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# Challenges of Estimation Precision of Irrigation Water Management Parameters Based on Data from Reference Agrometeorological Stations †

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**Abstract:** In this study, operational decision support systems (DSSs) for irrigation water management that utilize data from weather stations (W/S) or weather data services are presented. The challenges and the ways in which various systems address them are summarized based on a review of the relevant scientific literature and information provided on the websites of the systems under consideration. The selected systems that are presented are categorized into those that utilize W/S data (IRMA_SYS, CIMIS, BlueLeaf, CoAgMet) as well as those that employ remote sensing data (Manna irrigation, Irrisat, Sencrop). Remote sensing DSSs are included in this study because their functionality is closely related to that of W/S-based systems, as it is explained in the study. Additionally, Foreca and OpenET are also examined as they provide data to DSSs for irrigation management. The discussion about the challenges encountered in the use of DSSs based on W/S data aims to stimulate further research and development in this field by the scientific community and system developers.

**Keywords:** evapotranspiration; open-access; agrometeorological stations; remote sensing; weather stations



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## 1. Introduction

A Decision Support System (DSS) for irrigation water management is an essential tool for ensuring optimal water usage and crop growth. Many DSSs for irrigation management have adopted the approach of using data from evapotranspiration, precipitation, and irrigation in order to calculate water balance. The rate of evapotranspiration is influenced by several factors such as temperature, humidity, wind speed, solar radiation, soil water availability, and crop type.

The Penman–Monteith [1,2] method is a widely accepted standard for calculating evapotranspiration (ET) from meteorological data. Developed by Allen et al. [3], it is based on the energy balance at the land surface, which includes both the energy used for evaporation and transpiration. The method uses measurements of temperature, wind speed, solar radiation, and atmospheric pressure to calculate ET.

The FAO (Food and Agriculture Organization) Penman–Monteith method [3], also known as FAO-56, is a modified version of the Penman–Monteith method developed by the FAO to calculate crop water requirements. The FAO-56 method is based on the original Penman–Monteith method, but it includes some additional modifications and simplifications that make it more suitable for use in practical applications such as irrigation management. The FAO-56 Penman–Monteith method requires several meteorological measurements to calculate reference crop evapotranspiration ($ET_0$): Net radiation ($R_n$) at the crop surface, Soil heat flux (G), Air temperature (T), Actual vapor pressure ($v_p$), Saturation vapor pressure ($e_s$), Actual vapor pressure ($e_a$), Wind speed ($u_2$) at 2 m above the crop surface, Air pressure (P), Slope of the saturation vapor pressure–temperature curve ($\Delta$), and Psychrometric constant ($\gamma$). There are also many other methods to estimate $ET_0$ using less data that are referred below [4,5].

## 2. M/S Network Topology and $ET_0$ Calculation

The topology of a meteorological network for calculating reference crop evapotranspiration ($ET_0$) refers to the spatial arrangement of weather stations within the network and the method in which data from these stations are used to estimate $ET_0$. There are several different approaches to design a meteorological network topology, depending on the specific goals and objectives of the network, such as power and communication coverage. Some common approaches include [6]:

Density: Placing weather stations densely across the area of interest to achieve a high spatial resolution of weather data. This approach is useful for studying small-scale variations in $ET_0$ and microclimates.

Stratified: Dividing the area of interest into different regions or grid cells based on factors such as vegetation type, land use, or topography and placing weather stations in each stratum to represent conditions in that region. This is useful for studying large-scale variations in $ET_0$ and the effects of different land uses on $ET_0$.

Random: Placing weather stations randomly across the area of interest to achieve a representative sample of weather conditions. This is useful for studying the average $ET_0$ for an area.

Hybrid: Combining elements of the above topologies by using a combination of density, stratified, and random arrangements of weather stations.

Examples of use of meteorological networks and their topologies include Blueleaf [7] and Sencrop [8] using a density approach; CIMIS [9], IRMA_SYS [10] and CoAgMet [11] using a hybrid approach. Remote sensing systems such as Manna Irrigation [12] and Irrisat [13] use meteorological weather forecast models to estimate $ET_0$ and cannot be categorized into a specific type.

The Penman–Monteith FAO-56 method for calculating reference crop evapotranspiration ($ET_0$) relies on the availability of agrometeorological weather stations that measure various natural parameters. In situations where such stations are not available, $ET_0$ can be calculated using other models that make simplifying assumptions, such as Hargreaves, Hargreaves–Samani, Kimberly Penman, Makkink, Thornthwaite, Jensen–Haise, Blaney–Criddle, Priestley–Taylor, and Simplified Surface Energy Balance [14]. These models calculate ETo using more easily available quantities such as temperature, radiation balance, and remote sensing data such as NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature). Systems such as Blueleaf, Sencrop, IRMA_SYS, and CIMIS use the FAO-56 method for calculating $ET_0$, while the CoAgMet system uses the Kimberly Penman method.

W/S-based systems calculate $ET_0$ using their own data in various time steps and do not forecast $ET_0$. CoAgMet calculates $ET_0$ for any point using the data from the nearest W/S. IRMA_SYS and CIMIS use interpolation strategies to estimate $ET_0$ by taking into account the measurements of various weather stations. Remote sensing systems such as Manna Irrigation and Irrisat use meteorological data to form a virtual W/S at the unknown area of interest. Irrisat uses meteorological data produced by the Cosmo LEPs weather model of ECMWF [15], while Manna Irrigation takes the weather data directly from FORECA [16].

