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ThIRST: Targeted IRrigation Support Tool for sustainable coffee production

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The Central Highlands of Vietnam is an important Robusta coffee growing region.
However, the region is facing climate change impacts from rising temperatures
and irregular rainfall, while Vietnamese coffee farmers predominantly rely on
irrigation from heavily depleted aquifers. To continue productive and sustainable
growth, this system requires an innovative approach to meet this hydrological
challenge. Here we propose a user-friendly tool, which aims to support coffee
farmers' irrigation decisions, through the Targeted Irrigation Support Tool or
ThIRST. ThIRST combines seasonal forecasts, on-farm metrics, and farmer's
expertise. The research comprises baseline ($n = 400$) and endline ($n = 237$)
surveys of coffee farmers in Đắk Lắk and Lâm Đồng Provinces. Through the
surveys, farmers' irrigation needs and the applicability of the tool are evaluated.
Despite low smartphone usage for farming advisory, the results show the tool
allows coffee farmers to continually achieve water-use efficiency and adapt to
climate variability. Involving farmers in the design, production and evaluation of
climate services can improve the trust and uptake of agro-advisories and the way
this information is communicated.

1. Introduction

As a result of climate change, temperature and precipitation extremes have increased and
precipitation patterns have shifted across the globe (Caretta et al., 2022). Large areas across the
world are affected by droughts with devastating consequences for agriculture. Drought is a major
driver of reduced yields globally, causing economical damage in hundreds of millions of US
dollars in recent years (Grosjean et al., 2016; Funk et al., 2019; Kam et al., 2021). In Vietnam,
the 2015/16 drought caused economic losses of about 269 million US$ (Grosjean et al., 2016;
MARD, 2016; World Bank, 2017). Coupled with that, poor water management and overuse of
water have further depleted water resources, constrained agricultural production and threatened
ecosystems (FAO, 2017). Furthermore, droughts and other extreme weather events are projected
to be more frequent (Caretta et al., 2022). Agricultural irrigation accounts for 70% of water use
worldwide, therefore mitigation is a critical component (FAO, 2017; OECD, 2017).

Vietnam is the second largest coffee producer in the world (International Coffee Organization – Trade Statistics Tables, 2020; FAO, 2021). Robusta coffee accounts for 95% of the national coffee production (Byrareddy et al., 2020). The Central Highlands are the most important coffee growing area in Vietnam, accounting for around 90% of Vietnam's annual coffee export (Ho et al., 2017). Coffee has a large impact on people's livelihoods. Around 620,000 coffee farming households, the equivalent of approximately 2.5 million people, depend on coffee farming. This is approximately 40% of the Central Highlands population (D'Haeze, 2019).

Climate change poses serious threats to coffee production and quality (Byrareddy et al., 2020; Kath et al., 2020; Craparo et al., 2021) and seasonal norms are reported to be increasingly unpredictable. Even though total annual rainfall is reported to slightly increase, rainfall patterns are expected to shift with more rain in the wet season and less rain in the dry season (Baker et al., 2017) with adverse impacts on flowering and fruit setting (Koh et al., 2020). The number of extreme weather events will also increase, such as heavy rainfall events and more intense droughts becoming more frequent and intense (Baker et al., 2017; D'Haeze, 2019). In addition, water is not being managed efficiently due to the fact that most farmers are small and medium-sized and their access to sophisticated equipment and weather forecasts is limited. Water in the Central Highlands is freely accessible and has no licensing regulations (Havemann et al., 2015; D'Haeze, 2020). Given this, farmers are willing to use excessive amounts of water to sustain high yields without regard for groundwater volume or rainfall availability (Byrareddy et al., 2021). It is reported that farmers use more than double the amount of water needed (Byrareddy et al., 2020).

It is common practice to irrigate consistently at certain phenological periods, regardless of the current soil water status or seasonal forecasts. Coffee farmers in Central Highlands irrigate from two to four times per year (Sustainable Coffee Challenge, 2017). The first round of irrigation is around January or February, when the flower buds are fully developed (Amarasinghe et al., 2015; Milnes et al., 2015; D'Haeze, 2017). This irrigation is required to stimulate flowering and induce fruit setting. The following rounds of irrigation are recommended, when stress in the plant is evident or the leaves turn yellow. The months from January to April are also the dry season in Central Highlands and water shortages are prominent (Milnes et al., 2015). However, with controlled and informed irrigation practices, production and high yields can still be sustained even in drought years (Technoserve, 2013).

