irrigation and farm water application. Data and information from satellites and flying sensors (drones) combined with crop growth models provide predictions on crop yield and water productivity to support decision making.

This document is the final report following the agreed set of activities presented in the SMART-WADI proposal. The activities have been achieved according to plan. A complete viability analysis was developed considering technical, economic and political factors. Key stakeholders in the water and agriculture sector in Iran have been determined and described, the potential of using our three-source information service (flying sensors, satellites and crop growth models) has been analysed using the SWOT approach, and local market information has been obtained through structured surveys, questionnaires and interviews for risk assessment. Specifically, the technical and economic viability of using our information service was evaluated in irrigated farms in the Mashhad basin. Positive results were obtained, both in technical aspects as well as market potential. Cost-effective drones were used to obtain valuable images of irrigated farms, in combination of satellite images and crop growth predictions. Results show how farmers can reduce up to 20% of groundwater use without losing crop yields. Hence, farmers can reduce pumping costs and water authorities can benefit in estimating real irrigated water requirements. Small and large farms (from 60 hectares to 5000 hectares) are interested in continuing testing and validating the proposed solution.

In Iran, even though local interest and user demand for our three-source information service proved to be high, the expectation for further testing, validation and potential upscaling is limited due to political instability and economic recession. In neighbouring countries, we visualize better opportunities, thus we have requested a subsidy to the Partner for Water Programme for a pilot project for SMART-WAD in Turkey.

# 2 Activities and results

The activities and results generated during the SMART-WADI project are presented in the following section (section 2). These are presented according to each Work Package (WP) initially defined in the proposal of this project: WP1 – User requirements consolidation, WP2 – Service and system definition, WP3 – Proof of Concept, WP4 – Viability analysis, and WP5 – Pilot implementation roadmap. In section 3 a summary of key results is presented, and in the Appendix sections more details about the performed activities, methods and results can be found.

## 2.1 Identification of stakeholders and user requirements

Identifying stakeholders and their needs is key to plan the adequate pathways to the application of our potential service, including levels of decision making and inter-institutional interactions. We focused on private and government institutions working in the water and agriculture sector in Iran. The stakeholders involved were identified and classified in type (government or private), and size (large, medium and small), and scope of activities involved either at local, provincial or national scale. This activity was developed by our local partner EWERI through a literature review process and information requests to the identified stakeholders and potential users. In Appendix A the list of stakeholders and classification is presented.

A survey was prepared to obtain information about user needs from different focus groups, and information about ambitions, strengths and limitations for developing the viability analysis of our smart irrigation decision service. This survey includes questions about preferences on how information for farms is received, competitors in the precision agriculture sector, stakeholder's willingness to pay and risk aspects for service implementation, among others. Another survey was prepared to obtain information about the irrigated farms and existing hydro-meteorological data to support the development of our feasibility study and service. This survey includes information of water use, crop characteristics, field management procedures, and soil texture. An outline of both surveys is shown in Appendix A.

## 2.2 Service and system definition

The backbone of the irrigation service of SMART-WADI is based on the use of a crop growth model called AquaCrop. AquaCrop is a widely used crop growth model developed by FAO, which predicts the yield response to water using physically-based parameters and meteorological input data which can be obtained from satellites and local ground data. The crop growth model has been used in climate change impact studies in various parts of the world (Hunink et al., 2014; Hunink and Droogers, 2010, 2011). Also, the combination of flying sensors and crop growth models has been explored to predict water productivity and crop yields (den Besten et al., 2017) Furtherscenarios on irrigation schedules have been assessed in Iran and in other countries in the middle east region (Goosheh et al., 2018).

AquaCrop is the appropriate crop growth model for SMART-WADI purposes because it is specially recommended for farm level scale, it has been extensively tested worldwide to predict the crop yield response to irrigation and it is freely available online. Through this model we can provide advice at the beginning of the cropping season on how much and when to irrigate for target crop yields and water productivity. This irrigation advice would help the farmer in reducing water use without losing crop yields.

Even though AquaCrop is a useful tool to improve water management in irrigated fields, the drawback is that it is designed to predict crop yields at the single field scale (point simulations). The irrigated field is assumed to be uniform without spatial differences in crop development, transpiration, soil characteristics or management. In order to assess those spatial differences, we introduce the innovative application using data from flying sensors and satellite imagery. The irrigation advice from the model is complemented with field maps derived from flying sensors and satellite imagery (Figure 1). These maps provide information to farmers on the spatial variability in the irrigated fields, thus it helps to identify in which locations the plants are suffering from water stress due to poor irrigation application and to identify hot and bright spots. Indicators such as the relative temperature and relative status of vegetation in the fields helps in quantifying this variability. The viability of this complementary service was assessed in irrigated fields in the Mashhad basin, Iran. Several tests were developed in irrigated potato and wheat fields, due to their relevance for local and international markets. It was found that our innovation is technically feasible. The results are shown in section 3.

The backbone of our service needs to be complemented with a front-end system if the service is expected to be operational and satisfy user information demands. The front-end service would consist of an online platform were the irrigation advice and mapping can be conveyed to the users through mobile phones or other information system (Figure 1a and Figure 2b). The potential idea is that a local startup company can provide the front-end system. According to local news and information provided by local contacts in Iran, the amount of startup and knowledge-based companies is growing. However, in Iran we did not find an interested and experienced company who could potentially help us with the front-end system in the future.

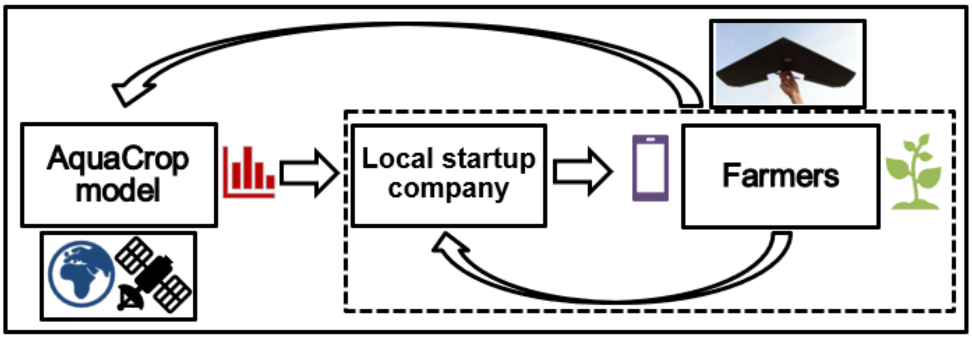


**Figure 1a. Potential SMART-WADI service to farmers using prediction models (irrigation advice), and crop mapping using flying sensors and satellites.**

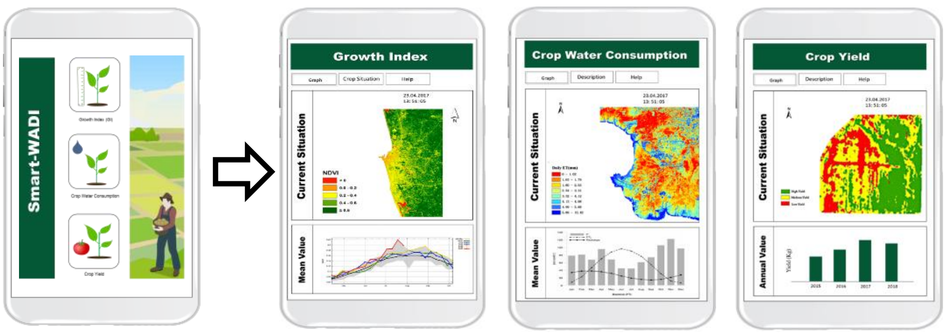


**Figure 2b. Example of proposed user interface of the SMART-WADI app.**

## 2.3 Proof of concept and performance assessment

The proof of our concept was assessed in irrigated fields near the city of Chenaran in the Mashhad basin, Iran. Several tests and demonstrating flights were developed in potato and wheat fields. One of the key tests were performed in the farm of Mr. Hosseini, a local agri-business investor. Initially, we obtained general information about the surface area and water use in the farm presented in Appendix B. Water for irrigation is pumped from wells, which is a common practice in the Mashhad basin. The fields are irrigated in average every 14 days with a total water use for wheat of 4500 $m^3$/ha/season (gross water use of 6000 $m^3$/ha/season). We collected soil, crop, irrigation, and farm management information to develop the crop growth modelling. Details about data collection and model inputs and outputs are shown in Appendix B.

The outputs of the crop growth model were compared against actual crop yield and satellite derived actual evapotranspiration (ET). The actual evapotranspiration (ET) was derived from Landsat 8 satellite images for the Mashhad basin. A long period of historical ET information is available which is helpful to compare against ET results from the crop growth model, especially when actual crop yields are not available to model calibration procedures. In Figure 3a, the mean actual evapotranspiration is shown for April 2014, where the red areas (pixels) are the plots with the highest evapotranspiration (140 mm/month) and the yellow areas (pixels) are the plots with the lowest evapotranspiration (67 mm/month) in which lower irrigated water is applied. In the farm boundary (polygon), we choose the red areas which are known wheat fields and compared the monthly ET satellite values against the monthly ET results obtained with the crop growth model. A high correlation is obtained between both ET outputs (Figure 3b) as well as matching actual crop yields (information collected from the field). Hence, a good performance of the crop growth model was found. The application of the crop growth model and satellite imagery is technically viable. The crop growth model can be used to assess different irrigation scenarios and evaluate if the crop yield can be maintained or improved. In section 3 the results of crop yield and water productivity are shown for different irrigation scenarios.

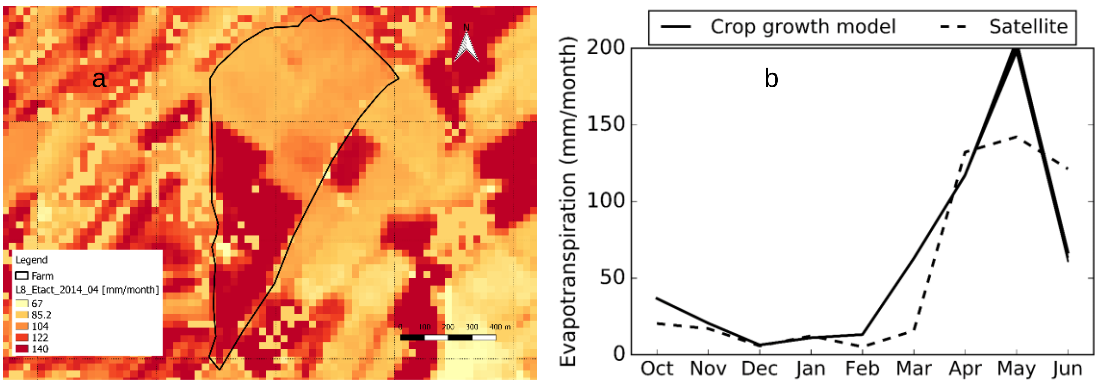


**Figure 3. Map of the mean actual evapotranspiration (Etact) in Abril, 2014 in Mr. Hosseini farm (the farm boundary is shown as a polygon). The actual evapotranspiration is derived from Landsat 8 satellite images (a and b) and from the crop growth model (b).**

In the Mashhad basin, the wheat fields are sown in October and harvested in June for a total growth period of eight months. In the farm boundary, two wheat plots were selected to obtain flying sensor imagery. The total area of the wheat plot 1 is 4.1 hectares, and the total area of the wheat plot 2 is 5.5 hectares (Figure 4). Imagery of these plots were obtained with the flying sensors at the end of April 2019 deriving maps of vegetation growth status and temperature. A Mavic2Pro drone was used with different cameras to obtain the necessary imagery. In addition to the RGB camera which is built into the drone, we mounted a NIR camera and a thermal camera to obtain spatial information about vegetation and temperature. The vegetation and temperature maps are shown in section 3 for wheat and potato.