It is important to note that the provided weather information nowadays is a combination of multiband satellite images, ground-based weather stations, and mathematical forecast models. Although it may seem that W/S have been replaced by satellite weather data, ECMWF states that all meteorological models take into account the ground W/S of Europe to evaluate satellite measurements and initialize forecast models. In addition, FORECA [17] states the usage of national weather institutes' observations for their forecasts. Manna Irrigation and Irrisat suggest the implementation of an in situ weather station to improve their services. FORECA also uses any available W/S system to adjust errors in predicted meteorological values using simple or complex mathematical models. The accuracy of virtual weather station data is lower compared to in situ W/S, but Irrisat and Manna Irrigation take advantage of weather forecasts to project future $ET_0$ values in time. OPEN_ET [18] describes the challenges of calculating ET using satellite images and meteorological models and uses about 800 weather stations from grid-MET, Spatial CIMIS, DAYMET, PRISM, and NLDAS, and six different models to estimate ET. They also describe known issues such as reflection problems from large water masses, shadowed areas, cloud issues, model limitations, and resolution issues.

## 3. Water Balance—Challenges of Precipitation and Irrigation Water Calculations

Calculating $ET_0$ and the amount of water loss from crops is only half of the task in setting up an irrigation decision support system (DSS). The other half is calculating the amount of water available for crops, which mainly comes from both precipitation and irrigation water.

All W/S-based systems monitor rainfall straightforwardly by using rain gauges. However, measuring rainfall without a rain gauge near a field is challenging because rain is a highly localized phenomenon and cannot be simply calculated using interpolation methods. Systems such as Blueleaf, Sencrop, CIMIS, CoAgMet, and IRMA_SYS can be accurate, depending on the density of the W/S and the spatial distribution of rain. All weather-based systems retrieve irrigation water measurements, mostly from farmers by hand or automatically, to calculate the water balance and produce irrigation recommendations.

Remote sensing DSSs do not have accurate measurements from rain gauges, but meteorological data can provide rainfall timeseries to them. Both Irrisat and Manna Irrigation take into account precipitation forecasts and suggest the installation of weather stations with rainfall meters as an option. Irrigation water measurements can also be registered manually from farmers, but Irrisat and Manna Irrigation do not require rainfall and irrigation water information to produce recommendations.

Irrisat does not provide information about the implemented water balance estimation method. Manna Irrigation [19] uses a Kc-t (Crop coefficient versus time) plot to determine crop milestones and estimate the Kc progress for the current season. After that, using NDVI satellite measurements, the actual Kc is calculated and compared to the estimated Kc. It also refers to a predicted Kc and an AI method using meteorological data. Applying this methodology, Manna Irrigation calculates the water balance and produces irrigation recommendations.

None of the weather-based systems use remote sensing data or any type of weather forecast in the same way that remote sensing DSS does. It would be interesting to study and adapt remote sensing methods such as Manna Irrigation and Irrisat to improve their efficiency, as NDVI data are often unreliable due to cloud coverage and other parameters, as described analytically by the OPEN_ET system.

## 4. Resolution

The resolution of all systems refers to the minimum spatial area to which their conclusions can be applied. It is usually expressed in square meters or in hectares. There is no specific way for every system to certify their resolution. The results of a specific interpolation method can produce a different accuracy for different datasets coming from the same W/S network. In W/S-based systems, the resolution is dependent on the interpolation resolution. In remote sensing systems, the resolution is limited by the resolution of satellite images and the resolution of weather forecast models.

The spatial resolution of all systems can vary. For W/S-based systems, IRMA_SYS reports 200 m while CIMIS reports 2 km. For remote sensing systems, the Manna Irrigation resolution is 5 km, Irrisat reports $ET_0$ with a spatial resolution of 375 m, and that of OPENET is 33 m. Comparing the resolution of all systems, there is no sure conclusion about which type of system is more accurate or not.

## 5. Results and Conclusions

The study of operational Decision Support Systems (DSSs) for irrigation water management based on weather stations has yielded some useful results. DSSs can be classified into those that use in situ data and those that use remote sensing information. Despite this, weather stations are still necessary for remote sensing systems, as remote sensing data rely on in situ measurements for evaluation and there is often an option/suggestion for the installation of a weather station in the field of interest.

All systems use the evapotranspiration method ($ET_0$) to calculate crop water needs. To calculate the water balance, all systems require or have the option of irrigation water volumes to be added from farmers. Remote sensing systems face the challenge to accurately estimate precipitation. Manna Irrigation is the only remote sensing system that describes the actual method used to produce irrigation suggestions. It also has a unique approach to estimate water balance using Kc values and the correlation between Kc and the NDVI index.

Remote sensing systems introduced the concept of virtual weather stations by using meteorological data to measure $ET_0$, incorporating forecasting methods and AI algorithms to produce results. IRMA_SYS has also adopted the method of a virtual weather station based on the interpolation of measurements that can be placed virtually on a field.

The spatial resolution of the systems varies. Theoretically, W/S-based systems are expected to be more accurate due to the use of actual measurements compared to the combination of satellite and meteorological data. A simultaneous comparison between systems on the same field, using several benchmarks against actual data, could provide a means for evaluating their performance.

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