With current irrigation practices, farmers are likely to experience water shortages once every five years, particularly evident in El Niño years, such as in 2005/06, 2010/11 and 2015/16 seasons (Technoserve, 2013; Nguyen et al., 2016; Nguyen and Nguyen, 2019). The 2005–2006 drought left a serious impact on the national production, with losses reported at 20% (Technoserve, 2013). The 2010/11 drought resulted in up to 25% reduction of the total production of green coffee beans (Nguyen, 2005; MARD, 2016), while the 2015/16 drought caused economic losses of about 269 million US$ and led to a small price hike in world coffee prices (Grosjean et al., 2016; MARD, 2016; World Bank, 2017).

Seasonal forecasts can play a vital role in helping farmers to make better and more informed decisions. Although this type of information is available, it is challenging to translate into actionable insights for farmers (Coulier et al., 2018; Trinh et al., 2018; An-Vo et al., 2021). The rapid development of Information Communication Technology (ICT) has provided extensive new outlets for this translation to happen. However, in Southeast Asia in general, and in Vietnam specifically, the high adoption of phones contrasts with the limited demand and supply of climate and geospatial digital services (Simelton and McCampbell, 2021). To address these challenges, we test the applicability of a tool for farmers to manage their water resources more efficiently for sustainable coffee cultivation.
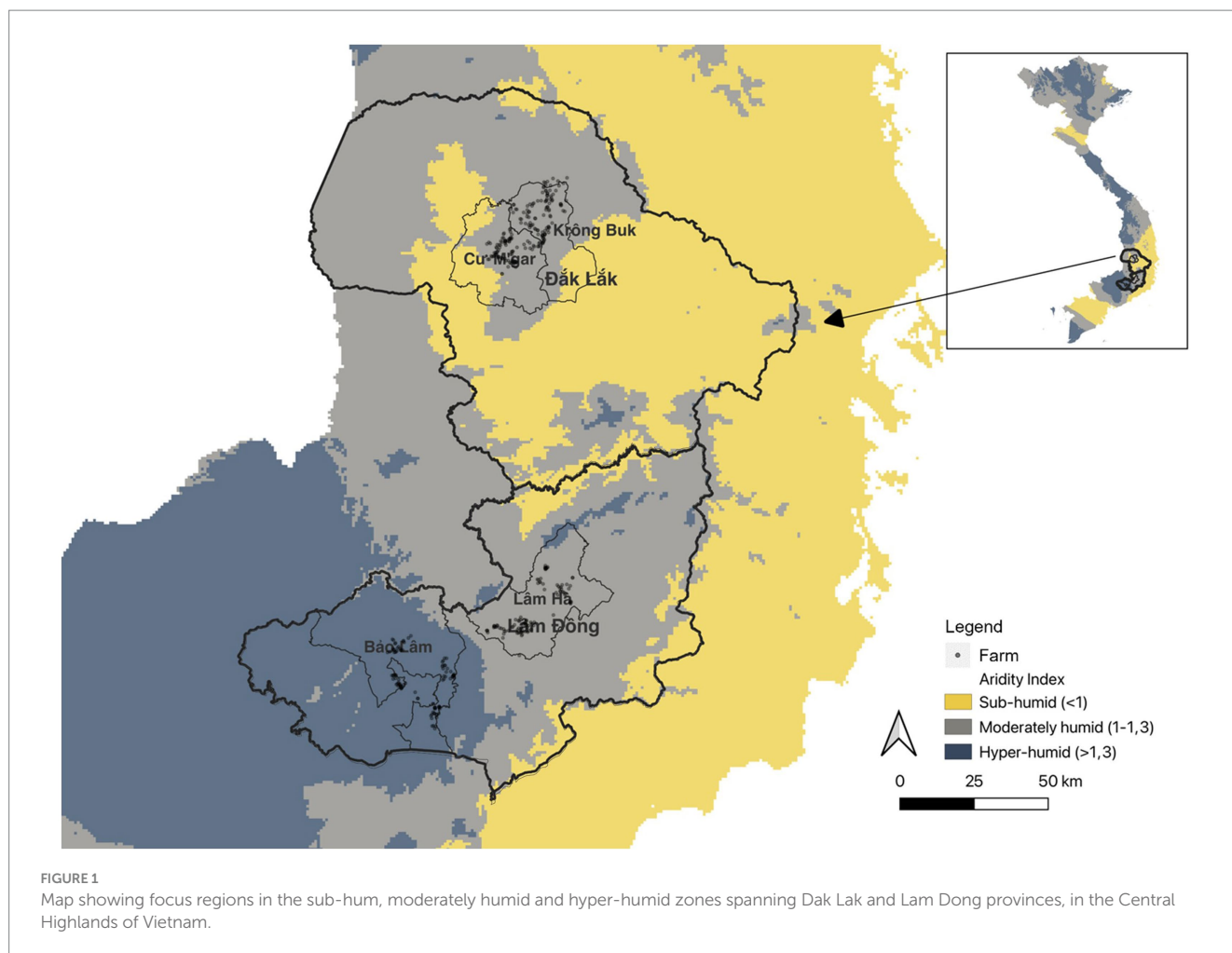
2. Materials and methods