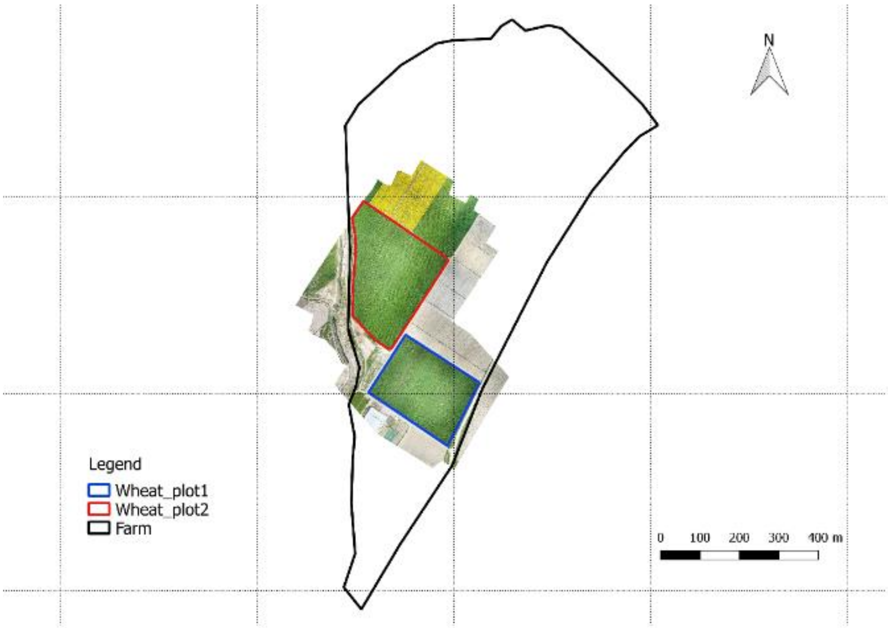


**Figure 4. Image of wheat plot 1 and wheat plot 2 in Mr. Hosseini farm obtained with the RGB camera (April 2019).**

## 2.4 Dissemination of results

Since the beginning of the project different activities have been developed to disseminate the potential service and results of the project.

A first seminar about the SMART-WADI project was held in Mashhad on December 2nd, 2018 in the Educational Institute of Agricultural Organization of Razavi-Khorasan province, Mashhad (Appendix C). Several stakeholders including agricultural organizations, farmer associations, water authorities and university students attended the seminar, such as the Razavi-Khorasan Agricultural Organization, Jovien agro-industry company (JAIC), and the Association of Allowable Agricultural Wells in Mashhad Basin (AAAWM). The feedback about the project was positive.

Another visit was organized in April 2019. Several field visits were organized to the farm of Mr. Husseini to undertake drone flights for irrigated wheat mapping and demo flights for different stakeholders (Figure 5). There was high interest among the stakeholders and the benefit and possible collaboration opportunities were discussed. The basin authority and agricultural authority were interested on how to improve water productivity and crop yields. Private organizations including our local partner EWERI also joined the session. In addition, a seminar was organized in the Ferdowsi University including expert survey feedback (Appendix H).

**Figure 5. Field trip with stakeholders and drone flights in irrigated fields in Iran (April, 2019).**

The last visit to the Mashhad basin was in August 2019 in order to obtain temperature mapping of potato fields of Mr. Husseini and also other potato farms in the region. Special interest was shown by Astan Quds (Figure 6). This organization has high interest in developing new tests with the flying sensors in the region and for other crops in the Mashhad basin. Astan Quds own more than 2000 hectares of irrigated land.

**Figure 6. Presentation of flying sensor results with Astan Quds, Iran (August, 2019).**

An article about the SMART-WADI project was published in the website of the *Ministerie van Landbouw, Natuuren en Voedselkwaliteit* mentioning the use of drones for water productivity

assessment (Appendix F). Also, project information and newsletters were posted in the FutureWater website:
https://www.futurewater.nl/2019/06/smart-wadi-project-drone-images-for-farms-in-iran-nl/

## 2.5 Viability analysis

Initial analysis shows that the proposed model integrated with data from satellite and drone-based services has technical applicability as well as market viability in the Mashhad basin, Iran. The market potential is shown based on the size and diversity of stakeholders involved in water and agriculture projects and in the amount of irrigated area in the basin (over 2000 hectares only with Astan Quds). Irrigated land depends on groundwater in the basin. The groundwater use for agriculture has been reported to be at peak with increasing land subsidence and overexploitation of aquifers (Moridi, 2017). The Mashhad city is the second largest city in Iran located in the Mashhad basin. The economic growth in the Mashhad city is strongly threatened by water shortages and unregulated groundwater extraction. The situation is critical, and the government is considering drastic infrastructural measures such as desalination and water supply from the Sea of Oman (Ministerie van Landbouw, 2018). Hence, finding solutions to reduce water consumption in the Mashhad basin is of regional interest, specially reducing water consumption for agriculture.

Meetings with the Dutch Embassy in Iran have been held to obtain more information about the market opportunities and threats. The agricultural counsellor (Mr. Hans Smolders) and water officer (Ms. Michelle Damen) provided advice and information and potential linkages to ongoing activities supported by the Embassy. Advise was given to focus on two main crops being irrigated in the region: potato and wheat. Wheat is sowed in October and irrigation starts in March. Potato is sowed in June and harvested in October. This information is key in selecting the case studies and plan drone flights during the crop growth in order to obtain maps of the planted fields.

According to the regional resources, the number of startup companies providing knowledge-based solutions were on the rise in the beginning of year 2019. However economic recession has affected further developments. A more detailed analysis was made to understand the market and the full potential of partners and clients in the region. Competitors and competitive positioning were assessed by identifying Strengths, Weaknesses, Opportunities and Threats (SWOT). The results of the SWOT analysis are shown in section 3. The topics to be covered by the market analysis were planned based on the questionnaire and surveys shown in Appendix C.

Using flying sensors can be a useful tool to monitor the adequate growth of crops. However, costs associated to the use of flying sensors are to be accounted for. A service including solely the use of flying sensors tend to be not cost effective (Erickson and Widmar, 2015). It is key to offer a complete information service which can provide more benefits to farmers. Additional information from crop models and satellites provides these benefits which may result in a cost-effective flying sensor service. The AquaCrop model is a useful model that can predict crop yield and water productivity. In addition, evapotranspiration data from satellites is useful for model calibration and monitoring of water productivity. Both, the model and satellite information are freely available. The cost associated are the processing costs of data and images by a professional expert. The key for financial success is to use low-cost equipment and develop local capacity to perform the flying sensor flights. The benefits to the irrigators are related to a more efficient use of groundwater, but also time management, as labor costs will decrease in case of optimal farm management. Additionally, the crop yield increases, which will lead to more revenue at the end of the season.

Previous cost-benefit analyses conducted by FutureWater have shown positive results for other regions in Africa and Asia. Costs in Iran are too variable due to constant change in exchange rates. The local currency is devaluating rapidly, thus an additional risk for further implementations in the country.

Staff from the Dutch Embassy in Iran provided advice and information about current legal and political barriers. To establish official guarantees on drone flights, a support letter from the Razavi-Khorasan Regional Water Authority was obtained (Appendix D).

## 2.6 Pilot implementation roadmap

One of the main objectives of this feasibility study was to design a roadmap for successful pilot implementation in the region. As explained in the previous sections, feasibility of the technology was well established with the studied farms. We envision developing a Growth Index (GI) by combining the aforementioned information from field, and three-source datasets and deliver it as a simplified crop status report useful for individual farmers as well as associations. The weekly report will help the farmers and decision makers to plan and intervene accordingly. Any such system requires a comprehensive testing and validation plan in order to validate the results and to calibrate the system periodically to improve the predictions. We are recommending a possible workflow to implement system during pilot as shown in Figure 7.

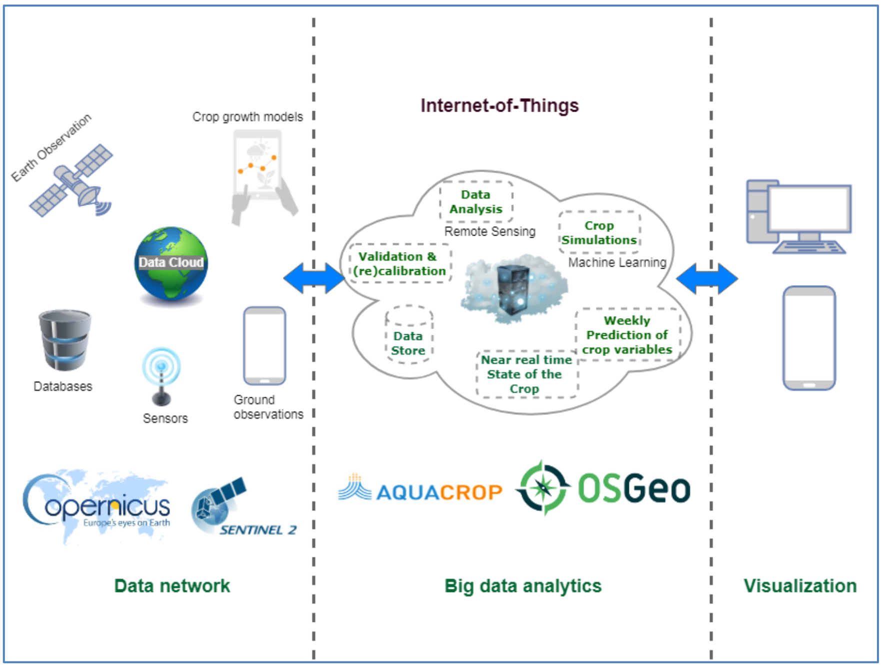


**Figure 7. The proposed framework for practical implementation of the three-source data based monitoring system.**

The entire system is divided into three major parts: i) Data network, ii) Big data analytics and iii) Visualization. The validation and (re)calibration of the model is included in the analytics part where data from the field will be fed into the system. This will be collected via the front-end application itself. For this we have identified certain farms and stakeholders to collect data from field to validate and calibrate the model. The roadmap to such a system given the feasibility of the established technical back-end looks promising and need to be implemented and sustained via local expertise. The viability of implementing such a system locally is addressed in the previous section and in section 3.

One of the main advantages of the three-source data as explained in the previous sections is that its availability is not constrained to a geographic location. Other than data from drones which will require planned activity all the data we propose from satellites and the AquaCrop is available everywhere and through time. Hence facilitating the upscaling of the approach to other areas as well. Roadmap to a pilot phase implementation is shown in Figure 8.


**Figure 8. Road map from feasibility to a successful pilot program and upscaling. The phases a) and b) belongs to the feasibility study, c), d) and e) to pilot phase and f) is upscaling upon maturity of the product and services.**

## 2.7 Changes in project end date

The SMART-WADI project original end date was May 2019. However, to capture a full growing season of wheat and potato in the Mashhad basin an extension of the project was needed. An extension was requested until the end of October 2019. Project costs have not change.

# 3 Summary of the substantive results

Results are described in relation to the objectives stated in the work plan. The results have been achieved according to the plan. The service was defined according to the needs of the users, the technical concept was proven, and an analysis of the viability of the service was developed. Due to political instability and transfer money limitations in Iran, future testing, demonstrating the concept, and potential of upscaling was assessed considering the market potential in a neighboring country (Turkey).

## 3.1 Technical feasibility

The technical feasibility of the concept was proven in Iran but can be applied in any other country, basin, or farm around the world. The following is a summary of the main technical results for irrigation advice and innovative mapping of agricultural fields with flying sensors and satellites.

The farm of Mr Husseini was among the farms selected to run tests of the crop growth model, satellite and flying sensor imagery. It is a farmland of 60 hectares, which includes wheat and potato crops and is representative of most of the irrigated areas in the Mashhad basin. Meteorological data was collected (local data and satellite) and simulations using the crop model AquaCrop were completed. Positive results and good performance were obtained for the simulations, and mapping of fields derived from satellite and flying sensor imagery.

