

# A Review on Remote Sensing as A Tool for Irrigation Monitoring and Management

## ABSTRACT

Remote sensing has played a vital role in advancement of agriculture and is effective technical method for agriculture crop management. It is a technology which acquisite information regarding objects on earth surface as well as atmosphere from a distance without being in contact with the object. Researchers have proved its high potential with accuracy in the field of agriculture. After various experiments, the qualitative and quantitative assessment of soil, crop and atmosphere demonstrated the better understanding between the crop and its management practices. The collected spatial and temporal data via various passive and active sensors has been utilized not only for morphological study but also for monitoring the vegetation moisture content. The paper reviews about the potential studies carried out to investigate the water content in plant to make use in irrigation management. Diverse spectral reflectance indices have been mentioned from which special emphasis on NDWI has been given. It is an index which is used in remote sensing to assess the crop water status and can be utilized in efficient operation of irrigation to improve water use efficiency (WUE) in agriculture. **In order to make irrigation practices more efficient by making the lab restricted irrigation scheduling methods like IW:CPE method applicable in regular practice by using remote sensing.** This paper firstly identifies areas where researches and techniques have real-world application. Next, it identifies actual issues that remote sensing could address and solve with further research and its related development. **All opportunities for managing agricultural water resources effectively to be explored and made successful through precision agriculture.** Using the fast, impartial and reliable information offered by remote sensing is a significant difficulty in the field of water resource management.

Keywords: Precision Agriculture, Remote Sensing, NDWI, Water use efficiency (WUE)

## 1. INTRODUCTION

**To meet** the emerging demand of food grains for present as well as future generation, it is important to manage our resources especially water as only 3% of total water on earth is fresh water. The sudden climate change made it compulsory to conserve water in sustainable, efficient and precise manner. In crop production, among various management practices like nutrient management, disease and pest management, irrigation management plays a vital role and hence a large amount of water **(upto 30-40%)** is used for the production of crop (Seckler et al., 1998). It is not an easy task to manage such situation with high degree of pollution with environment degradation, the possible way to overcome will be by incorporating new technologies to gather precise information of water resources and its reliable management practices with accuracy. Conventional irrigation practice involved the irrigation application based on either set schedule or visual observations. This approach has lead to under or over-irrigation

which could be harmful to crop and also the wastage. Presently, Remote Sensing emerged as an automated technology with acquisition of spectral data based on reflectance at varied wavelength and provide us readily available vegetation, land cover, or soil imagery. It makes it more accessible to the scientists to cover large area with site specific information by satellite constellations, MODIS (Moderate Resolution Imaging Spectroradiometer), LANDSATs, MERIS (Medium Resolution Imaging Spectrometer), AVHRR (Advanced Very High Resolution Radiometer) and aerial photography, to capture and analyze figures, based on which it characterizes the vegetation (Ozdogan, 2010). The space-borne sensors are capable to capture data of million hectares of area at a time and provide particulars related to farmers field or nearby water resources such as river basins, irrigation channels to fasten the decision making.

Remote Sensing collectively gathers spatial (varied resolution) and temporal data (satellites revisiting intervals of 15-25 days) by using sensors that senses multiple spectral bands of electromagnetic spectrum. The specific wavelengths of electromagnetic spectrum are found to be sensitive towards the moisture content that makes possible to predict the moisture content in crop plant (Stimson et al., 2005). The reflectance values integrate in such a manner to give various indices viz. vegetation indices (NDVI), soil adjusted indices (SAI), Chlorophyll indices (CI), water indices (WI) etc. These reflectance-based indices have numerous implementations, NDVI is commonly used in agriculture for various purposes (Calvao and Palmeirium, 2004; Wallace et al., 2004) like assessing the condition of vegetation (Rouse et al., 1973), Normalized difference water index (NDWI) obtained by combining green spectral wavelength reflectance and near infrared reflectance been used in agricultural, hydrological and environmental monitoring. NDWI estimates moisture content that assists practitioners to understand the dynamics of water and its impact on the crop yield. It facilitates in determining the exact amount of water required by the plant to avoid excess and deficit use of water. Similarly, water stress in crop can also be identified and utilized for précised water management. This paper consists of the information about the remote sensing and NDWI application for irrigation management. The initial part provides the basic information of remote sensing highlighting normalized differential water index. Finally, discussion about the applied areas of water index for irrigation management in relation with the water content estimation in crop.