2.1. Study region

The geographical focus of the project is Cư M'gar and Krông Búk Districts of Đắk Lắk Province, and Lâm Hà and Bảo Lâm Districts of Lâm Đồng Province, Central Highland, Vietnam (Figure 1). The two provinces were selected based on their diverse climate and farming systems. While both is influenced by a tropical monsoon climate with distinct rainy and dry seasons, Đắk Lắk Province is characterized by a drier, more arid environment compared to Lâm Đồng, which is more humid and experiences greater amounts of rainfall. Coffee production is highly intensified and coffee is often intercropped with black pepper (Kahsay et al., 2022).

With changing weather and climate, coffee farmers in Vietnam often adapt practices such as water management, crop diversification and intercropping (Thi and Chaovanapoonphol, 2014; Nguyen and Nguyen, 2019). A recent study in the region found that farmers with access to internet were more likely to take adaptation measures (e.g., water and crop management practices) and obtain higher coffee yields (Kahsay et al., 2022). With Vietnam has a high number of mobile internet users (70% of the population in 2018) (World Bank Group, 2019) and the Ministry of Agriculture and Rural Development promotes the use of ICT for agriculture information distribution (Hoang, 2020), smartphone applications have the potential to be an effective agricultural advisory tool.

2.2. Product design and user needs

The ThIRST model was developed within the framework of the project "Improved Business through Seasonal Forecasting for Coffee in Vietnam." The project was funded by the Nordic Climate Facility and implemented through cooperation between University of Copenhagen (UCPH), the Alliance of Bioversity and CIAT, Sustainable Management Services Vietnam (SMS), and Real Time Analytics (RTA). The project aimed to transform and re-orientate agricultural development under climate change with the development of a tailored seasonal climate forecasting system and a set of associated decision support tools for coffee farmers. A key output of the project was a mobile app which provides advisory on different aspects of coffee farming such as fertilization, pests and disease management, intercropping, irrigation, pruning, mulching, and registration of farm practices. An important component of the app was the provision of seasonal forecasts together with associated agronomic advisory based on the forecast and current phenological

FIGURE 1
Map showing focus regions in the sub-hum, moderately humid and hyper-humid zones spanning Dak Lak and Lam Dong provinces, in the Central Highlands of Vietnam.

period. The ThIRST model was one of the advisory tools incorporated in rtWork app available for both Android https://play.google.com/store/apps/details?id=vn.rta.rtwork and iOS https://apps.apple.com/vn/app/rtwork/id1097767529, and in two languages: Vietnamese and English.

User needs were gathered in 2019 via a baseline survey of 400 farmers, stakeholder consultation (SMS) and expert interviews (agronomists). These 400 coffee farmers were randomly selected from two districts of Đắk Lắk (n = 200) and two districts of Lâm Đồng (n = 200). For each household, one main coffee farmer and one secondary farmer (opposite gender) were interviewed. The survey asked them about their socio-economic characteristics, coffee farming systems and practices, use of ICT, access to information and farming advisory, adaptation practices, and personal attitudes toward trust and risks.

Subsequently, the sampled farmers were introduced to and trained in the use of the rtWork app, however, installation of the app on their phone was optional. In 2022, an endline survey was carried out to assess the project's impacts. Out of 400 sampled farmers, 237 participated in the endline. The endline survey gathered similar information to the baseline with the addition of farmers' habit on using rtWork app and the advisory modules in the app. These data provided valuable information on the usability and applicability of ThIRST model.

2.3. Development of the ThIRST model

2.3.1. Input variables

The ThIRST tool uses three input variables: (1) current soil moisture content, (2) slope of the land, and (3) the seasonal precipitation forecast. Variables (1) and (2) are input by the farmer, while (3) is an automatically generated backend value.

2.3.1.1. Soil moisture (farmers' input)

Monitoring of soil moisture at the plant root level in irrigated areas is an important technique for irrigation management (Evangelista et al., 2013). In the context of coffee farming in Vietnam, where the use of soil moisture sensors is not widespread, we advise farmers to estimate their current soil moisture based on the United States Department of Agriculture (USDA) soil feel and appearance method. The soil feel and appearance method consists of 4 steps. In order to make it easier for farmers to follow the instructions and interpret the results, a short video tutorial conducted by SMS agronomists is provided in the app. This method aims to estimate the soil moisture deficit (SMD), which is the amount of water (precipitation in mm) required to replenish the soil water content back to field capacity (Keane, 2001). Farmers choose the option that best describes their soil feel and appearance, and the options are in turn converted into an input value for the

ThIRST equation (See Annex A1 A1 for details of the soil feel and appearance options).