### *3.1.1 Irrigation advice*

Predictions of crop yield and water productivity for wheat were developed using different irrigation schedules. Irrigation for wheat starts in March until June. For the tested scenarios the best irrigation schedule is an application of 40 mm of water every 14 days (starting in March). Currently the farmer is using an application of 50 mm every 14 days for a total water use for wheat of 4500 $m^3$/ha/season.

We found that additional 10 mm every 14 days does not increase crop yield. Hence, the farmer can reduce irrigation application from 50 mm to 40 mm every 14 days (from 4500 $m^3$/ha/season to 3600 $m^3$/ha/season), maintaining its crop yield and potentially reduce costs for groundwater pumping. Actual and simulated dry crop yields are obtained between 5 and 5.5 t/ha for a total evapotranspiration (ETa) between 510 and 540 mm/season (Figure 9). This irrigation advice can be provided for wheat or any other crop (e.g. potato) in the Mashhad basin targeting the desired crop yields and water productivity. Water productivity results for the recommended irrigation schedule is between 0.97 kg/m³ to 1.03 kg/m³.

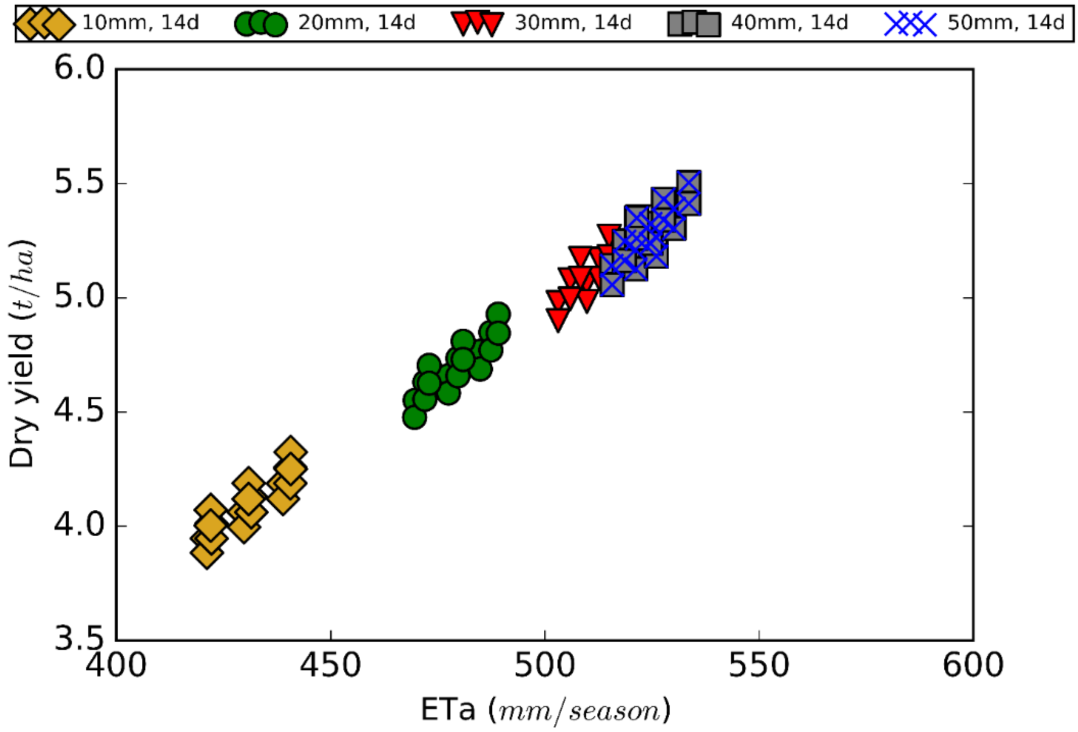


**Figure 9. Different irrigation application (10 mm, 20mm, 30mm, 40mm, and 50mm every 14 days) from March to June, total evapotranspiration ETa, and impact on crop yield.**

### *3.1.2 Mapping the status of vegetation and temperature in crop fields*

As explained in section 2 two wheat plots were selected for flying sensor (drones) evaluation. The total area of the wheat plot 1 is 4.1 hectares, and the total area of the wheat plot 2 is 5.5 hectares. The mapping results are generated in less than 2 hours for 10 hectares of monitoring crop fields using drones. Results show that plot 1 contains several areas with poor vegetation growth indicated by the red colors (Figure 10). The farmer can improve the drip irrigation in those places or any other farm management procedure which can improve vegetation growth leading to better crop yields and water productivity. In plot 2 the vegetation growth is better than in plot 1 (Figure 10) and allows prioritizing the areas of higher water stress.

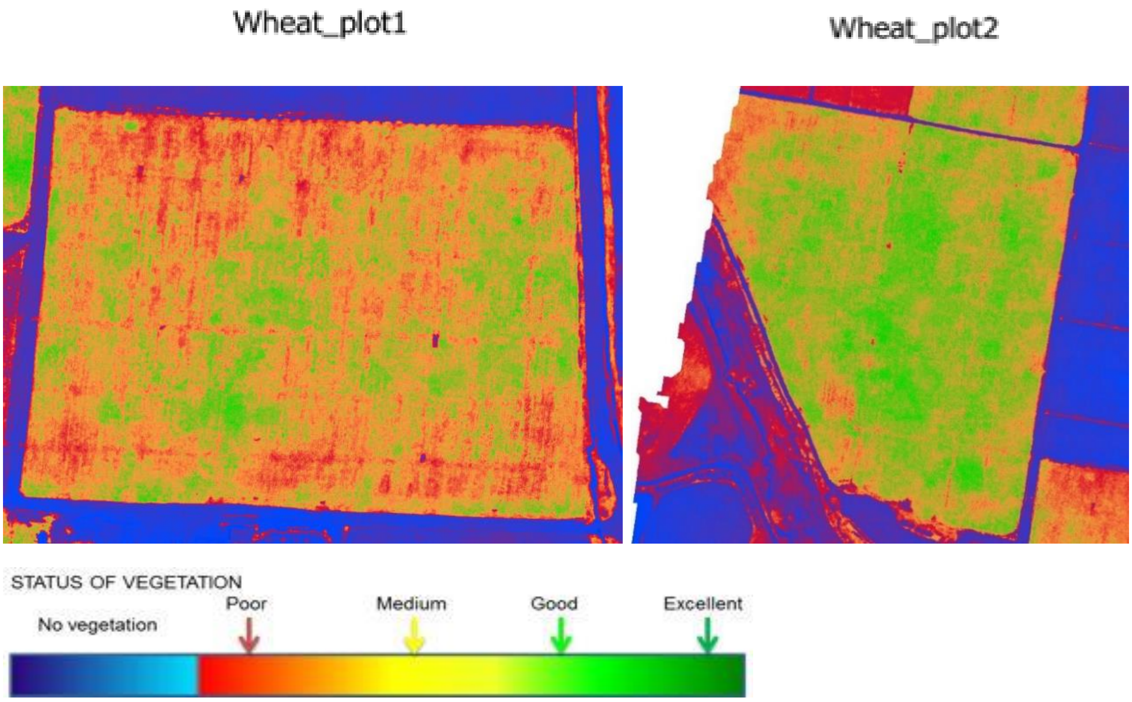


**Figure 10. Status of vegetation growth in wheat plot 1 and wheat plot 2 obtained with the NIR camera (April, 2019). Irrigated farm, Mashhad basin, Iran.**

A thermal camera mounted on a drone was used to obtain temperature maps of potato and wheat fields. The mean temperature found in wheat plot 1 and wheat plot 2 is similar (18.1 ºC and 17.9 ºC) with temperatures ranging from 15.6 ºC to 20.7 ºC in plot 1 and 16.04 ºC to 19.7 ºC in plot 2. As expected, we obtained higher temperatures in plot 1 than in plot 2, considering that the vegetation growth in plot 1 is suffering from higher water stress than in plot 2.

In Figure 11 a temperature map is shown for potato fields. Relative low temperatures mean that the plant is under normal water conditions thus generating expected crop yields. Relative high temperatures mean that the plant is under water stress thus generating potential yield losses. The RGB image provides information about the boundaries of the planted area. Hence the farmer can evaluate the relative change of temperature in each planted area and check which field management procedure should be improved.

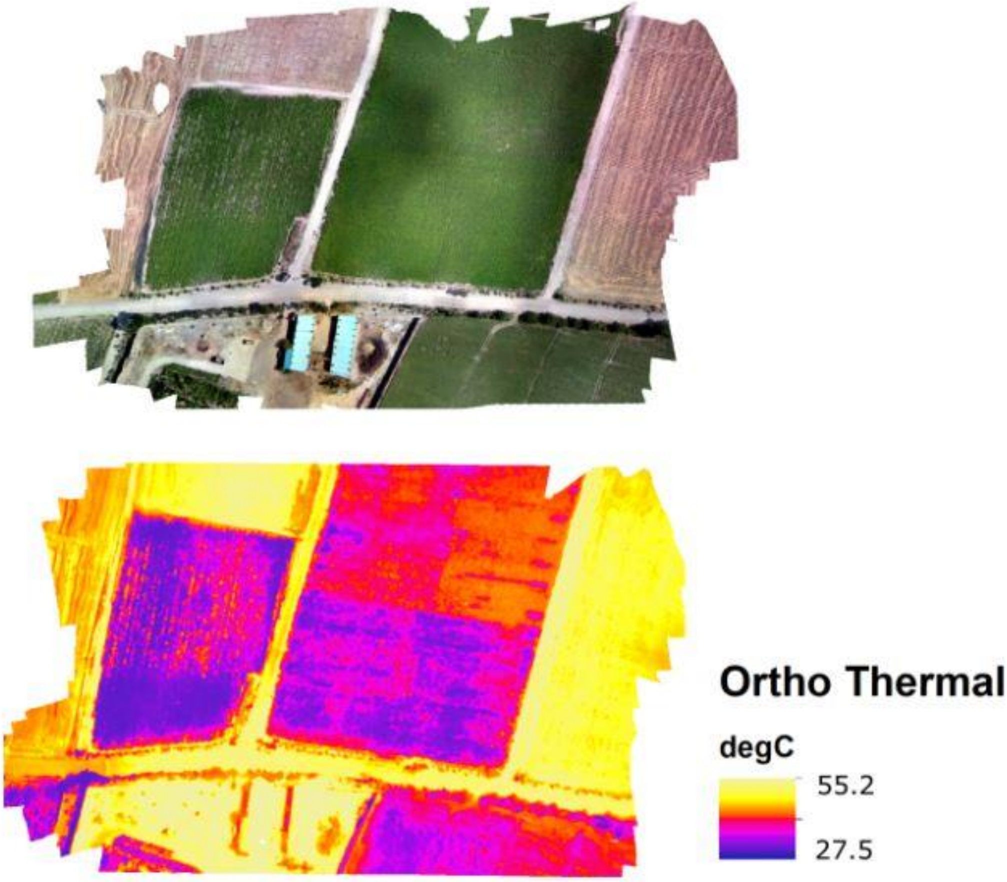


**Figure 11. Temperature status in potato fields using a thermo sensor mounted on a drone (August, 2019). Irrigated farms in the Mashhad basin, Iran.**

#### *3.1.3 Mapping actual evapotranspiration*

An online portal was developed to show maps of actual evapotranspiration in irrigated farms in the Mashhad basin: http://www.wa-urmia.org/mapbender/application/smart_wadi
Actual evapotranspiration maps were generated from satellite information. In Figure 12, the actual evapotranspiration is shown for the year 2017 in the farm of Mr. Husseini.