## **2. REMOTE SENSING: AN INTRODUCTION**

Remote sensing collects spatial and temporal data and provides an information of entire land cover and with GIS (Geographic Information System) it outlay the data in the form of imagery (single spectral or multiple spectral imagery). It provides timely and repetitive data to continuously monitor the changes in the vegetation, atmosphere or environment (Justice et al., 2002). Now the question arises in what form does the data is collected? The answer is reflected, dispersed or refracted light provides the information about the earth surface and different targeted object in the form of reflectance. The electromagnetic

spectrum (Visible, NIR, SWIR and microwave regions) hits the objects and response differently, that distinguishes the soil, vegetation, water and other entities present on earth. Remote sensing has various applications in agriculture like weather forecast, land cover, land mapping, monitoring disease and pest and by combining it with the simulation models it manifests in yield prediction. It is a cost-effective alternative for acquiring information of large geographical area (De beurs and Townsend, 2008). Automated approaches are included in the remote sensing for the visual interpretation of satellite data (Thiruvengadachari, 1981; Kolm and Case, 1984; Keene and Conley, 1980; Haack et al., 1998). In visible and NIR regions of EMS (Electro-magnetic Spectrum), irrigated field exhibit high spectral difference from the harvested as well as fallow lands, which is advantageous for the irrigation researches. Even research by (Thiruvengadachari, 1981), showed that although it is more difficult to differentiate different crop kinds, irrigated lands by surface water from ground water by visual interpretation through single Landsat Imagery. The EMR readings obtained are used in vegetation indices. That are derived by adding, subtracting, dividing or multiplying the reflectance of specific wavelengths that can be very helpful in discriminating crops but also differentiating based on the irrigation sufficiency or deficiency. Although interpretation of satellite images visually is helpful, but recent works focused on digital clarification of images, because processing time is faster and mapping expenses are less, making it more cost effective. The classification based on index values will be more advantageous as they eliminate the surrounding mixing of data and being precise in nature. The unsupervised learning, multiple- stage classification (Thelin and Heimes, 1987; El-Magd and Tanton, 2003), flow chart classification (Simonneaux et al., 2008), clustering (Thelin and Heimes, 1987; Eckhardt et al., 1990; Kauth and Thomas, 1976), density slicing classification (Ozdogan et al., 2006; Manavalan et al., 1995; Starbuck and Tamayo, 2007) are some methods used for classifying the digital images. The plant type, water content, pigmentation, chlorophyll content are some intrinsic factors that create variation in reflection pattern of light that causes variation and eventually classify the crop and their conditions. The following spectra of electromagnetic radiation and factors affecting the reflection of spectrum (Bal et al., 2021)

- (i) Visible region (350nm to 750nm): leaf pigmentation affects the reflection.
- (ii) Near infrared region (750nm to 1300nm): cell structure of plant affects the reflection; the total internal reflection is the major reason for maximum reflectance at NIR.
- (iii) Shortwave infrared (more than 1300nm): water content in plant affects the reflection

### **3. NORMALIZED DIFFERENTIAL WATER INDEX (NWDI)**

There are different indices like NDVI (Normalized differential vegetation index), Chlorophyll index (CI), SAVI (Soil Adjusted Vegetation index), WI (water index) etc. These indices have various application in mapping, drought monitoring and assessing vegetation health as well as productivity (Doraiswamy et al., 2005; Ferencz et al., 2004; Prasad et al., 2006). NDWI is one index in remote sensing