2.3.1.2. Slope gradient (farmers' input)

Slope of the cultivated land is an important input in the model, as farmers with sloping land, especially when located in the higher areas of a watershed, are the first to experience water deficiency. As slope increases, the water retention capacity decreases, and the faster it takes for water to infiltrate (Vandecasteele et al., 2018). The Lam Dong and Dak Lak provinces are both located in the Central Highlands, which have a very diverse topography, making slope an important component for irrigation decision making. Lam Dong province is a highly elevated, mountainous province with 60% mountainous, 20% highland, 17% hilly and 3% valley terrains (Lam Dong Foreign Affairs Department, 2020). Meanwhile, Dak Lak province is situated on a large plateau sloping down from South-East to North-West, with relatively flat terrains (DakLak Provincial People's Committee, 2015).

For slope input parameters, farmers select the option that is closest to their coffee farm's slope (see details in Annex A2), and the options are in turn translated into input value for the ThIRST equation. The app also contains an illustration on slope reference to help farmers visualize which slope range their farms are in. Given the diverse topography of the region, slope in a particular coffee plot can vary quite widely. In such cases, the app provides farmers an option to list several sub-plots and receive tailored recommendations for each sub-plot.

2.3.1.3. Seasonal climate forecast (back-end value)

The third variable to the ThIRST tool is a seasonal forecast for the following three months (see details in Annex A3). In this case, the seasonal forecasts are produced by the University of Southern Queensland (USQ) from an ensemble of six general circulation models (GCMs): the European Centre for Medium-Range Weather Forecasts (ECMWF), United Kingdom Meteorological Office (UKMO), Deutscher Wetterdienst – German Meteorological Service (DWD), METEO France, Euro-Mediterranean Center on Climate Change (CMCC), National Centers for Environmental Prediction (NCEP). The forecasts can be accessed from DeRisk SE Asia website.[1]

2.3.2. ThIRST equation

Three variables are then used to provide an output which gives farmers an indication of their current situation and near-term future. To produce the ThIRST output, the input variables are multiplied by a weighting factor. The weightings are determined based on the importance of soil moisture, land topography, and seasonal forecasts with regards to water conservation and runoff. Soil moisture has the highest weighting (0.8) in the equation as it is a critical factor for plant growth, in particular for coffee at certain development stages. Soil moisture is a crucial parameter in designing an intelligent irrigation system (Ling, 2004; Oukaira et al., 2021) and monitoring of soil moisture is very important in water conservation activities and water usage efficiency (Scherer et al., 1996; Fakhar et al., 2021). On the other hand, topography or slope of land is also fundamental for water

conservation in farming. Studies point out that land topography is associated with water and nutrition runoff (Scherer et al., 1996; Oweis et al., 1999; Wang et al., 2019). The final parameter in the ThIRST equation is the seasonal forecast value which is given lowest weighting factor due to the inherent uncertainty of weather and climate prediction (Palmer, 2000; Slingo and Palmer, 2011).

The equation is given as follows:

$$T_{i,t} = M^* 0.8 + S^* 0.5 + P^* 0.6 \qquad (1)$$

Here $T_{i,t}$ refers to ThIRST value for location i at the observed time t, M is soil moisture index, S is slope index, and P is seasonal precipitation forecast index. The value ranges for these indices are detailed in the Annex (from A1 to A4). Following the equation, a higher ThIRST output value indicates greater need for irrigation, a lower value indicates lesser need. For example, if the current soil moisture content is high and there is a high probability of normal rain forecast, the ThIRST tool will produce a low number indicating there is no requirement for irrigation, and any applied water would be a waste if implemented. However, if in the following weeks, there is no precipitation, soil moisture deficit will increase, making the ThIRST output increase when the farmer reruns the tool. Each component of the equation is weighted according to the importance in providing and maintaining water for the plant. To further help interpretation of the output, a recommendation on irrigation needs of the coffee plot is also given based on the ThIRST value (Annex A4). In addition, to make the output visually friendly, the ThIRST value is displayed in a traffic light color system for range of severity (Supplementary Figure A3).