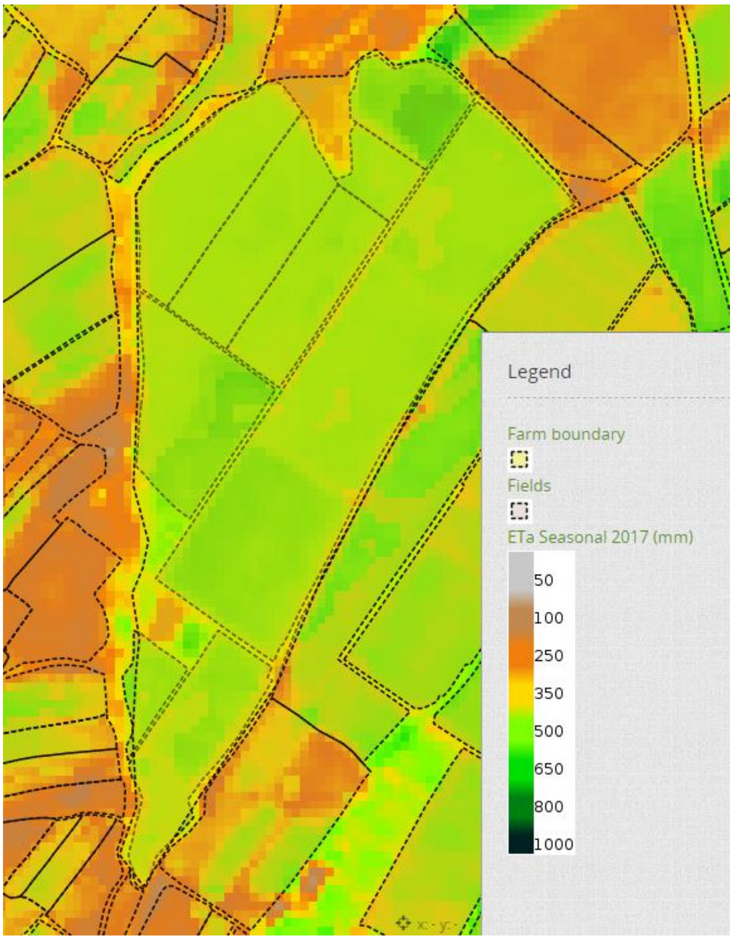

Figure 12. Actual evapotranspiration in the Mr. Husseini farm in 2017. From developed website: http://www.wa-urmia.org/mapbender/application/smart_wadi

## 3.2 Viability analysis

### *3.2.1 Key potential users in the Mashhad basin, Iran*

The stakeholders and user types in Iran were identified and categorizes including farmer associations, private and governmental institutions (Appendix A). Initial market prospects showed that the proposed service can be further tested, and potentially be upscaled in the Mashhad basin in Iran. During the development of the project, key stakeholders and potential users in the Mashhad basin were identified. Key potential users of the service are the following:

a. Astan Quds: Private organization owning several agricultural and industry companies in the province including more than 2000 hectares of agricultural land.
b. AAAWM: A farmer's organization with 400 members, which seek to improve water management.
c. Mr. Husseini farm for further testing and demonstrating the concept.
d. Mashhad Plain Agricultural Cooperative Company (CEO, Mr. Khabir) for further testing and demonstrating the concept.

Meetings and field trips were organized with these potential users to explain and show in detail the benefits of the proposed service. Positive feedback was obtained, especially from Astan Quds. This organization is interested to further test and demonstrating the service in their agricultural land. Astan Quods has provided a letter of support stating their intention of co-funding a possible pilot project (see Appendix D).

### 3.2.2 SWOT analysis

The strengths, weaknesses, opportunities and threats (SWOT analysis) were evaluated for the SMART-WADI project considering the potential of the consortium and the Iranian setting. The strengths and weaknesses were determined according to the attributes of our project consortium (internal analysis). Thanks to the local company in Iran (EWERI) strong connections and potential partnerships with local stakeholders, especially with Astan Quds were made. For this analysis also internal weaknesses are summaries according to the capacities of each partner and due to the natural constrains of the current stage of this project (feasibility study).

| | | |
|---|---|---|
| Attributes of the system (Internal analysis) | ***Strengths***<br>• Strong position with flying sensor and model application;<br>• Supporting team of researchers and consultants;<br>• Experience in multiple similar projects;<br>• Good connections and experience for follow-up funding;<br>• Partnerships with local stakeholders;<br>• Local opinion and requirements are involved. | ***Weaknesses***<br>• First experience in Iran using flying sensors;<br>• Foreign player in the field of water productivity;<br>• Lead time for implementation can be lengthy;<br>• SMART-WADI is a feasibility study, a next phase is constrained based on results |
| Attributes of the environment (External analysis) | ***Opportunities***<br>• Growing number of start-up companies;<br>• Increasing demand innovative solutions;<br>• Spinoff products for IT and applications: platform technology;<br>• Development of platform technology based on flying sensors with water productivity predictions. | ***Threats***<br>• Negative results for selected crops;<br>• Users and partners aversion;<br>• Entry of strong competition with alternative technology;<br>• Political instability;<br>• Changing rules for flying sensor use. |

The opportunities and threats were determined according to the attributes of the country (external analysis). Initial information about a growing number of start-up companies involved in IT services for agriculture and water was provided. This was an obvious opportunity for continuing testing and potentially upscaling our service. However, in practice these start-up companies need to be explored further.

During the process of the project we received feedback from our local partner in order to update opportunities and threats in the local context. Increasing demand for innovate solutions was one of the most important opportunities (also shown in the surveys), but on the other hand an increasing political instability and limitations in money transfer was threating the ambition of further testing and potentially upscaling the service.

### *3.2.3 Market analysis*

To analyze the market for our service in Iran, a survey was developed to obtain expert feedback. The questions of the survey are presented in Appendix C. This survey was done during a seminar hosted in the Ferdowsi University during our visit to Mashhad on April 2019. The group of participants consisted of farmers and university students, as well as professionals from water associations, private companies, government institutions related to water and agriculture.

Results showed that at least one or two companies are using remote sensing technologies in Mashhad for agricultural purposes. These companies provide advice about irrigation, crop growth, crop water consumption, crop yield prediction, and water productivity prediction. However, most of these services are too expensive. The limitation of the service is that the information is inadequate, not reliable and difficult to use. This information is mostly conveyed online or in written format. According to the survey information updates are needed every 5 to 10 days during the growth of the crop for irrigation application. Most of the interviewed persons mentioned that wheat and potato are important crops to be monitored.

The farmers in the group responded that they would pay up to 30% of the cost of farm production for irrigation advice to improve their crop yield. Most of the persons consider that the lowest risk in implementing the service is related to information delivery and the aversion of using new technologies. The highest risk is the legal and political barriers in using flying sensors. Interesting is that the risk on flying sensor restrictions was ranked second. Even though our team was able to fly drones in the farms, local experts advised that restrictions may be a risk in trying to further test and upscale the service. The following table (Table 1) shows the rank of risk factors for using our service in Iran according to the responses provided:

**Table 1. Risk factors for further testing and potentially upscaling the service in Iran (1 highest risk factor, 6 lowest risk factor). Survey expert results.**

| Risk factor | Rank from 1 to 6 |
|---|---|
| Flying sensor restrictions | 2 |
| Legal/political barriers in using flying sensors | 1 |
| Mobile service limitations | 5 |
| Information delivery | 6 |
| Farmers not understanding the information | 3 |
| Existing information service | 4 |
| Aversion of using new technologies | 6 |
| Not cost effective | 4 |
| No willingness to pay | 4 |

## 3.3 Pilot implementation roadmap

During the project, the partners IHE-Delft and FutureWater assessed the risks in continuing a pilot project in Iran. Even though local stakeholders showed interest in our services and willingness to pay, our consortium determined high risks in continuing efforts in Iran for a pilot implementation. Main risks include the legal and political barriers in using flying sensors (drones) due to formalities to get flight permissions. These formalities are worsened due to increasing political and economic instability since the beginning of 2019, which by they own represent a risk for further testing and demonstrating the service, and ambitions to upscale the service. Our consortium met directly with Hans Smolders from RVO to get additional advice about the matter. We discussed about our success in Iran regarding technical and market factors, but we expressed our concerns about the increasing risks.  Uncertainty regarding this matter forced the Dutch partners to look for another country for potential pilot implementation. We decided to send a pilot project proposal with the SMART-WADI idea for the Partners for Water Programme, but to be implemented in Turkey instead of Iran. Turkey is one of the priority countries of the Partners for Water Programme. Turkey is a similar country as Iran regarding environmental issues and conditions (suffering from water scarcity in a semi-arid region), but Turkey has a thriving economy, strong irrigated agriculture development, and special interest in precision agriculture applications (e.g. drones) which can reduce water consumption in agriculture and lead to water safety at basin level. More information about the testing and validation plan, pilot implementation roadmap in Turkey, and the country’s potential is shown in Appendix H.

# 4 Ambition, upscaling and future perspective

The ambition of the partnership at the beginning of the project was to share the results of the feasibility study with stakeholders in the Mashhad basin and to assess the scope for testing, validating and assess the potential upscaling of the service in Iran. The initial results indicated that there is a high potential of upscaling due to existing irrigated areas and user groups actively involved in agricultural production and water management. A market analysis was needed to understand the actual upscaling reach. This analysis included an evaluation of the potential partners and clients, determining their willingness to pay and their interest of incorporating such a system for specific crops in the region, but also political and economic stability.

For the short-term ambition, we have expressed our concerns about drone use (formalities for getting flight approval) and political and economic factors in Iran (see section 3.3). We decided to send a pilot project proposal for the Partners for Water Programme but to be implemented in Turkey instead of Iran. Turkey is one of the priority countries of the Partners for Water Programme and is a similar country as Iran regarding environmental factors (water scarcity in a semi-arid region) with a thriving economy and specially interested in precision agriculture applications.

Long term future perspectives for a pilot project may be partner up again with EWERI. Astan Quds has indicated their interest to host a pilot phase of the project contributing with irrigated land for further testing and possible co-funding (Appendix D). Other stakeholders (Mr. Husseini and Mr. Khabir) also would like to see the preliminary results of the project and more testing.

# 5 Cooperation between project partners and with foreign parties

The collaboration work between the project partners was good. An important factor about our collaboration success was the excellent communication with our local partner (EWERI) and our Dutch partner (IHE-Delft). In total we hold seven structured meetings, with tasks agreements and revisions. In addition, several other meetings were held in the Netherlands and also in Iran, including field visits and stakeholder interaction. Specially, the local partner worked well in providing the necessary data and information from the case study. Also, the logistic preparation (e.g. transport, food and stakeholder meetings) was planned adequately when we visited the country.

Certainly, the ambition to work together with EWERI (local partner) exists. However, due to the current situation concerning drone use and political factors our company assessed a high risk concerning the success in a 2$^{nd}$ phase (pilot project). Even though the local organization Astan Quds has stated their interest in providing in-kind contribution for a second phase, the formalities for approving drone flights limits the success of a pilot project with further testing and potential upscaling.

The partnership now runs between IHE-Delft and FutureWater for a proposal in another country (Turkey). IHE-Delft and FutureWater has both interest in developing future projects with EWERI, but if to be developed with local funding in Iran, it has to be led by EWERI.

The collaboration with local partner EWERI was excellent. The tasks assigned were delivered on time and they provided a clear idea of the current stakeholders in the region for the market assessment to be delivered by FutureWater. Special collaboration and initiative was provided by EWERI when we visited Mashhad, Iran. Logistics, field visits, meetings with stakeholders were planned according to the demand of our tasks. Without the support of our local partner the performed drone flights would have been impossible. EWERI obtained the necessary permissions and support staff to make the drone flights a success.

# 6 Innovation of the product

Our product has turned to be innovative as previously estimated. We found a way of combining three cost-effective information sources for irrigated farm level decision making. These sources include satellite information for determining historical crop evapotranspiration (mapping), drone images to determine farm level variability in crop growth quality (mapping), and predictions in crop yield and water productivity using a crop growth model. Accurate predictions on future crop yields and water productivity are obtained for different irrigation scenarios thanks to innovative model calibration procedures (see section 2.3).

