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Review Article

Utilization of Remote Sensing and GIS Techniques for Diagnosing Irrigation Water Resources: A Review

Zainab Fakhri Merzah[1], Sokina Fakhry[2] and Hussein Sabah Jaber[3]*

[1]*Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq*

[2]*Al Furat Intermediate School for Girls, Ministry of Education, Babylon, Iraq*

[3]*Assistant Professor, Department of Surveying Engineering, University of Baghdad, Iraq*

***Corresponding Author:** Hussein Sabah Jaber, Assistant Professor, Department of Surveying Engineering, University of Baghdad, Iraq.

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Abstract

Irrigation has the largest share of water exploitation. Therefore, it is vital to access the irrigation performance in any region of the world. Furthermore, estimation of the evapotranspiration and evaluation of the Irrigation performance by using the traditional methods represented by the field measurements is very difficult. The integrated monitoring, diagnosing and assessment of the irrigation systems required the use of effective tools that enable the decision makers to study large area and analyses large number of the variables that concerns the processes of monitoring and assessment.

The remote sensing and GIS techniques are considered as an efficient technique that can be used for achieving such works. This paper reviews main topics directly related to diagnose irrigation water resources in Iraq using remote sensing and GIS techniques. It reviews and discusses the previous studies on diagnosing water resources using remote sensing and GIS. Also, it presents and synthesizes the methods and approaches used for estimation of evapotranspiration (ET) from remote sensing data and identifies the advantages and disadvantages of the previous studies on the evaluation of performance of irrigation systems. More ever, it reviews the important studies on rainfall-runoff modelling using GIS technique.

Keywords: Remote Sensing; GIS; Irrigation Performance; SEBAL; Evapotranspiration

Introduction

Previous and recent predictions show that there will be in the near future a significant decrease in water withdrawals on a global scale [1]. More seriously, this decrease will be followed by an increase in water demand for urban, industrial, environmental sectors and agriculture. To reduce the effects from this problem, remote sensing and geographic information systems (GIS) are widely utilized to better manage water resources around the world. The largest water consuming sector accounting around 69% of the water withdrawal is agriculture. Therefore, more research on water resources and developing realistic solutions for agriculture sectors are highly required.

Irrigation is a vital input for effective and maintainable agricultural production. Improving water utilization through effective and economical irrigation water management is the primary key for increasing food gain production [2]. Better water management saves water demands for other uses and improves agriculture productivity. Scientific literature shows that the importance of agriculture water management through various and wide range of studies conducted and published in the last decades. GIS and RS are the core tools used for approximating ET [3], optimization water utilization [4], and water resource management [4,5], assessing irrigation performance [6], runoff-rainfall modelling [7], and estimating water balance models for different size catchment areas [8].

The unique vital for the populations of the countries in the Euphrates and Tigris basins is water [9]. In Iraq, water is a vital value for economic sectors such as agriculture and industry.

This paper is organized as follows. First, a brief introduction on diagnosed irrigation water resources will be given. Then, a discussion on evapotranspiration and various methods to estimate ET from field and remote sensing data will be presented. After that, various studies on assessing performance of irrigation systems using remote sensing will be explained. Finally, studies on runoff-rainfall modelling using remote sensing and GIS will be summarized and discussed.

GIS and remote sensing for diagnosing irrigation water resources

Water plays a major and vital role in meeting the demand for food for the growing population and irrigated agriculture was considered as a major user of water in the world [10]. Diagnosing the causes of water lack in complex water resources is a necessity to approve active water resources management. GIS and remote sensing are the tools that could be used for diagnosing water resources at different spatial scales and temporal periods [2]. Discussed the importance of GIS for irrigation water resources. They argued that most of the irrigation water management and monitoring data are complex and spatially related. GIS provides efficient tools to deal with such data complexity. GIS also found to be very useful by the authors for spatial and temporal data visualization and mapping. This visualization and mapping usually help farmers and irrigation experts for better and faster decision-making. They also discussed the capability of ArcGIS software from ESRI for water management especially irrigation water through various spatial data supported tools. ArcGIS also can be customized through model builder and/or python scripting to suit with specific applications. Further details on these issues, the reader can read in [2].

In addition, a GIS allows users to combine and integrate all types of spatial and attributed data and out them in one framework [11].