3. Results

3.1. App to respond to farmers' needs

According to the baseline survey of 400 participants, the irrigation needs among farmers varied greatly across the regions; in Bao Lam district only 20 of 100 surveyed farmers irrigated their coffee, while all farmers in the Dak Lak Province depended on irrigation. This was confirmed during a workshop conducted in October 2019, where experts expressed that irrigation and water resources are more of a concern among farmers in more arid areas such as Dak Lak province, rather than in less arid areas in Lam Dong province. This also matched expectations based on the aridity index of the central highlands (Figure 1). Workshop participants also stated that there had been unpredicted changes in weather patterns in recent years and so the need for weather forecast and advisory is pressing. 87% (347/400) of the surveyed farmers have experienced changes in rainfall patterns and in the timing of the dry and rainy season; all of which affects irrigation practices. The most common coping strategy to these changes was to "irrigate more," as mentioned by 150 farmers of the 230 farmers who at least carried out one coping strategy. Meanwhile, only a very few farmers (11/400–3%) applied any kind of soil feel test to determine when to irrigate. Furthermore, when asked about the most important adaptation practices to reduce the amount of ground water used for irrigation, the most common answer was: "more accurate and timely weather forecasts to prevent having to irrigate just before it rains".

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1 https://deriskseasia.org/climate.html

The majority of farmers in the baseline survey still relied on word-of-mouth advice from friends, neighbors, and local input suppliers instead of traditional extension services or TV/internet-based advisory (Figure 2). This was further expanded in the WEFOCOS project workshop, in which local experts were asked about the information sources that coffee farmers in the Central Highlands use to make irrigation decision. Experts came to a consensus that in less arid areas, farmers mostly rely on informal information channels such as their own experience and friends' and neighbors' experience to define how much to irrigate. In more arid areas, farmers mostly rely on formal information channels such as advice from coffee traders and government extension officers. Regarding the usage of smartphone for agricultural advisory, even though 83% (331/400) of the surveyed coffee farming households had at least one smartphone, only 3% (13/400) stated that they receive information or advice on coffee farming from online sources and smartphone applications. This suggests a large information gap in the delivery of extension services, especially ICT-based extensions, revealing a unique opportunity to take advantage of the high rate of phone ownership to deliver extension to farmers in a more efficient way.

3.2. Use and uptake of irrigation advisory through the app
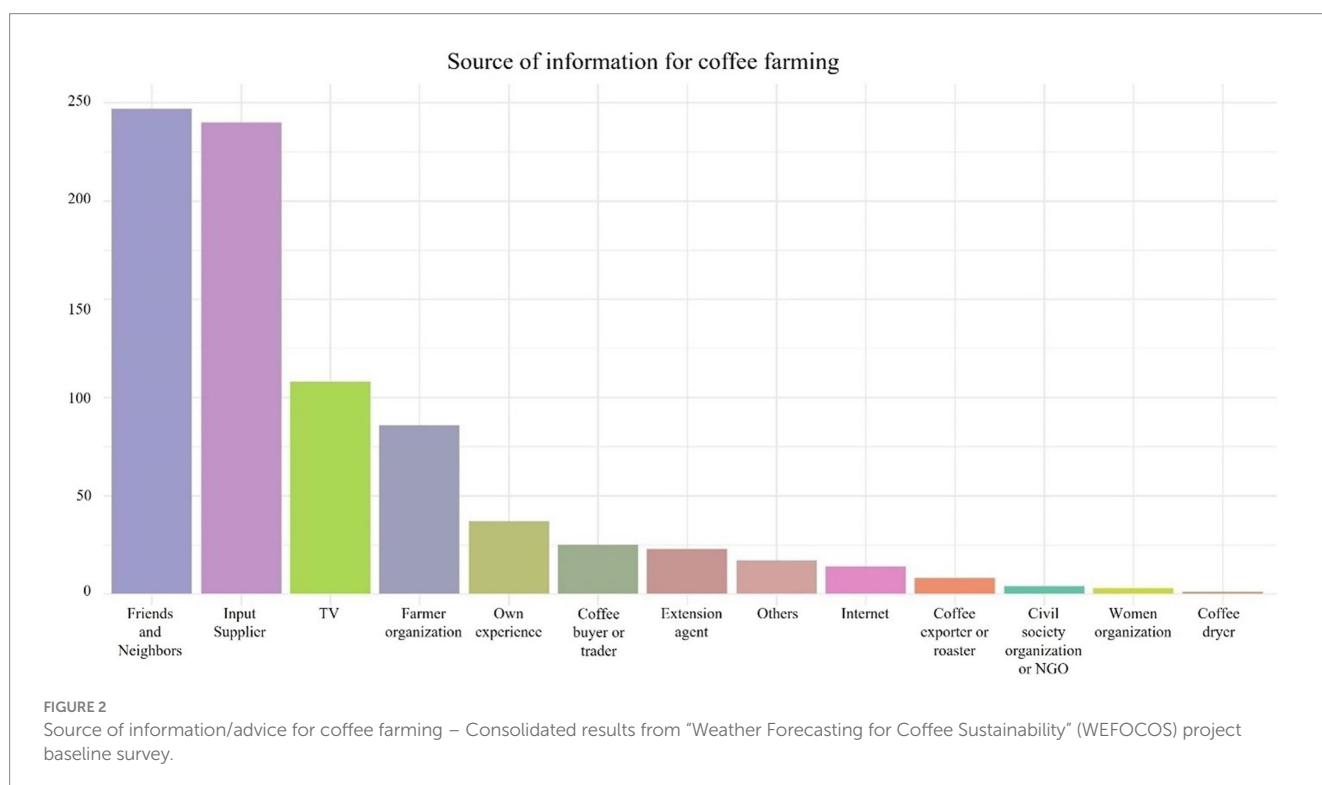
The endline survey was conducted in July 2022, 3 years after the baseline survey. Out of 400 farmers interviewed in baseline, 237 participated in the endline, 156 in Đắk Lắk and 81 in Lâm Đồng Province. The lower number of participants in the baseline survey was due to various reasons such as farmers transitioning to alternative crops, relocating to other places, and more. For instance, coffee farmers in Bảo Lâm district, who participated in the baseline study, had converted from coffee to vegetables in the period leading up to the dissemination of the smartphone application. Thus, these farmers were therefore not included in the endline survey.