used to evaluate the presence of vegetation water content. It is commonly used in agriculture to help monitor and quantify changes in water content in crops. The vegetation spectrum reflectance at 0.9 to 1.3 $\mu\text{m}$  wavelength band is very sensitive towards the water content in the leaf (Lillesaeter, 1982). High water content in vegetation cause absorption of electromagnetic spectrum (it's a property of water to absorb radiation) due to which differentiation between the vegetation based on water can be observed in spectral reflectance curve of the vegetation. The emission value not only contains the reflective value of target object but contains disturbances or surrounding area and noises to nearby objects. NDWI is less sensitive towards the atmospheric disturbances or noises in reflectance (Gao BC, 1996). This index does not completely remove the soil reflectance noise but it provides accurate value of water content present in the canopy. It differentiates the irrigated and non-irrigated areas in the satellite images. The multi-temporal NDWI features such as its range and maximum value are set to thresholds to distinguish the crop fields. If the NDWI observations are at hand from several years and of same season, it is possible to identify crops and their changes in irrigated areas. The value of NDWI ranges from -1 to +1. Higher value of the NDWI indicates a higher water content in the vegetation, which is important information for monitoring crop health, irrigation needs, and also drought conditions. It assesses the water content and as per the requirement of water by plant the irrigation can be planned.

### NDWI Computation

Normalized difference water index (NDWI) can be formulated by using the two spectral bands near-infrared region (NIR) and green bands (visible region).

$$\text{NDWI} = \frac{(\text{Green} - \text{NIR})}{(\text{Green} + \text{NIR})} \text{ (U.S. Geological Survey)}$$

This normalization process helps to minimize the impact of atmospheric effects and sensor noise on the NDWI values.

Also,

$$\text{NDWI} = \frac{\{R(0.86\mu\text{m}) - R(1.24\mu\text{m})\}}{\{R(0.86\mu\text{m}) + R(1.24\mu\text{m})\}} \text{ (Gao BC, 1996)}$$

Where,  $R(0.86\mu\text{m})$  is the Reflectance at 0.86 $\mu\text{m}$  wavelength

$R(1.24\mu\text{m})$  is the reflectance at 1.24 $\mu\text{m}$  wavelength

The analysis of water content in the vegetation can help in making decision related to when and how much irrigation is needed by the plant. There are various studies and researches carried out in respect to find out the moisture content in the crop, some of them are mentioned in Table 1.

## **Crop Monitoring:**

Irrigation system administrators should ideally incorporate routine performance monitoring into their management strategies. In the section of operations, this is covered in more detail. Sometime a problem's nature or intricacy calls for a more thorough diagnosis. To find performance constraints in such cases, consultants or researchers are contacted. When consultants are aware of prospects, satellite remote sensing, particularly in vast complicated areas, can be cost-effective tool for diagnosing and determining the performance of irrigation.

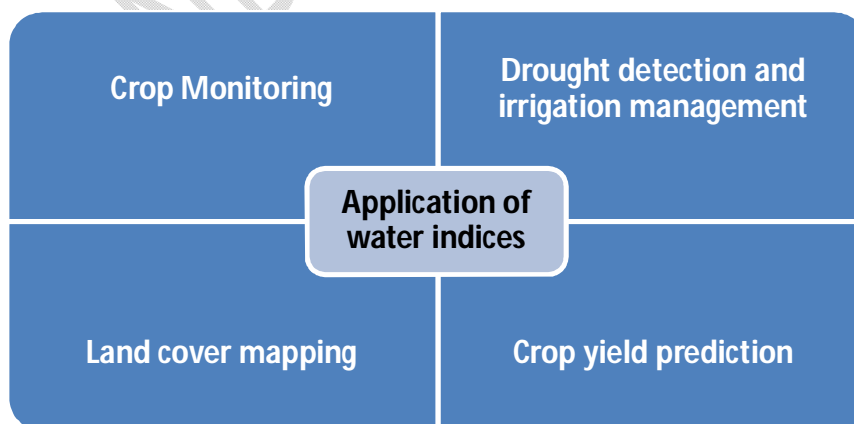
The timely data collected by satellites of different resolution capacity (Landsat, CARTOSAT-2, Resourcesat-2 etc.) with GIS, presented it in imagery form and the data is converted into NDWI value-based imagery. Thus, comparing different crops and classifying them on the basis of NDWI gives comparative information about vegetation. The rays of electromagnetic spectrum are able to penetrate the object and provide information regarding intrinsic factors of crop. Such as, relative water content of crop which is a best yardstick to determine moisture stress status, as stated by (Slatyer, 1967 and Chaves et al., 2002) at different stages of crop growth. The hyperspectral characterization, differentiation and mapping of crop according to its biochemical and biophysical property (Thenkabail et al., 2013) is highly beneficial in studying the innate properties. These relative details about crop provides knowledge wide range of figures like water availability, nutrient stress, moisture stress, pest and disease infestation indicating crop health status which results in efficient monitoring and mapping of crop.