On the other hand, few studies have presented the vital of RS for managing irrigation. The first active uses of satellite explanations in water resources were established in the early 1980s [12] Remote sensing provides high spatial-temporal satellite images, which are helpful for information extraction and understanding the relationships among various parameters. In another paper, [13] concluded that remote sensing is a great toll for water management. In his study, Landsat 8 data was used to identify the irrigated areas and to assess the identified areas using remote sensing-based indicators such as Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). The study confirmed that Landsat 8 played a great contribution to the water management and to the evaluation the irrigated areas identified before. Figure 1 illustration sequence of procedures required to understand satellite spectral measurements.

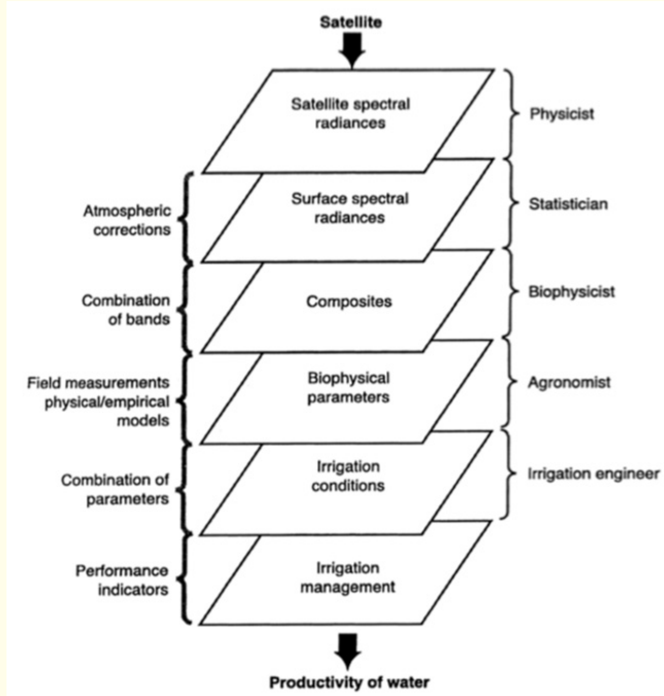

Figure 1: Disciplines and sequence of procedures needed to interpret satellite spectral measurements for use in practical water management.

Several studies used GIS and remote sensing techniques for diagnosing water resources. According to [14]. Others believe that deficiencies in design of irrigation projects and in technologies are the causes of poor performance of irrigation [15]. New technologies are steps towards target water security in the future. Those measures are not solely sufficient to cope with water scarcity in where population increase exceeds the water resources development. In addition, [16] presented an innovative method to explore water management options in irrigated agriculture using remote sensing and optimization techniques. RS was used to approximation the irrigation properties and management practices.

Estimation of evapotranspiration (ET) using remote sensing technique

Methods of estimation of et from field and remote sensing data

There are several methods and techniques developed by researchers to estimate ET either from field measurements or remote sensing data. In a recent paper, [17] reviewed and discussed the remote sensing approaches to estimate ET and described their advantages and disadvantages. The author mentioned several methods and algorithms for estimating ET from remote sensing data. Emprical direct methods was first explained. These methods assess the energy balance using land surface properties such as albedo, canopy cover, leaf area index and surface temperature. These factors can be estimated by remote sensing data. Second, residual methods were presented in the paper. However, ground-based weather data are necessary to introduce the results for the longer periods of daily or monthly records. Some models have been presented and engaged to study the spatial variation of radiance and reflectance. Surface energy balance algorithm for land (SEBAL), Surface energy balance index (SEBI), Simplified surface energy balance index or S-SEBI, Two-source energy balance or TSEB are the most common approaches used. Thirdly, inference methods are also discussed in their study. The inference method generally uses vegetation indices. After that, deterministic methods were explained for estimating actual ET from remote sensing data. This technique is rely on the conventional soil, vegetation, atmosphere transfer (SVAT) models. SVAT simulates the interaction between vegetation canopy, the given land surface reflectance and the environment. Table 1 shows the advantages and disadvantages of the studied methods and models for estimating ET based on remote sensing data which was presented in their study. [18] reviewed the SEBAL and SEBS models for evapotranspiration estimation from remote sensing data for South African examples. The review showed that SEBAL model is widely used for ET estimation which was found mostly applied for water use efficiency studies. On the other hand, SEBS models was found to be available as part of open source ILWIS software and could be used to estimate ET from remote sensing data in South Africa. In terms of remote sensing data, the review indicated that Landsat data is more suitable than MODIS data. Landsat data has moderate spatial resolution while MODIS has low spatial resolution which subsequently affected the accuracy of ET estimated. In contrast, Landsat was found to be suitable for estimation of ET. As the SEBS is open freely in a variety of packages, its use for teaching and training purposes. Figure 2 shows the components of the evapotranspiration process.