Only around 5% (11/237) of the farmers reported using smartphones and the internet to get advice and information on agriculture and coffee farming. The majority of farmers still rely on information from input suppliers as well as their friends and neighbors. This is reflected in the number of farmers who use the app. 48 out of the 237 farmers in the endline survey originally installed rtWork in their smartphone, however, only 10 of them reported to currently have the app in their phone. In addition, very few farmers stated that they would look or had looked for another agricultural advisory app (4 and 5/237). In terms of modules in the app, of the 9 farmers having used ThIRST, 7 of them found it to be useful. When asked about the reasons making ThIRST useful, most of the users stated that it was easy to follow the advice (6/7), the others said that the information was well adapted to their needs (3/7) and the instruction video was quite informative (2/7). 12 out of 13 weather forecast users would find this module useful and 4 out of 12 farmers that used seasonal advisory made changes to their coffee farming. Among the 237 interviewed, around 10% (23/237) of the farmers reported making their irrigation decision based on soil feel test. This indicates an increase from the baseline, despite most farmers still irrigate to stimulate the coffee flowering process regardless of the current or upcoming weather conditions.

4. Discussion

Climate change and water use inefficiency has had significant negative impact on coffee production as well as the environment in

FIGURE 2
Source of information/advice for coffee farming – Consolidated results from "Weather Forecasting for Coffee Sustainability" (WEFOCOS) project baseline survey.

the Central Highlands of Vietnam (Byrareddy et al., 2020; Craparo et al., 2021). If inefficient water use practices continue, farmers' livelihoods and coffee production would be negatively impacted. Here, we elaborate how the ThIRST tool helps coffee farmers by (i) providing inexpensive, accessible scientific based recommendations on sustainable water use practices, (ii) taking into account the mismatch between the supply and demand of digital technologies, and (iii) building trust between farmers and the app. We also point towards improvements in the development and promotion of the app.

4.1. Inexpensive, accessible scientific based recommendations for increased sustainability

Our tool directly brings scientific based recommendations to users through their smartphones and translates the scientific information into actionable insights (Figure 3, English translation in Annex A5). Seasonal forecast information is delivered to its potential users through various channels. In Vietnam, seasonal forecast information is communicated nationally and regionally via radio and television, and via loudspeakers at local level (Coulier et al., 2018). Previous studies have demonstrated that internet access is associated with higher agricultural outputs, higher income, and higher adoption rate of sustainable practices (Kaila and Tarp, 2019; Kahsay et al., 2022; Nguyen et al., 2022; Zheng et al., 2022). However, there is a distinction between climate information access and use. Climate information itself does not relate to information use in management practice decisions. However, it is still unclear how this information is building end-users and farmers' adaptive capacity with regards to climate change and climate shocks (Nkiaka et al., 2019; Sen et al., 2021). In fact, regardless of the weather forecast, coffee farmers in the Central Highlands perceive irrigation as an insurance to maintain high yield levels, increasing the risk of draining water resources and impacting the environment (D'Haeze et al., 2005a,b; Byrareddy et al., 2021; Tran et al., 2021). Our tool makes seasonal forecast information easily available to farmers and importantly, incorporates farmers in the process of building recommendations. This innovative process aims to increase the usage rate of seasonal forecasts among coffee farmers.

In addition, the tool has made scientific information more actionable for farmers who can adjust and adapt their management practices. Due to a gap in advisory, seasonal forecasts are often perceived as complex scientific information and hard to interpret by various levels of users (Christel et al., 2018). ThIRST has been able to translate and simplify these complex seasonal forecasts into an index that farmers can combine with their knowledge on soil moisture and land slope to make more informed decisions on sustainable irrigation and water use. Thus, the tool bridges the gap between scientific information and practical recommendations.