## **Drought Detection and Irrigation Management**

Remote sensing provides informative data not only to monitor crop but also diagnose stress in the crop (Kingra et al., 2016). The spectral reflectance pattern results in detection of water stress in crop (Menon, 2012). When it comes to irrigation management the question arises when to apply? How much to apply? How to increase the efficiency of human and cover large area? The answers to these queries are provided by many scientists (Stimson et al., 2005; Serrano et al., 2000) by working on different crops and spectral indices, they registered relation between water content in plant and spectral indices (water indices). Its vegetation indices become less sensitive to soil background reflectance and atmospheric disruptions like SAVI (Soil Adjusted Vegetation Index) or SARVI (Soil and Atmosphere Resistant Vegetation Index), the application of vegetation indices can be improved. The complete review on this is mentioned in detail by (Rondeaux et al., 1996). The value of NDWI indicates water stress and sufficiency, high values indicate the water sufficient condition and low value shows water stressed condition. This water index is the best solution to help farmers, respond to water stress more effectively. The use of remote sensing gives promising results. The involvement of aerial vehicle or drones, either automated or manually controlled in remote sensing for immediate action in irrigation has better result and provide well timed irrigation management.

**Table 1. Water index and their association with water content in diverse plant species.**

Water Index	Study and conclusion	Reference
NDWI	The water content of vegetation and observed at field and laboratory and found NDWI highly associated with water content of plant.	(Gao BC, 1996)
NDWI, SRWI and PWI	Used MODIS (satellite spectrometer and stimulated different models to evaluate the water content in vegetation and found the sensitivity of indices in correspondence to the biomass thickness of leaf, and LAI.	(Zarco-Tejada and Ustin, 2001; Zarco-Tejada et al., 2003)
NWI-1, NWI-2, NWI-3 and WI	Demonstrated the potential association of NWI-3 with leaf water potential ( $\psi_{leaf}$ )	(Gutierrez et al., 2010)
NDWI and NDVI	The satellite imagery (Landsat) based on NDWI proved better for mapping of vegetation moisture content with $r^2=0.44-0.68$ on corn and soybean crop.	(Jackson et al., 2004)
WI, NWI-1, NWI-2, NWI-3 and NWI-4	The WI and NWI-2 were observed to have maximum variability with grain yield and biomass yield of 92% and 78% respectively under varied IW: CPE levels and also these indices proved to be better for yield prediction in wheat	(Bal et al., 2021)



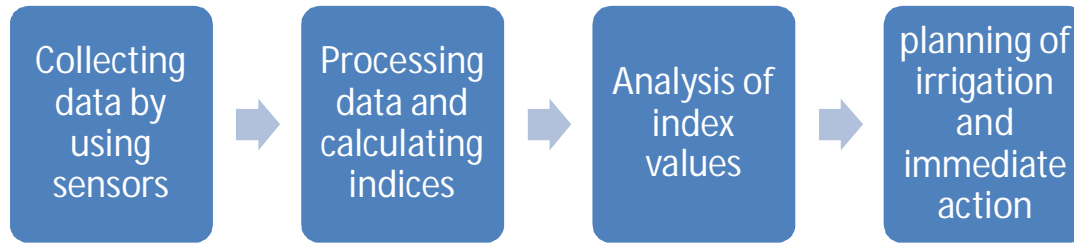
**Fig.1 Application of remote sensing and water indices**