Method/ Model	Advantages	Disadvantages
Empirical direct	Operational from local to regional scales	Spatial variation of coefficients
Interference model	Operational if combined with ground measurement methods or models	Requires calibration for each crop type
Residual (SEBAL, S-SEBI)	Low cost Needs no additional climatic data	Kc varies according to water stress Requires detection of wet and dry pixels
Deterministic (SVAT)	Permits estimation of intermediate variables such as LAI Possible links with climate and/or hydrological models	Requires more parameters Requires accurate remote sensing data

Table 1: Advantages and disadvantages of ET estimation models and methods adopted from [17].

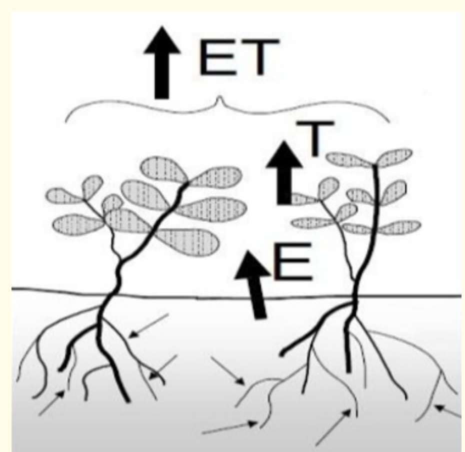

Figure 2: Describes the components of the evapotranspiration (ET) Process.

Review of SEBAL model for ET estimation

[19] described the major principles of SEBAL and summarized its accuracy under several climate conditions and spatial areas. Beside the study showed the ability of remote sensing to estimate actual ET, it showed the accuracy of 85% at field scale for 1 day and an accuracy of 95% on a seasonal basis could be achieved. This conclusion was based on estimation the evapotranspiration over 30 countries around the world. This paper showed the superiority of SEBAL models for ET estimation using remote sensing and me-

teorological data. However, other researchers further investigated this model under different climate conditions and environments. Some of these studies are summarized and discussed in this section.

[20] presented a study on estimating actual ET from remote sensing data (MODIS) using SEBAL model. The SEBAL model was modified to estimate the sensible heat flux from only wind speed data. this process was simplified and application of SEBAL for estimating ET from satellite images.

In another paper, [21] integrated remote sensing and GIS modelling for estimating actual ET in Paphos District of Cyprus. SEBAL model was used to investigate its capabilities in the local soil and meteorological conditions of the study area. In terms of data, remote sensing data from Landsat TM and ETM+ sensors were used to retrieve the needed spectral information. SEBAL model was enhanced by developing empirical equations determined in the study from field data.

[22] discussed the analysis of remotely sensed data for estimating components of surface energy balance and validated the results obtained from SEBAL model. Remote sensing data from NOAA-AVHRR sensor was collected for the estimation of fluxes using SEBAL model. On the other hand, field data was collected in Brazil during the summer of 1999 and the satellite pass date. Results from SEBAL model and field measurements were compared and the accuracy evaluation indicated that the average errors are less than 4%, 6%, and 7% for net surface radiation, surface heat and latent flux estimations, respectively.

Moreover, [23] validated SEBAL model for the estimation of ET over areas in the western United States. The model done well in terms of Nash-Sutcliffe efficiency (NSE) coefficients (daily = 0.82, monthly = 0.77). Figure 3 and 4 show the sequences of energy balance.

Other methods for ET estimation

In addition to SEBAL model, there are other methods developed for ET estimation from remote sensing data for different climate conditions and environments. These methods are also important here to be reviewed and discussed. In this section, some of these methods are discussed.

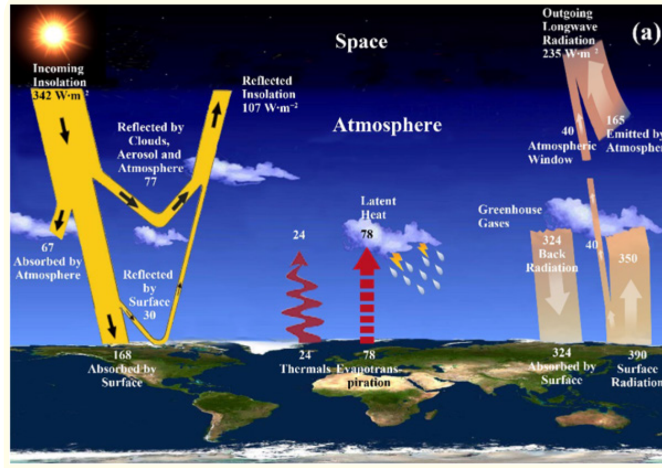

Figure 3: Diagram of the global mean annual energy balance of the Earth.