We developed an online platform for visualizing crop evapotranspiration and vegetation growth in different farms in the Mashhad basin:
http://www.wa-urmia.org/mapbender/application/smart_wadi

The online platform is an initial effort to provide accessible historical data about the irrigated water consumption in the Mashhad basin. Further efforts are needed for developing an operational service to farmers which can provide weekly reports on their water consumption and vegetation growth (see section 2.6).

A key innovation is the use of cost-effective flying sensors and calibration procedures to obtain reliable indicators of vegetation growth (e.g. NDVI) for potato and wheat fields. Also, thermal cameras were used (mounted on a drone), which is an innovative solution to quickly determine the temperature variability in irrigated fields and pinpoint water stress areas. This variability in irrigated fields has been clearly shown through maps. During the SMART-WADI project these maps were enhanced and technical viability for a pilot project has been achieved.

# 7 Success and failure factors

The most important success aspect for the SMART-WADI project, is the fact that we managed to submit a next phase pilot project proposal (for the PvW programme) thanks to the knowledge acquired and feasibility assessment of our solution. At the beginning of the project the consortium was confident about the technical knowledge, local connections, and market potential in Iran. However, as the project progressed the market potential deteriorated (as explained in section 3.3). Hence, the proposal for a pilot project was developed in a neighboring country (Turkey) with similar environmental conditions, but with more market opportunities.

The success of our project is not measured by the feasibility of our solution in one single country, but by the applicability of our solution in growing agricultural markets (key countries), which require low-cost technology to remain competitive and need environmentally friendly solutions (e.g. reduce groundwater use) to reduce negative impacts.

The consortium has learned that the market potential not only lays on the national interest and local market opportunities, but also on international influences affecting the local market potential. Our product has a large potential in similar semi-arid regions which expand from Iran throughout Turkey. The Dutch partners involved in the SMART-WADI project have developed a proposal for implementing the tools developed in Iran to be tested and validated in Turkey. In this country, our tool is technical feasible and ready to be tested, moreover, considering the market aspects it has a high potential such as Iran, but with the added value of economic stability, flexibility in monetary transactions and innovative investments in the agricultural sector (more information about this proposal is shown in Appendix H).

# 8 Contribution and implementation of the Partners for Water program

The ambition set at the beginning of the project was to develop a feasibility study for a tool which could provide farm level water productivity advice. The Partners for Water program contributed in achieving this ambition by providing financial support and guidance.

Hugo de Vries from RVO, has been supporting the project since the proposal phase. Hugo is a communicative person who showed interest about our solution and was always ready to provide advice on how to go forward for administrative challenges. We had a request on delaying the end of the project and he understood the technical arguments that we provided. Also, we had an important meeting with Hugo about our proposal idea for a pilot project (for testing our SMART-WADI tool) changing the country of implementation from Iran to Turkey. Hugo understood our arguments and he encouraged us to submit the pilot proposal for PvW in Turkey.

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# Appendix A: Stakeholders in Iran

**Table A1. Stakeholders for the SMART-WADI project in the Mashhad basin, Iran**

| No. | Name | Type | Size* | Scope of activity |
|---|---|---|---|---|
| 1 | Razavi-Khorasan Regional Water Authority | Governmental | Large | Province scale |
| 2 | Razavi-Khorasan Agricultural Organization | Governmental | Large | Province scale |
| 3 | Razavi-Khorasan Province Pressurized Irrigation Guild Association | Private | Small | Province scale |
| 4 | Razavi Ghods State (Astan Quds) | Private | Large | Province scale |
| 5 | Iran Chamber of Commerce, Industries, Mines & Agriculture (ICCIMA) – Razavi Khorasan Branch | Semi-Governmental | Medium | Province scale |
| 6 | Agricultural Research Institute of Razavi-Khorasan Province | Governmental | Medium | Province scale/national scale |
| 7 | Agricultural Home – Mashhad Branch | Private | Small | Province scale/national scale |
| 8 | Parks and Landscape Organization of Mashhad Municipality | Governmental | Medium | Mashhad City |
| 9 | Water Savor Society | NGO | Small | National/ Head Branch in Mashhad City |
| 10 | Mashhad Plain Agricultural Cooperative Company | Private | Small | Mashhad basin |
| 11 | Association of Allowable Agricultural Wells in Mashhad Basin (Chenaran Town) | Private | Medium | Local scale |
| 12 | Individual Farmers | Private | Small | Local scale |

***** Large size > 50 member, Medium 20> and <50, Small < 20

The responsibilities and functions of each stakeholder are summarized as follows:

1. **Razavi-Khorasan Regional Water Authority (RWA)**

The RWA is responsible for water supply and management in the province. Its main functions are as below:

- Water resources development

- Water resource monitoring
- Water allocation to different sectors of consumption
- Hydroelectric power generation
- Construction, development, operation and maintenance of water structures (e.g. dams and reservoirs)

**2. Razavi-Khorasan Agricultural Organization (RAO)**

The RAO is responsible for agricultural affairs in the province such as supporting farmers, seed production, pressurized irrigation development, livestock affirms It can be categorized as three parts as below:

- Agricultural development
- Agricultural Support Services
- Commercial affairs in the agricultural sector

**3. Razavi-Khorasan Province Pressurized Irrigation Guild Association (RPIGA)**

The RPIGA is a formation that seeking for improvement of irrigation methods and its efficiency in the region. At the moment the PRIGA is responsible for supervision of pressurized irrigation application in the province and identification of contractors for its implementations.

**4. Razavi Ghods State (Astan Quds)**

The Astan Quds is an autonomous charitable foundation in Mashhad, Iran. It is the administrative organization which manages the Imam Reza shrine (who was a descendant of the Prophet Muhammad and the eighth Shi'ite Imam) and various institutions which belong to the organization. The administrative apparatus of Astan Quds is considered the longest-lasting organization since the martyrdom of Imam Reza about 1200 years ago. The main resource of the institution is endowments, estimated to have annual revenue of $210 billion. The Astan Quds is a major player in the economy of the city of Mashhad. The Astan Quds has different cultural and educational institute, Economic institutes, Social institute and many agricultural land (farming)/gardens in the Mashhad plain.

Website: https://globe.aqr.ir/en

**5. Iran Chamber of Commerce, Industries, Mines & Agriculture (ICCIMA) - Razavi-Khorasan Branch**

The ICCIMA is a non-profit semi-governmental institution, established to facilitate economic growth and development in the country. Its main functions are:

- Facilitating cooperation among business persons and owners of industries, mines and agricultural units
- Advising in the implementation of relevant state laws and regulations,
- Providing advisory opinions to the Government on commercial and economic issues
- Establishing relations with chambers of commerce in other countries.
- Seeking to identify export markets for Iranian products and services,
- Creating a suitable entrepreneurship environment and removing business obstacles

Website: en.iccima.ir

**6. Agricultural Research Institute of Razavi-Khorasan Province (ARIR)**

The ARIR is a research institute which is in close collaboration with agricultural organization of Razavi-Khorasan province (RAO). Its main functions are:

- Doing Research projects

- Publication of texts and scientific articles
- Information and Public Relations
- Technical and research services
- Laboratory affairs

Website: kanrrc.areeo.ac.ir

7. **Agricultural Home – Mashhad Branch (AHM)**
   AHM is an NGO that is constituted as a political formation. Its aim is to organize and coordinate farmers and to promote human, social, political, cultural and economic rights in Mashhad.

   Website: www.khanehkeshavarz.com

8. **Parks and Landscape Organization of Mashhad Municipality (PLOM)**
   The PLOM is affiliated with the municipality of Mashhad and its main functions are as below:
   - Construction and maintenance of parks, Green space, squares and recreational facilities
   - Scientific and agricultural research in relation to green space issues

   Website: https://parks.mashhad.ir

9. **Water Savor Society (WSS)**
   WSS is (an NGO) is a group of elites, exploiters, experts, artists and enthusiasts. This group focuses on strengthening social awareness to save water in different ways. This NGO has different educational, cultural, executive, and Student subgroups.

   Website: http://najianab.ir/

10. **Mashhad Plain Agricultural Cooperative Company (MPACC)**
    MPACC (an NGO) is in the category of manufacturing companies that aims to improve the economic conditions of farmers. The main function of MPACC is providing agricultural facilities as follow:
    - Medicinal Herbs Services
    - Sale of chemical pesticides and fertilizers and agricultural implements

    Website: http://www.t-keshavarzan-mashhad.ir

11. **Association of Allowable Agricultural Wells in Mashhad Basin (Chenaran Town**)
    The AAAWM is the first formation of farmers in Iran who has owned legal wells in a basin. The aim of this formation is to bring in the farmers into decision making process accordance with the governmental organization especially the regional water authorizes in Razavi-Khorasan province. The AAAWM has a key responsibility in decreasing the groundwater extractions in Mashhad basin as well as improving the crop water productivity.

12. **Individual Farmers**
    Mashhad basin has lots of individual framers. Some of them may be a member of some NGOs such as AAAWM and Agricultural Home, but they act individually and have their own agricultural wells.

Among the 12 identified stakeholders in the region, three main categories are defined (excluding the individual farmers): i) Influential governmental organizations, ii) Influential private organization, and iii) Influential private/ semi-governmental agricultural organization. Categories i) and ii) have the authority on defining regulations and provide facilities for agricultural activities. The third category is related to extension and learning activities for the farmers or organizations which own agricultural land and water projects. Organizations in this category are especially relevant for the SMART-WADI project.

**Table A2. Influential stakeholders and their main activities related to SMART-WADI Project**

<table>
<tr><td>Category Type</td><td colspan="3">Catrgory1: Influential governmental organizations</td></tr>
<tr><td>Stakeholder</td><td>Razavi-Khorasan Regional Water Authority</td><td colspan="2">Razavi-Khorasan Agricultural Organization</td></tr>
<tr><td>Main Activities</td><td>➢ Water supply and allocations<br>➢ Issuing permits for water withdrawals</td><td colspan="2">➢ Supplying inputs, loans and facilities for agricultural activities<br>➢ Buying of agricultural product from farmers</td></tr>
<tr><td>Category Type</td><td colspan="3">Catrgory2: Influential private/semi-governmental organizations</td></tr>
<tr><td>Stakeholder</td><td colspan="3">Iran Chamber of Commerce, Industries, Mines & Agriculture (ICCIMA) - Razavi-Khorasan Branch</td></tr>
<tr><td>Main Activities</td><td colspan="3">➢ Defining strategies for improving water and agricultural economical management<br>➢ Providing and facilitate business environment for agricultural products export</td></tr>
<tr><td>Category Type</td><td colspan="3">Catrgory3: Influential private agricultural organization</td></tr>
<tr><td>Stakeholder</td><td>Astan Quds</td><td>AAAWM</td><td>Jovien agro-industry company (JAIC)*</td></tr>
<tr><td>Main Activities</td><td>➢ Owning several cultivation and industry companies in the province (more than 2000 ha of agricultural land)</td><td>➢ A formation with 400 farmers members in Mashhad basin for improving water management</td><td>➢ The JAIC is one of the prominent agro-industry in Iran in Razavi Khorasan province with 9000 beneficiaries</td></tr>
</table>

*JAIC is located in neighboring basin to the west of the Mashhad basin (Sabzevar and Jovien basin)

# Appendix B: Definitions, modelling, satellite data and flying sensors

***Water productivity and crop growth modelling***

In order to meet the future needs of food and fibre production, developing and developed countries need to focus more on efficient and sustainable use of land and water (Bastiaanssen and Steduto, 2017). Farmers have been able to gain profit by increasing agricultural production per unit of land. However, it is key to include the water consumption component in agricultural production. This would allow to improve agricultural production per unit of water consumed.