A more accurate decision support tool would involve the use of soil moisture sensors. Moisture sensors such as Watermark, Acclima and Rain Bird have been used to time irrigation rounds more accurately, thus increasing water use efficiency (Cárdenas-Lailhacar and Dukes, 2012; Haley and Dukes, 2012; Evangelista et al., 2013). According to Haley and Dukes (2012), moisture sensor irrigation controllers reduce 2.5–4 unneeded irrigation events per month for turfgrass, while still maintaining the same quality. However, sensors are expensive for Vietnamese coffee farmers (Sharma, 2019). In the absence of such high technological investment, ThIRST has the potential to fill the information gap by providing inexpensive, easily accessible scientific based recommendations to improve water use efficiency.

4.2. Supply and demand of climate services

There is a gap in what is available and what farmers need (Bell-Pasht and Krechowicz, 2015; Sen et al., 2021). The production and supply of climate services rarely match with users' needs (McNie, 2012; Bell-Pasht and Krechowicz, 2015; Visscher et al., 2020). While designing a climate service, scientists and researchers would aim to inform adaptation for climate variability and change (Vaughan and Dessai, 2014; Tall, 2015). By utilizing ThIRST, farmers would have the ability to accurately refine irrigation rates, reduce stress on constrained water resources and in turn, reduce associated production costs (Technoserve, 2013; Byrareddy et al., 2021). However, we are aware that the current low use of the app is likely also affected by water for irrigation not being regulated and so far, not being a scarce resource for most farmers. We expect that as water becomes scarce due to extended period of excessive use and as rainfall patterns become even more erratic than today, farmers' incentives for using tools such as ThIRST and seasonal weather forecasts will increase.

4.3. Trust

Farmers lack trust in climate information (Sen et al., 2021; Simelton and McCampbell, 2021). Involving farmers during the design, production and evaluation of climate services can improve the trust and uptake of agro-advisory apps (Tall et al., 2014). Involving end users in app co-design increases the feeling of ownership, app usage and data quality (Brofeldt et al., 2018; Theilade et al., 2021). However, app developers tend to not include users/farmers in the development of the app and as a result, compromising the longevity of the app (Simelton and McCampbell, 2021). Because of this, farmers would not have enough trust in the app and therefore, the recommendations become less usable. Our tool addresses a part of this issue, in which it integrates seasonal forecast with farmers' knowledge, which is known to foster trust, local relevance and use (Tall et al., 2014).