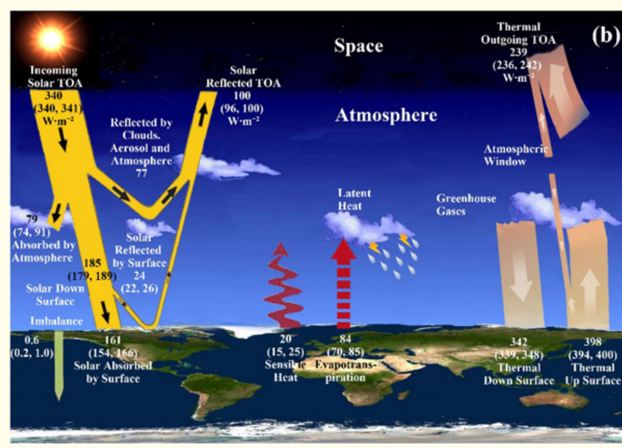

Figure 4: Diagram of the global mean annual energy balance.

[24] studied the use of SEBS rely on ASTER data and field observations for estimating ET over Coleambally Irrigation Area, Australia.

[25] studied a new manner to valuing unstressed ET rely on the ability of vegetation indices in southern Spain. High spatial resolution images were applied to find vegetation indices such as (SAVI).

[26] expected the temporal and spatial variations of ET for different land cover types in China. First, remote sensing data from Landsat, high-resolution satellite images were downloaded from USGS website over the study area and processed using (METRIC) model for estimating ET.

[27] shown a study to fix the suitability of different techniques namely cubic spline, fixed, and linear for estimating seasonal ET from RS data. ET was estimated using METRIC model and the modified wet MATRIC model at high resolution [28]. Parametrized aerodynamic in METRIC model for estimating ET in Spain. The model proposed in their study was compared with FAO-56 soil-water balance-based ET model.

Evaluation of irrigation performance by RS and GIS

Irrigation performance is essential not only because it avoids water insufficiency or saves water. An suitable management of irrigation rises the good use of water resources and reductions the environmental effects in irrigated areas [29].

In addition, irrigation performance assessment is considered one of the important elements for improving irrigation management [30]. conducted a study on the assessment of irrigation performance in an arid area using remote sensing-based method. The performance assessment of the twin main canals of the Gezira Scheme located in Sudan (an arid area) were examined and evaluated using a set of performance indicators. These indicators were water productivity, relative water supply, overall consumed ratio, depleted function, and relative ET. In terms of spatial data, Landsat remote sensing data were used to estimate land ET. Then the climate data were combined to estimate the mentioned indictors. ET was estimated by using SEBAL model utilizing the Landsat images. The results showed that the predicted ET from SEBAL model has reasonable agreement with the field measured ET.

[31] evaluated the irrigation performance in the Lower Gediz Basin in Turkey where RS procedures were applied and the performance was evaluated based on five indicators. These indicators were overall consumed ratio (ep), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD) and relative evapotranspiration (RET). RS data was applied to estimate the potential and actual evapotranspiration using SEBAL.

[32] developed a combined approach for evaluating irrigation system performance in semi-arid climate area (Iran) using different practices. The study evaluated irrigation systems from various types cover an area of (2000 ha) based on the study of internal irrigation processes and considered by both classical and no-classical efficiency.

[33] assessed the operational performance of the irrigation in Uzbekistan to support recommendations for strategic water management planning where some indicators were applied to measure this performance. Relative evapotranspiration (RET), delivery performance ratio (DPR), drainage ratio (DR), and depleted fraction (DF) were applied as performance indicators.

[34] showed a study on irrigation performance assessment for some areas in India using RS and GIS and based on some indicators to evaluate this performance.

[35] assessed the irrigation performance of the Gezira Scheme located in Sudan. Both field data and remotely sensed images were collected and used for the assessment of the studied irrigation system. The study used some indicators for the assessment were: Relative Irrigation Supply (RIS), and Relative Water Supply (RWS). Furthermore, Water Use Efficiency (WUE) is applied to evaluate the water productivity.