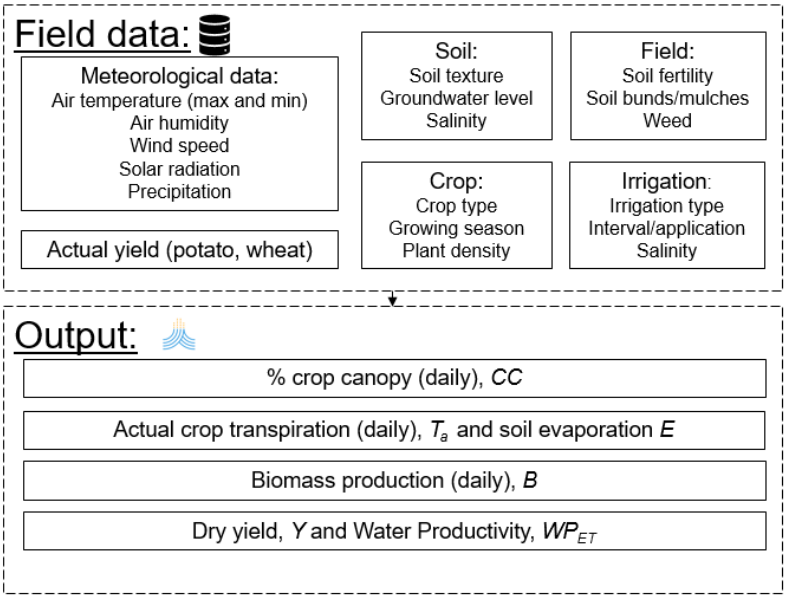
Water productivity consists of two components: crop yield and water consumed. Water consumption occurs through evapotranspiration which is the sum of plant transpiration through the stomata in the leaves, and evaporation that occurs from the soil surface and intercepted water by the leaves (Squire, 2004). As such, water productivity can be expressed as:

$$WAP = \frac{Y}{ET} \qquad (1)$$

where $WAP$ = water productivity (kg/m$^3$), $Y$ = crop yield (kg/ha) and $ET$ = actual evapotranspiration (m$^3$/ha)

Several crop models have been developed to predict crop yield and water productivity. The model selection depends on the application scale and the ability to constrain model parameter uncertainty. AquaCrop is a widely used crop model developed by FAO, which simulates the yield response to water using physically-based parameters. It has been used in climate change impact studies in various parts of the world (Hunink et al., 2014; Hunink and Droogers, 2010, 2011). In addition, AquaCrop has been applied to predict water productivity and crop yield based on flying sensor information (den Besten et al., 2017) and to assess irrigation scheduling scenarios (Goosheh et al., 2018). It is specially recommended for small scale farm level application. In addition, it is an open source model which is freely available for application. Hence, the appropriate model for SMART-WADI purposes.

Below is the input field data needed and output variables obtained with the AquaCrop model:




***Soil, crop, water and farm management information in the Mashhad basin obtained for crop growth modelling***

In the Mashhad basin the crops are sowed directly (e.g. potato and wheat). The field management practices allow a general healthy crop production (crops yields are relatively high, around 6t/ha for wheat). Water is available to irrigate the crops. The weed management practice consists of chemical weed control and hand weeding for canola, tomato and onion. During the development of the crop a high weed cover is managed. Part of the crop production is sold on the market and self-consumed. The soil texture in the farm is sandy clay (heavy soil). The depth of the groundwater table below the soil surface is 80 meters. The groundwater has a drinking water quality (no salinity).

**Table B1. Characteristics of each crop in the selected farm.**

| Crop | Wheat | Canola | Potato | Tomato | Onion |
|---|---|---|---|---|---|
| Area (ha) | 25 | 12 | 10 | 12 | 0.8 |
| Water use ($m^3$/ha/year) | 6,000 | 8,000 | 10,000 | 10,000 | 10,000 |
| Plant density (plants/ha) | 400,000 | 80,000 | 45,000 | 50,000 | 100 |
| Crop yield (t/ha) | 6.0 | 6.5 | 35 | 55 | 5 |
| Sowing date | 23/09-11/11 | 11/09-02/10 | 01/03-11/03 | 01/03-11/03 | 01/03-11/03 |
| Harvest date | 22/06-06/07 | 15/06-06/07 | 07/10 | 23/07 | 23/10 |

The following is the survey used to obtain this information from farmers:

General questions

- Name:
- Location: X: …………….. Y: ……………….
- Gender: □ Male □ Female
- Age:
- Tel. number:
- Experience: ….. year(s)
- What crop(s) do you cultivate? 1. ……..… 2. …..... 3. ……...
- Area of cultivated Crop: 1. …..….ha 2. ……..…ha 3. ……...ha
- Crop rotation:
- How much of your field is fallow?......... ha
- Main constraint: □ water □ Land □ Labor □Capital □ Fertilizers □ Machinery
  □ Legal (with name:) □ Market constraints □ Other:

Water use

- Water resource: □ Well □ River
- Irrigation method:
  □ Rainfed
  □ Surface irrigation: □ Basin □ Border □ Furrow
  □ Sprinkler irrigation
  □ Drip irrigation
- Water withdrawal point (main channel, secondary channel, tertiary channel)
- Water right: …… l/s and Frequency: ……day
- Amount of irrigation water used for each crop (think about units):
  1. ………..$m^3$/ha/year 2. ……..…. $m^3$/ha/year 3. ……... $m^3$/ha/year
- Frequency and application of irrigation:
  - How is the irrigation frequency and application for each growth stage of the crop? Please, attach a calendar with the daily water volume application during the crop development.

- How is buying system? □ Cash □Ratio of yield □After harvesting
- Method of water transfer: □Soil channel □ Concrete channel □ Pipe
- Season (Month) of water shortage:
- What is your response to water shortage?
- Water quality (EC, SAR,…):

Crop Characteristics

Crop: …………….

- Cropping period? Sowing date: ………………. Harvest date: ……………….

- Direct sowing or transplanting of the plant?

- Plant density on the field? ………………………plants/ha
- Crop production is affected mainly by (can be more than one):

  □ Low soil fertility □High soil salinity □Water shortage □Low temperature

Field management

- How much is crop production affected by low soil fertility?

  □Low □ Moderate □High
- Mulching practice?

  □Yes □ No
- If yes, what is the soil cover by mulches?

  □Low (5%-25%) □ Moderate (26%-75%) □High (76%-100%)
- Are soil bunds used in the field?

  □Yes □ No
- If yes, what is the height of these bunds? ……………meters
- What is the weed management practice? During the development of the crop what level of weed cover is managed?

  □Low weed cover □ Moderate weed cover □High weed cover

Soil profile and groundwater

- What is the soil texture? ………………..(combination between sand, silt and clay)
- What is the depth of the groundwater table below the soil surface? ……………..meters.
- Is the salinity of the groundwater low, medium or high?

  □Low □ Moderate □High

Yield

- Production per year per crop: 1. ………..ton/ha 2. ……..….ton/ha 3. ……...ton/ha
- Goal of production: □self-sufficient □sell on market □sell to family □trading
- Price of crop production: 1. ………..$/ton 2. ………..$/ton 3. ………..$/ton
- Cost (Planting, Growing, Harvesting): ………………..$/year
- Fixed cost: ………..$/year

***Model calibration and prediction of crop yield and water productivity***

In the AquaCrop model, crop parameters are defined in different types based on how well the parameter can be generally applicable or not. The default parameter values are those which may not change in different conditions and stay constant for the given plant (Raes et al., 2009). Other model parameters are cultivar specific and recommended values for each crop can be found in Raes et al. (2009) and Steduto et al. (2009). Goosheh et al. (2018) and Mohammadi et al. (2016) have established model parameter values for winter wheat in Iran. Mohammadi et al. (2016) calibrated model parameters such as maximum canopy cover (CCX), canopy growth coefficient (CGC), canopy decline coefficient (CDC) and maximum effective rooting depth (Zx) for irrigation conditions until the simulated grain yield is similar to the observed. These model parameters can be tuned for other annual crops such as potato.

We developed AquaCrop simulations using available meteorological data from the Golmakan station. In addition, soil, farm management, and model parameters were derived based on local information and from reference papers for winter wheat.

Based on local information, irrigation frequency is every 14 days with an average irrigation application of 50 mm. The average soil texture is sandy clay. The model parameter values for wheat growth simulations were obtained from previous studies using AquaCrop in Iran. Cultivar specific and non-cultivar specific model parameters used for the simulations are shown in the Appendix (Table A1).

In Table B2 the calibration parameters are shown. These can be tuned according to the selected objective variable such as actual evapotranspiration, canopy cover, or biomass. In this study, we used the actual evapotranspiration as objective variable to calibrate the model.

**Table B2. Calibrated crop-type model parameters for simulation grain yield of winter wheat.**

| Model parameter | Values |
|---|---|
| Maximum canopy cover, CCx (-) | 0.90 |
| CGC for GGDays (-) | 0.005 |
| CDC for GGDays (-) | 0.004 |
| Zrx (m) | 1.5 |

***Flying sensors and satellites providing crop information***

Low-cost flying sensors can compute vegetation indices from images taken over the crop fields (Figure B1 and Figure B2). For example, the Normalized Vegetation Index quantifies the difference between near infra-red (NIR) and red light. NIR is reflected by vegetation, while red light is absorbed. Low NDVI values can be caused by a lack of water, lack of fertilizer, pests or abundancy of weeds. Relevant crop information can be derived such as canopy cover, biomass and crop stress. The key benefit in using the flying sensor is that it provides information on the status of the vegetation of the crop about 10 days earlier of damage manifestation. Also, temperature information from the fields can be obtained with thermo cameras.

**Figure B1. SMART-WADI team using flying sensors in agricultural fields.**

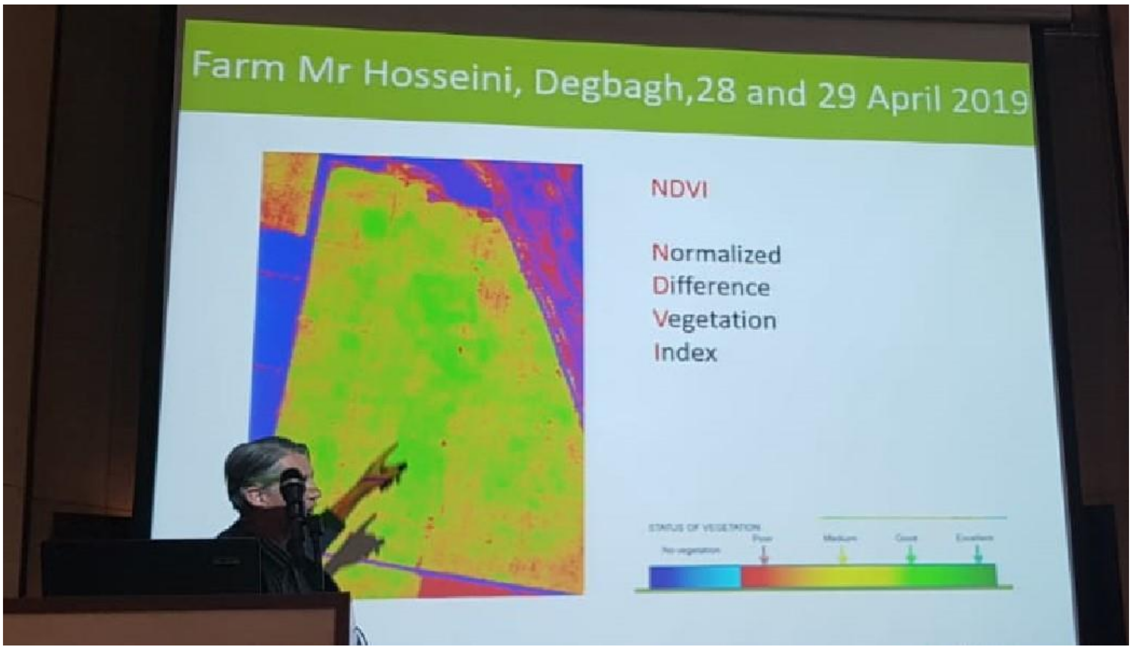



**Figure B2. Vegetation index (NDVI) map indicating localized crop damage (derived from flying sensors).**

Satellites also provide images from which information on crop growth can be derived. Information from Landsat and Sentinel satellites include NDVI and actual evapotranspiration datasets. The benefit is that these datasets are available for the past 10 years and new measurements are included every 15 days. The drawback of using satellite datasets is that it is available at a coarser spatial resolution compared to the dataset provided by the flying sensor. In addition, satellite measurements can be affected by clouds. The benefit consists of complementing both information sources for mapping and the crop growth model for crop yield and water productivity predictions.