4.4. Need for continuous improvements

it is also evident that the low number of currently active users of our app and the ThIRST tool means that the app is not having the intended impact. Firstly, even though smartphone use in Vietnam is high and a large proportion of the farmers in our study own a smartphone, most farmers prefer traditional methods of obtaining information from input suppliers and their neighbors, who farmers perceive to understand their production. Secondly, the endline survey showed that the number of farmers using soil feel tests has slightly increased. We believe that the low cost and convenience of this
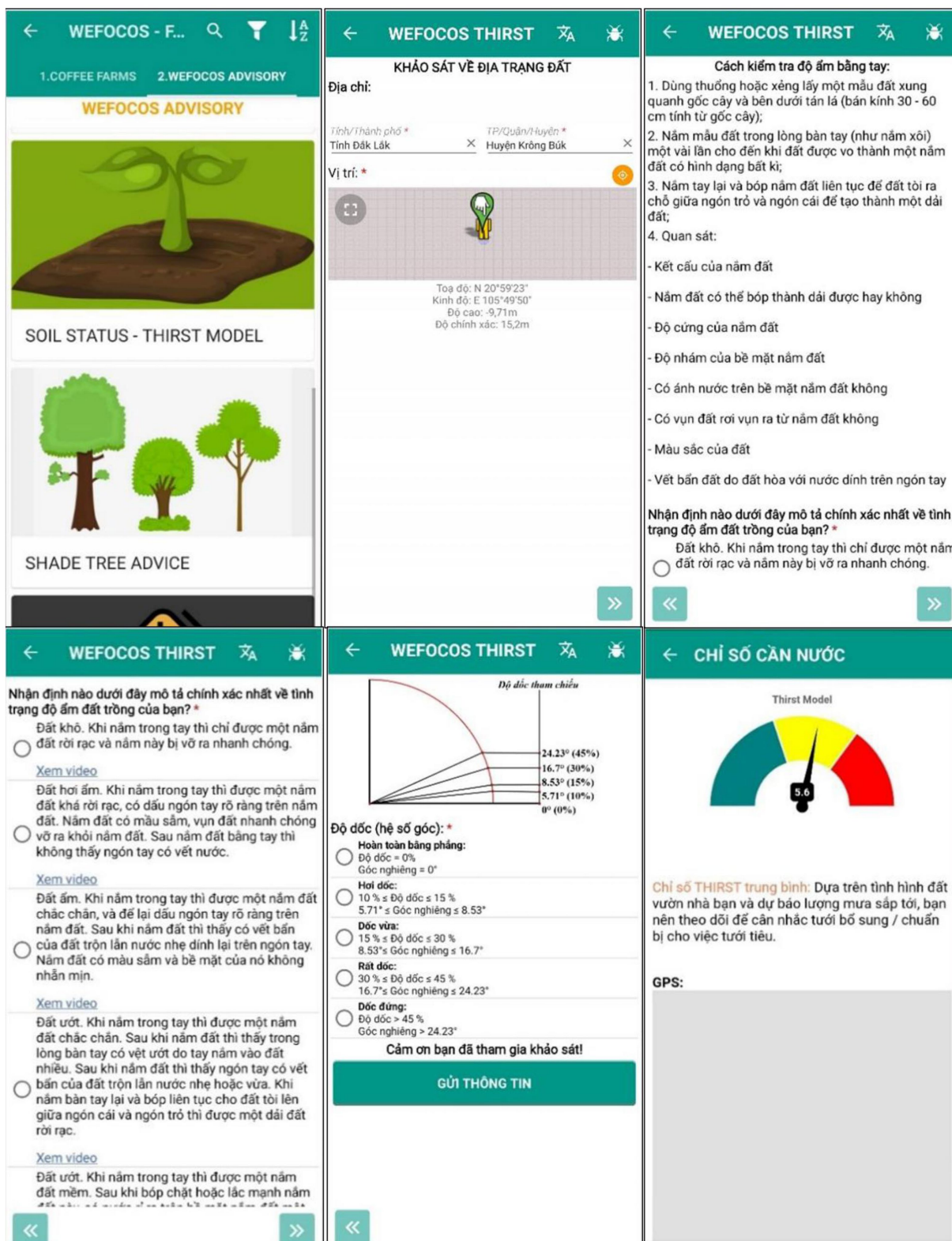
FIGURE 3
Screenshots of the ThIRST module inside the rtWork app, Vietnamese version, showing the start page, input pages, and result page (For explanations in English see section 2.3 Development of ThIRST model).

method shows its potential as a valuable tool for famers in water-sensitive areas. The low usage of soil feel tests also indicates that our documentation and guidance in the digital form in the app might not be an effective way to get buy-in from farmers. Thus, there is a strong

need for direct training and guidance in the field for coffee farmers. Thirdly, farmers lack trust in climate information (Sen et al., 2021; Simelton and McCampbell, 2021), which very likely also resulted in the low usage of the app and all the modules. One positive sign is that farmers, who used one or more advisory modules, i.e., weather forecast, seasonal advisory, shade tree advice, fertilizer advice, and ThIRST modules, find them useful and even use the advisory to make changes to their management practices. This again emphasizes that it requires direct training and guidance for farmers to strengthen the usage level and make a larger impact. Last but not least, further research should expand on the tool to devise a way to quantitatively measure the water saved.

5. Conclusion

As climate change exacerbates the sustainability of critical water resources in the Central Highlands of Vietnam, there is a need for a decision support tool to address information gaps on use water efficiency. Along with the wide-spread use of smartphones in Vietnam and the advance of ICT, the use of mobile apps for climate and extension services is becoming more feasible. The app-based ThIRST model was developed to provide inexpensive and accessible scientific based irrigation recommendations, to address the mismatch between the supply and demand of digital technologies, and to build farmers' trust and reliance in ICT-based climate services. ThIRST combines seasonal forecasts, on-farm metrics and farmer's expertise in an accessible digital tool that helps farmers answer pressing irrigation questions. Despite that only around 5% (11/237) of farmers reported using smartphones and the internet to get advice and information on agriculture and coffee farming, 77% of them found it to be useful. Therefore, confirming the potential of the app, despite the premature use of the technology in irrigation advisory in Vietnam. This advisory may be more applicable in coffee regions with higher digital service usage and could be further improved with digital soil moisture monitoring. In addition, the app provides advisory on different aspects of coffee farming such as fertilization, pest and disease management, intercropping, pruning, mulching, and registration of farm practices. The approach in this paper can serve as a basis training and capacity building guideline for extension workers and coffee farmers in water stressed coffee growing regions.

Data availability statement

The data analyzed in this study is subject to the following restriction: the co-authors are working on other publications and will publish the data once these publications are ready. Requests to access the dataset should be directed to Aske Skovmand Bosselmann/ University of Copenhagen, ab@ifro.ku.dk.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1267388/full#supplementary-material

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