[36] valued the performance of the irrigation system in Pakistan. The evaluation was based on large spatial and temporal scales for reallocation of water resources in the irrigation system. First, evaporative fraction was determined by SEBAL model using MODIS images. Second, differences in consumptive water use. The main findings of the study were as following: SEBAL model results were comparable with the advection aridity methods based on the accuracy assessment conducted.

[37] evaluated the irrigation performance in the upper Amu Darya Delta by combining some of spatially distributed data that derived from multitemporal MODIS data. The remote sensing is acceptable for this performance.

[38] studied the performance of irrigation systems using remote sensing in Spain during the 2004-2005 irrigation season based on some indicators that required ET input data which were calculated using METRIC model.

[39] used remote sensing techniques to estimate crop evapotranspiration for irrigation performance evaluation in Morocco. Crop evapotranspiration for the study area was extracted from satellite images using the FAO-56 dual approach with relationships

between crop by physical variables and NDVI. Satellite images from high spatial resolution SPOT and Landsat sensors were obtained. The performance of the irrigation was evaluated using some indicators. This study revealed how remote sensing provide better assessments of irrigation performance than traditional field survey methods.

[40] analyzed the performance of irrigation scheme in Niger in Mali. The large scale rice based irrigation system was analyzed using remote sensing technology. In order to evaluate the performance, four indicators which entirely based on remote sensing were applied at different organizational levels of the system. SEBAL model was used integrated with high resolution satellite images from Landsat sensor to calculate rice production and water consumption over the study area.

[41] demonstrated the importance and the use of remote sensing technology for the estimation of water consumption and water stress. Several remote sensing based indicators were used for the assessment of irrigation performance using MODIS data.

[42] integrated groundwater parameters with energy fluxes in GIS to evaluate irrigation systems in (Greece). The procedure delivered the parameters needed for irrigation system despite the limited availability of actual water measurements.

[43,44] developed a combined approach based on irrigation performance analysis and water accounting to evaluate the performance of an irrigation scheme in USA based on a soil survey to obtain the data required to simulate the water flows. Results showed insights to funding the decision-making processes of farmers, water user associations, and policy makers.

Runoff-rainfall modelling review

Runoff-rainfall modelling using curve number (CN) method

Curve number (CN) shows runoff potential of land and it is the function of hydrologic soil group, antecedent rainfall, land use pattern, and conservation practices followed in the land [45]. Estimated runoff for different watersheds using CN method. ''The SCS-CN approach is a theoretical model of hydrologic abstraction of storm rainfall, provided by experimental data. Its aim is to assess direct runoff volume from storm rainfall depth, rely on CN''. RS with GIS techniques help to gather, analyze and understand the multidisciplinary data rapidly on large scale. These techniques can augment the old method to a great extent in rainfall-runoff modelling and can be successfully utilized to increase accuracy in estimation of CN for a watershed.

[46] argued that GIS and remote sensing are useful tools for estimating runoff depths because runoff depth requires spatial modelling and includes geomorphologic variations. Run off curve was determined based on several factors. Landsat images were used to derive land use for the study area. Spatially distributed runoff CN and runoff depth were determined for the watershed.

[47] modelled the runoff-rainfall relationship in Egypt using remote sensing and GIS techniques. Based on the factors which CN method depends on, GIS and remote sensing were found to be suitable tools for such analysis. On the other hand, Landsat TM, ETM+ data was used to derive the land use of the study area. Soil maps and derived land use classified image were used to estimate curve number. In addition, slope map was derived from 30m DEM derived from ASTER to adjust the curve number and correct it for topography effects. The study showed the suitability of GIS and remote sensing techniques for runoff-rainfall modelling. Remote sensing data help tremendously in SCS-CN model.

[48] evaluated the potential water harvesting using CN method and GIS techniques. The spatial analysis of GIS and a continuous runoff potential accounting procedure, based on the SCS-CN was used to determine the suitable site for water harvesting. FAO suggests the FAO-56 Penman-Monteith method as the standard for the calculation of ETO, but its application is limited by the relatively high demand of meteorological data which are not always available.

[49] estimated the CN method using GIS and RS technique in a micro watershed Buriganga, Assam. hydrologic soil groups, land use and slope map has been created using GIS. To create CN map, the CN values from NRCS Standard Tables were selected to intersected hydrologic soil groups and then to estimate runoff depth for selected storm events in the micro watershed.