# Appendix C: Risk assessment and survey

Risk factors which have to be considered to implement and upscale the near real-time water productivity service in the Mashhad basin, Iran. Through scoring each risk on an ordinary scale between 5 and 1, where: 5=very high; 4=high; 3=mid; 2=low; 1=very low. The weight of each factor may be adjusted between 0 and 1.

**Table G1. Internal risk assessment at the beginning of the project**

| No. | Risk category | Risk factor | Weight, w | Scores, s | w*s |
|---|---|---|---|---|---|
| 1 | Political | Drone flying restrictions | 10% | 4 | 0.400 |
| 2 | | Legal/political barriers | 10% | 5 | 0.500 |
| 3 | Technical | Phone service limitations | 10% | 1 | 0.100 |
| 4 | | Information delivery and conveying limitations | 10% | 1 | 0.100 |
| 5 | | Users not-understanding the information | 10% | 2 | 0.200 |
| 6 | | Technical limitations of the user | 10% | 2 | 0.200 |
| 7 | Socio-economic | Existing information service | 10% | 1 | 0.100 |
| 8 | | Local partner aversion | 10% | 1 | 0.100 |
| 9 | | Not cost effective | 10% | 3 | 0.300 |
| 10 | | No willingness to pay | 10% | 3 | 0.300 |
| | | | 1.0 | | 2.3 |

**Table G2. Internal risk assessment at the end of the project**

| No. | Risk category | Risk factor | Weight, w | Scores, s | w*s |
|---|---|---|---|---|---|
| 1 | Political | Drone flying restrictions | 5.6% | 4 | 0.22 |
| 2 | | Legal/political barriers | 50% | 5 | 2.50 |
| 3 | Technical | Phone service limitations | 5.6% | 1 | 0.06 |
| 4 | | Information delivery and conveying limitations | 5.6% | 1 | 0.06 |
| 5 | | Users not-understanding the information | 5.6% | 2 | 0.11 |
| 6 | | Technical limitations of the user | 5.6% | 2 | 0.11 |
| 7 | Socio-economic | Existing information service | 5.6% | 1 | 0.06 |
| 8 | | Local partner aversion | 5.6% | 1 | 0.06 |
| 9 | | Not cost effective | 5.6% | 3 | 0.17 |
| 10 | | No willingness to pay | 5.6% | 3 | 0.17 |
| | | | 1.0 | | 3.5 |

An initial questionnaire was developed to understand the market which later inspired the development of an expert survey showed below

- Who are the potential clients?
- What do they produce? (description of the value chain)
- What are their main challenges / requirements?
- The main challenges of the farmers is to reduce pumping costs, as the groundwater
- How many of them are there? (market size)
- How much are they willing to pay? What is the market value?

- Who are the competitors?
- What have their challenges and successes been?
- Are these well-established services? What are strong and weak points of these competing services according to clients?
- What is the competitive positioning of our solution (Strengths, Weaknesses, Opportunities and Threats)?
- Are there any potential partners active in the region that provide complementary services?

The following is the **expert survey** developed for local stakeholders in Iran. This can be developed for any country around the world to get feedback on the market potential in implementing our proposed service:

1. **Select type of institution/company currently working:**

□ Farm □ Extension office □ Water association

□ Agricultural association □ Government institution □ Private company

□ Semi-Government institution □ NGO □ Other

2. **Select current work position:**

□ Agricultural expert □ Hydrologist □ Irrigation expert

□ Engineer □ Water manager □ Farmer

□ Other

3. **Select current work experience:**

□ 1-3 years □ 4-6 years □ 7-9 years □ 10-12 years

□ >13 years

4. **In Iran, how many companies are offering farm information services using remote sensing?**

□ 1-2 □ 3-5 □ 6-9 □ More than 10

5. **In general, which farm information service is provided by these companies?**

□ Irrigation advice □ Crop growth monitoring

□ Crop water consumption □ Crop yield prediction

□ Water productivity prediction □ Other

6. **Are you (or your company) currently paying for one of these farm information services?**

□ Yes □ No

7. **What is the reason of not paying for such a service?**

□ Service is too expensive □ Not useful information

□ Information does not provide added value

8. **What is the limitation of current farm information service?**

□ Useless □ Not easy to use □ Not easy to understand

□ Not reliable □ Not timely received □ No limitation

9. **How is the farm information from these services being conveyed?**
□ Mobile □ SMS □ Automated voice call

□ Online □ Written report □ Other

10. **Which type of farm information would you (or your company) like to receive?**
□ Irrigation advice □ Crop growth monitoring

□ Crop water consumption □ Crop yield prediction

□ Water productivity prediction □ Other

11. **Desired frequency of updated farm information?**
□ 5-10 days □ 10-20 days □ 20-30 days □ Monthly □ Other

12. **Desired crop to be assessed?**
□ Wheat □ Potato □ Wheat + potato □ Others

13. **How would you like to receive the farm information?**
□ Mobile □ SMS □ Automated voice call
□ Online □ Written report □ Other

14. **Would you (or your company) pay for a farm information service to improve agricultural water productivity ("More Crop per Drop")?**
□ Yes □ No

15. **How much percentage of the total farm production costs would you (or your company) pay for a farm information service to improve agricultural water productivity ("More Crop per Drop")?**
□ 1% □ 5% □ 10% □ 15%
□ 20% □ 25% □ More than 30%

16. **For Iran, rank the following risk factors in implementing a remote sensing service for agriculture from 1 to 9 (1=Highest risk factor, 9=Lowest risk factor):**

| Risk factor | Rank from 1 to 9 |
|---|---|
| Flying sensor restrictions | |
| Legal/political barriers in using flying sensors | |
| Mobile service limitations | |
| Information delivery | |
| Farmers not understanding the information | |
| Existing information service | |
| Aversion of using new technologies | |
| Not cost effective | |
| No willingness to pay | |

# Appendix D: Letters of support

Below are the letters of support for the SMART-WADI project:

وزارت نیرو
شرکت مدیریت منابع آب ایران
شرکت آب منطقه ای خراسان رضوی

مشهد۲۰۱۷
MASHHAD 2017

تاریخ : ۱۳۹۷/۵/۱۷
شماره : ۹۷/۸۷۳۱/۱۱/۳
پیوست :

شناسه ملی: ۱۰۳۸۰۱۲۶۱۱۹ به نام خدا کد اقتصادی: ۴۱۱۱۹۱۸۸۶۹۹۷

ریاست محترم جمهور: امروز دولت در خط مقدم مبارزه است و باید فشار را تحمل کند. اگر به جان یک و صورت مدیریت سابق کار کنید موفق نمی شوید.

**جناب آقای دکتر مجیدی**
**رئیس محترم مرکز پژوهشی آب و محیط زیست شرق**
**موضوع : حمایت معنوی**

با سلام و احترام

بازگشت به نامه شماره ۳۴۵ ن ۹۰۳ مورخ ۱۳۹۷/۰۴/۲۳ درخصوص پروژه مشترک آن مرکز با موسسه آب IHE Delft هلند با عنوان SMART WADI for IRAN به اطلاع می‌رساند این شرکت ضمن آگاهی از کلیات پروژه مذکور بدینوسیله آمادگی خود را جهت همکاری و حمایت معنوی در کاربرد فناوری‌های نوین درون (Drone Technology) در پایش اطلاعات کشاورزی و منابع آبی اعلام می‌دارد.

امید است با همکاری‌های مذکور و ایجاد ظرفیت‌های همکاری بیشتر زمینه انتقال فناوری‌ها و توسعه آنها در مدیریت هوشمند منابع و مصارف آب در میهن اسلامی عزیزمان بیش از پیش فراهم شود.

محمد علائی
رئیس هیئت مدیره و مدیرعامل

مشهد - بلوار خیام - نبش خیام جنوبی ۳۵ http//www.khrw.ir
کد پستی : ۹۱۸۵۹۱۶۱۹۶ تلفن : ۳۷۶۱۷۰۱۱ - ۱۹ نمابر : ۳۷۶۱۳۰۰۸ پست الکترونیک : ece@khrw.ir

Dear Dr Majidi
The President of East Water and Environmental Research Institute

Subject: Support statement
This statement is written regarding your letter on 14 Jul 18, about the SMART WADI project which is under collaboration with IHE Delft. It is our pleasure to mention that the Razavi-Khorasan Regional Water Authority (RKRWA) acknowledge this innovative project by cooperating in the implementation of drone technologies in the region for better monitoring of agricultural and water resources consumptions.
We hope that with such collaborations more capacity could be provided in field of technologies transfer and its development for smart water management in our country.

Mohammad Aliee
Head and Board of Director
Razavi-Khorasan Regional Water Authority

Dear Dr Majidi

Rector of East Water and Environmental Research Institute

Subject: Running the pilot of Smart water management project

Following the successful holding the Smart water management workshop in our company on 5th of August. I would like to thank you for this fruitful program. Our company (Mazrae Nemune) is one of the leading agricultural companies in Iran and has different kinds of facilities in field of irrigation management as well as machinery in agricultures. Regarding this, I would like to state that based on regulations and formalities for transferring agricultural technologies and training objectives, our company will eager to be the host for the pilot of the smart water management project in Iran and will provide co-funding as well for the implementation of the project.

On be behalf of Mahmud Sadeghi
CEO
Ali Oraee Zarea

Address: Mashhad, Kuhsangi Ave, in front of Masjed Nabi. POB: 9174613112

Tel: 051- 38530011-3 Fax: 051- 38545784

# Appendix E: Seminars


**Figure C1. Seminar in Iran, December 2018 (Mashhad).**


**Figure C2. Seminar in Iran, April 2019 (Ferdowsi University, Mashhad).**

**Figure C3. Seminar in Iran, August 2019 (Mashhad Plain Agricultural Cooperative Company).**

# Appendix F: News about our work

*https://www.agroberichtenbuitenland.nl/specials/voedselzekerheid/iran*

Ministerie van Landbouw, Natuur en Voedselkwaliteit

Agroberichten Buitenland > Specials > Voedselzekerheid >

## Geodata helpen Iran met efficiënt watergebruik

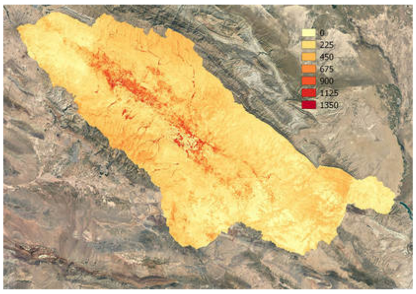
Iran staat voor de uitdaging om te anticiperen op de toenemende vraag naar water en de concurrentie om water tussen de landbouw, industrie en steden. Conflicten om water zullen in de toekomst toenemen door bevolkingsgroei en klimaatverandering. De watervraag stijgt het sterkst in de landbouw. Dat voert de druk op de verhouding tussen stedelijke en landelijke gebieden en met buurlanden verder op.

Droogvallen van Urmia-meer in Iran

Naast de maatregelen die zijn gericht op wateraanvoer is er in Iran dringend behoefte om de watervraag te laten dalen. Vooral in de landbouw kan hier grote winst worden behaald, door systemen efficiënter te maken en de productiviteit te verhogen. Een schrijnend watertekort en verzilting van de grond zijn tekenen dat de grenzen aan grondgebonden landbouwproductie in Iran zijn bereikt.