## **Crop Yield Prediction**

Modeling crop growth simultaneously is made appealing by the idea of incorporating remote sensing data into mathematical/ physical agricultural yield models (Bouman, 1992). For instance, evapotranspiration from crop and LAI from remote sensed data were utilized by (Moran et al., 1995) to update the parameters of a field-scale crop simulation model for yield based on physiological characters. Simplified statistical relationships can be employed in their place, if such crop growth models or input data, they require are unavailable. In the heading stage of crop, single data NDVI pictures have proven to be very profitable (Murthy et al., 1996; Thiruvengadachari and Sakthivadivel, 1997). Using these crop yield models for estimating the crop yield in advance can be very helpful in deciding the crop and its management to make agriculture a beneficial occupation with sustainable resource management. Remote sensing by using satellite data can also help in yield prediction (Doraiswamy et al., 2005; Bernerdes et al., 2012). Remote sensing data have shown a major statistical and empirical relationship with crop yield and water indices to predict yield (Bal et al., 2021). Water index is used in predicting the grain yield of different genotypes of wheat under sufficient and deficit irrigation conditions, and (Prasad et al., 2007) presented the yield for wheat (winter wheat) in rain-fed condition using the Normalized Water Index (NWI) and Water index (WI) manifesting water stress can negatively impact crop growth and production these spectral indices can predict the yield and benefit the farmers (the prime beneficiary).

## **Land Cover Mapping**

The mapping of the characterized objects on the earth surface is best source to observe and assess the large area in short time. These satellite data-based images are beneficial for visual interpretation due to their spectral transformations (Ozdogan et al., 2006; Eckhardt et al., 1990; Pax-Lenney et al., 1996; Kauth and Thomas, 1976; Starbuck and Tamayo, 2007). In particular NDWI proves to be an indispensable in identifying the irrigated areas and differentiate between the irrigated and non-irrigated conditions. Also, to identify and map different types of land cover, such as crop lands, wetlands, and forests after eliminating surrounding noises or disruptions of soil, surrounding or atmospheric disturbances. NDWI which eliminates majority of disruptions and provide precise values indicating the crop status with regard to moisture status in crop is a good tool for diagnosing the irrigation need. The remote sensing data-based image that locates the distinctive areas and classify the areas according to the stress conditions signifying the water need places. NDWI that shows the water content in plant makes it easy to find the water stressed condition in plants and mark the irrigation scheduling. (Anderson et al., 2004) used the ASIRIS an air-borne imagery for soybean and corn to estimate the water content in crop. In summary, NDWI is a valuable tool for farmers and researchers to understand the water status of crops, which can have a significant impact on crop health, yield and overall food production.



**Fig. 2 Series of collection and analysis of data**

#### **4. CONCLUSION**

Conclusively, remote sensing provides vastly applied data for classifying the crop and detecting the crop water status which is useful in diagnosis of water stress conditions and make management of irrigation easy. The timely monitoring of crop health and effective measure to be taken with precision. Reflectance based NDWI value gives information regarding the moisture availability that is used in making decision in water stress management of the crop. The researchers have recorded the correlations of spectral indices with water content in crop, LAI, grain or biomass yield or other crop factors. Thus, NDWI gives comparative value of water content so, there is a need of more researches to be carried out for several years and for similar season to estimate the threshold value for its practical application in agricultural irrigation.

#### **References**

- Anderson MC, Neale CMU, Li F, Norman JM, Kustas WP, Jayanthi H, Chavez J. Upscaling ground observations of vegetation water content, canopy height, and leaf area index during SMEX02 using aircraft and Landsat imagery. *Remote Sensing of Environment*. 2004;92:447-464.
- Bal SK, Wakchaure GC, Potekar S, Choudhury UB, Choudhary RL, Sahoo RB. Spectral signature-based water stress characterization and prediction of wheat yield under varied irrigation and plant bio-regulator management practices. *Journal of the Indian Society of Remote Sensing*. 2021;49(6):1427-1438.
- Bernardes T, Meriera MA, Adami M, Giarolle A, Rudorff BFT. Monitoring biennial bearing effect on coffee yield using MODIS remote sensing imagery. *Remote Sensing*. 2012;4:2492-2509.
- Bouman BAM. Linking physical remote sensing models with crop growth simulation models applied for sugar beet. *International Journal of Remote Sensing*. 1992;14:1-19.