Other method based on soft computing for runoff-rainfall modelling

[50] studied the relationship between rainfall-runoff in an experimental watershed in Turkey using statistical and artificial neu-

ral network methods. The performance of the two studied methods was measured and discussed. The results presented that the ANN, FFBP provided closer flow estimations reproducing the shape of the observed hydrograph more realistic. The advantage of FFBP was reflected in the performance assessment criteria.

[51] showed rainfall-runoff for a small casement in Turkey using 4 years of measurements of independent variables of rainfall -runoff. The models used in the study were (ANNs), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Gene Expression Programming (GEP).

[52] designed a Mamdani-type fuzzy logic to simulate daily discharge as a function of soil moisture and rainfall and its applied in central Italy. For each variable of soil moisture, 9 fuzzy subsets were engaged while 30 fuzzy rules, relating the input variables to the output variable were optimized.

Other method based on GIS and hydrological models for runoff-rainfall modelling

[7] studied the vital of information on runoff in any area. Supporting information on runoff is a vital step for locating run off-generating areas and finding areas within a catchment where surface water is created. Also, highlighted the use of GIS as a tool to facilitate runoff estimation.

[53] showed a GIS distributed rainfall-runoff model that capable for handling the catchment heterogeneity in terms of distributed information. Model inputs such as slope, flow direction, and overland flow sequencing are created for each cell of the catchment using a digital elevation model.

[54] presented a hydro-informatic modelling system (HIMS) rainfall-runoff model for semi-arid region.

[55] studied a GIS-based automated semi-distributed model (SDISTA) that is intended for engineering applications in semi-arid regions. SDISTA is a simple model that reconsiders the time-area technique using an improved approach.

[56] modelled ET and runoff for the island of Sjaelland which covers 7330 km2 in Denmark. The modelling was ready at multiple spatial scales. Remote sensing data from EOS/MODIS was used to map thermal to find the dynamic canopy coefficient of urban regions.

[57] suggested a modification to simple monthly water balance by integrating potential ET with land use coefficients to calculate runoff at basin scale. The Ep was estimated using temporal satellite images in Godavari Basin, India.

[58] assessed the performance of three hydrological models, suitable as hydrological planning tools in rural engineering projects. Runoff in both models is depended on the CN approach.

[59] combined watershed simulation with GIS to evaluate the influence of changes of land cover on the properties of runoff in Kerala, India. SWAT model is found to be suitable for this purpose as many GIS integration modules are available for this model.

[60] assessed temporally and spatially the water allocation in Nganjuk District. The study analyzed the land cover, water balance, and irrigation well density using GIS and remote sensing methods where water balance analysis based on CN method.

Conclusions

Previous studies discussed the importance of using GIS and remote sensing for agriculture water resources management and analysis. GIS and remote sensing found useful tools that could be used for improving water utilization and development effective and economical methods for diagnosing and assessing irrigation performance. In addition, irrigation water management and monitoring data are complex and spatially related. GIS provides efficient tools to deal with such data complexity. On the hand, GIS tools could improve the regularly computation of performance indices to provide irrigation managers and decision makers useful information about the status of irrigation systems. On the other hand, some studies have revealed the significance of remote sensing for irrigation water resources management. Remote sensing provides high spatial-temporal satellite images, which are helpful for information extraction and understanding the relationships among various parameters.

The literature review revealed that there are several methods and techniques to estimate ET either from field measurements or remote sensing data. Also, some models have been presented and engaged to study the spatial variation of radiance and reflectance. SEBAL, SEBI, S-SEBI, SEBS, and TSEB are among the most popular methods used. However, the literature review showed that SEBAL has the advantages of low cost, and no needs additional climate data. In addition, SEBAL widely used for ET estimation and mostly applied for water use efficiency studies. But these models require detection of wet and dry pixels from satellite images which makes it sensitive and careful selection of those pixels are highly important.

In terms of spatial resolution of satellite images, the conclusion from the literature review suggested in complex, semi-arid environments that Landsat TM, ETM+, OLI images were found to be suitable for estimation of ET because of high-resolution images.

Irrigation performance is essential not only because of it avoids water scarcity or saves water. An suitable management of irrigation rises the good use of water resources and reduce the environmental effects in irrigated areas. Several indices based on remote sensing were found to be useful for irrigation performance assessment.

In terms of runoff-rainfall modelling, SCS-CN method was observed as a widely used method. SCS-CN was used for approximating the runoff depth and water balance.

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