### Waterbalans

Een van de belangrijkste onderdelen van het project is een snelle beoordeling van de balans van inkomend en uitgaand water (WA-systeem) in het Urmia-bekken. Het Nederlandse kennisinstituut IHE-Delft ontwikkelt een set van satellietkaarten voor het stroomgebied. Ook worden trainingen verzorgd aan waterspecialisten van de universiteiten en plaatselijke overheden in onder andere Tabriz en Urmia om de kennis van WA-systemen te vergroten.




Eenjarig ETa (mm/jaar) voor het stroomgebied Mashhad (2014-2015)

### SMART-WADI project in Masshad

Het stroomgebied Mashhad, waarin zich de tweede stad van Iran bevindt, is een belangrijke economisch centrum van toerisme en industrie. De economische groei van de stad wordt sterk bedreigd door watertekorten en ongereguleerde grondwateronttrekkingen. De situatie is kritisch en de overheid overweegt drastische infrastructurele maatregelen zoals ontzilting en wateraanvoer vanuit het de Zee van Oman.

### Satelliettechnologie en dronebeelden

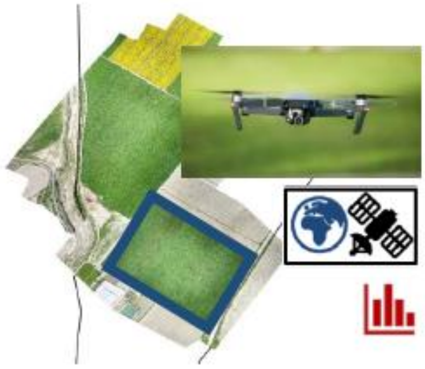
Het project SMART-WADI (SMART Water Decisions for Iran), uitgevoerd door een consortium van FutureWater, IHE Delft, en lokale partner EWERI, richt zich op boeren die hun gewas irrigeren met grondwater. Het doel is om actuele informatie en advies te verstrekken over de waterproductiviteit, irrigatie en farmmanagement. Het project combineert de laatste satelliettechnologie voor het kwantificeren van waterverbruik en -productiviteit, met hoge-resolutie flying sensor (drone-)beelden om de gesteldheid van het gewas te monitoren.

# Appendix G: Promoting our service

***The following is the one pager developed in the project to promote our service:***

## SMART-WADI

### Smart decisions in irrigated farms in Iran



FutureWater, IHE-Delft and EWERI, have jointly developed the next generation of crop growth monitoring and irrigation advice providing environmental and economic indicators.

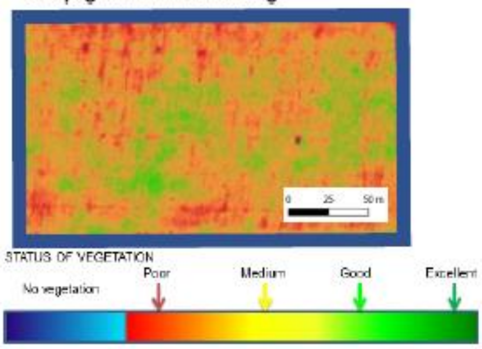
***Unique selling points***

Our noninvasive remote-sensing based service offers 100% coverage of the farm. The combined use of crop growth models, available satellites and low-cost, easy-to-use drone technology allows on-demand high resolution images of agricultural fields.

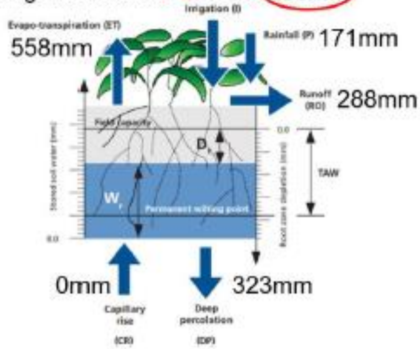
***Service and proof of concept***

With our multi-information platform technology (satellites, drones and crop growth models) we can monitor crop growth, provide irrigation advice, and predict crop yield and water productivity.

Crop growth monitoring:




Irrigation advice: ~~850mm~~ 680mm




| Environmental and economic indicators | | | | |
|---|---|---|---|---|
| Crop yield (t/ha) | Water productivity (kg/m³) | Current gross water use (m³/ha) | Recommended gross water use (m³/ha) | Groundwater use reduction (%) |
| 6.2 | 0.97 | 6000 | 4802 | 20 |

***Viability***

Based on interviews and surveys with farmers, private investors and government institutions the highest risk factor in implementing our service are the legal and political barriers in using flying sensors, and farmers not understanding the information. Still our team was able to fly a drone in wheat fields and showed the potential service to different stakeholders. There is interest in using these technologies and willingness to pay for such a service.

# Appendix H: Testing and validation plan and pilot implementation roadmap

As explained in section 3.3, the testing and validation plan and pilot implementation roadmap is proposed to be developed in Turkey instead of Iran. The total duration of the proposed pilot project SMART-WAD, SMART Water Decisions for Turkey is 2 years. If the subsidy is provided by the Partners for Water Programme, this pilot project will start on March 1st, 2020 and finish March 1st, 2022 (Figure H1).

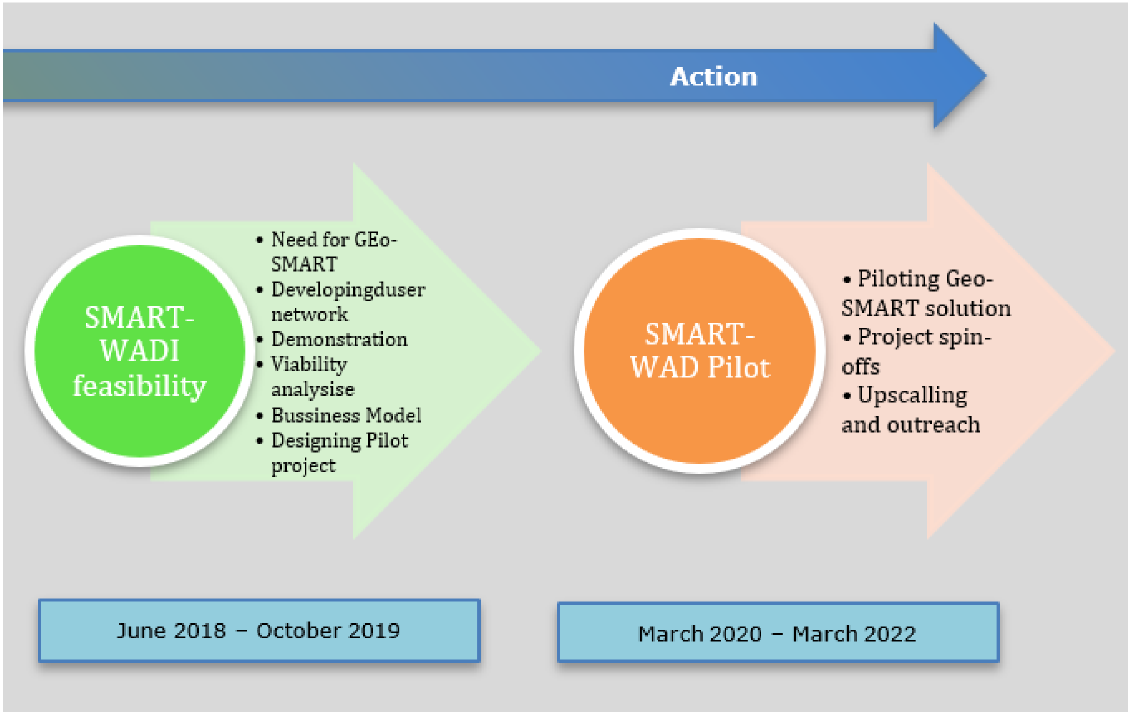



**Figure H1. SMART WADI feasibility study realized between June 2018 and October 2019 in Iran, and the planned SMART-WAD pilot project in Turkey between March 2020 and March 2022.**

Turkey is 7th biggest agricultural economy according to World Bank and country is looking for innovative technologies to keep grow its agricultural economy and to keep modernize agricultural practices so that country will not be in the back in agriculture sector. In 2003, Turkey ranked first for agricultural machinery (tractor) per capita amongst Muslim countries. Thanks to the national subsidies, farmers can buy tractors and other agricultural tools and that is one of the main reasons why farmers keep modernize their tools and vehicles. They also get subsidy for diesel, seeds, but currently there is no precision farming (e.g. drones) subsidy yet. According to Turkey's national aviation authority, the States Airport Administration of Turkey (SAMA), flying a drone is legal in Turkey. One of the beneficiaries of the SMART-WAD project is Konya Seker which is one of the companies of the Anadolu Birlik Holding: http://abholding.com.tr/en/icerik/liste/6832/sirketlerimiz. Konya Food and Agriculture University is a private university established by Anadolu Birlik Holding. In Regulation of the University precision farm specifically mentioned and they have an already interest to work on and develop themselves in precision farming techniques: http://www.resmigazete.gov.tr/eskiler/2018/11/20181105-5.htm.

We applied for a subsidy to the Partners for Water Programme to develop the SMART-WAD pilot project in Turkey. We foresee a high success rate in demonstrating, testing, validating, and even potentially upscaling our solution to support irrigated agriculture and water safety in Turkey. We have secured willingness to contribute from local partners such as Tarla (which is a private company providing information to farmers) and GAP Research Institute (which is a research institute dedicated to support agricultural and water management solutions) which is key for successfully piloting our solution. The added value of our partnership is the strong potential of incorporating our solution in the existing information service provided by Tarla, which already covers over ten business to business contracts in Turkey (e.g. Konya Seker, Toros). Tarla's clients such as Konya Seker and Toros have expressed their interest in using an updated crop-water information tool using flying sensors, satellite data and crop growth models for decision making. This means that our ambition is a complementary service, rather than a new service, thus resulting in a higher success rate for demonstrating, testing, validating and even potentially upscaling the service. Also, GAP Research Institute has confirmed their willingness for in-kind contribution. Specifically, this contribution includes the use of work areas (e.g. experimental farms) and equipment such as flying sensor kits (drones), laptops, and soil testing devices, and the support of staff for drone flying, internal ground transport and logistics between cities and farms in the Harran plain in Turkey. The different activities planned for testing and validating the solution is shown in Table H2, as well as the execution of each activity per month during the total duration of the project.

**Table H2. SMART-WAD project plan: Activities per month for 2 years.**

| Activities | | Month | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| **WP1** | **User engagement** | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.1 | User requirements | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.2 | Pilot area validation in GAP farms | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.3 | Coordination in pilot area in GAP farms | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.4 | Area validation of Tarla's user | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.5 | Coordination in Tarla's user area | | | | | | | | | | | | | | | | | | | | | | | | |
| **WP2** | **Demonstrate, testing and validation of product** | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1 | Inception visits | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2 | Pilot area validation | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.3 | Plan and develop drone flights | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.4 | Satellite data processing | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.5 | Crop model simulations | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.6 | Tests combining drone, satellite and model data | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.7 | Validation of product | | | | | | | | | | | | | | | | | | | | | | | | |
| **WP3** | **Embedding the product** | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.1 | Area validation of user | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.2 | Plan and develop drone flights | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.3 | Satellite data processing | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.4 | Crop model simulations | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.5 | Tests combining drone, satellite and model data | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.6 | Tests to incorporate the data in the front-end system of Tarla | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.7 | Validation of product | | | | | | | | | | | | | | | | | | | | | | | | |
| **WP4** | **Potential upscaling, spin-off and business opportunities** | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.1 | Presentation of results and seminar | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.2 | Upscaling assessment | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.3 | Develop business proposal | | | | | | | | | | | | | | | | | | | | | | | | |
| **WP5** | **Project management** | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.1 | Project coordination | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.2 | Reporting | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.3 | PR | | | | | | | | | | | | | | | | | | | | | | | | |