- Calvao T, Palmeirim JM. Mapping Mediterranean scrub with satellite imagery: biomass estimation and spectral behaviour. *International Journal of Remote Sensing*. 2004;25:3113-3126.
- Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CPP, Osorio ML, Carvalho I, Faria T, Pinheiro C. How plants cope with drought in the field? Photosynthesis and growth. *Annals of Botany*. 2002;89:907-916.
- De beurs K, Townsend P. Estimating the effect of gypsy moth defoliation using MODIS. *Remote Sensing of Environment*. 2008;112:3983-90.
- Doraiswamy PC, Sinclair TR, Hollinger S, Akhmedov B, Stern A, Prueger J. Application of MODIS derived parameters for regional crop yield assessment. *Remote Sensing of Environment*. 2005;97:191-202.
- Eckhardt DW, Verdin JP, Lyford GR. Automated update of an irrigated lands GIS using SPOT HRV imagery. *Photogrammetry Engineering and Remote Sensing*. 1990;56:1515-1522.
- El-Magd IA, Tanton TW. Improvements in land use mapping for irrigated agriculture from satellite sensor data using a multi-stage maximum likelihood classification. *International Journal of Remote Sensing*. 2003;24:4197-4206.
- Ferencz CS, Bognar P, Lichtenberger J, Hamar D, Tarcsai GY, Timar G, Molnar G, Pasztor SZ, Steinbach P, Szekely B, Ferencz OE, Ferencz-Arkos I. crop yield estimation by satellite remote sensing. *International Journal of Remote Sensing*. 2004;25(20):4113-4149.
- Gao BC. NDWI – A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water From Space. *Remote Sensing of Environment*. 1996;58:257-266.
- Haack B, Wolf J, English R. Remote sensing change detection of irrigated agriculture in Afghanistan. *Geocarto International*. 1998;13:65-75.
- Jackson TJ, Chen D, Cosh M, Li F, Anderson M, Walthall C, Doraiswamy P, Hunt ER. Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans. *Remote Sensing of Environment*. 2004;92:475-482.
- Justice CO, Townshend JRG, Vermata EF, Masuoka E, Wolfe RE, Saleons N, Ray DP, Morisette JT. An overview of MODIS land data processing and product status. *Remote Sensing of Environment*. 2002;83:3-15.

- Kauth RJ, Thomas GS. The tasseled cap: graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, West Lafayette, IN, USA. 1976;41-51.
- Keene KM, Conley CD. Measurement of irrigated acreage in western Kansas from Landsat images. *Environmental Geology*. 1980;3:107-116.
- Kingra PK, Majumder D, Singh SP. Application of Remote Sensing and GIS in Agriculture and Natural Resource Management Under Changing Climatic Conditions. *Agricultural Research Journal*. 2016;53(3):295-302.
- Kolm, KE, Case HL. The identification of irrigated crop types and estimation of acreages from Landsat imagery. *Photogrammetry Engineering and Remote Sensing*. 1984;50:1479-1490.
- Landsat Soil Adjusted Vegetation Index. U.S. Geological Survey, [usgs.gov.com](http://usgs.gov.com).
- Lillesaeter O. Spectral reflectance of partly transmitting leaves: laboratory measurements and mathematical modeling. *Remote Sensing of Environment*. 1982;12:247-254.
- Manavalan P, Kesavasamy K, Adiga S. Irrigated crops monitoring through seasons using digital change detection analysis of IRS-LISS 2 data. *International Journal of Remote Sensing*. 1995;16:633-640.
- Menon ARR. Remote sensing applications in agriculture and forestry. A paper from the proceedings of the Kerala environment congress. 2012;222-235.
- Moran MS, Maas SJ, Pinter PJ. Combining remote sensing and modeling for estimating surface evaporation and biomass production. *Remote Sensing Reviews*. 1995;12:335-353.
- Murthy CS, Thiruvengadachari S, Raju PV, Jonna S. Improved ground sampling and crop yield estimation using satellite data. *International Journal of Remote Sensing*. 1996;17(5):945-956.
- Ozdogan M. Mapping crop types from temporal unmixing of MODIS data: The case for Independent Component Analysis. *Remote Sensing of Environment*. 2010;114:1190-1204.
- Pax-Lenney M, Woodcock CE, Collins JB, Hamdi H. The status of agricultural lands in Egypt: The use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment*. 1996;56:8-20.
- Prasad AK, Chai L, Singh RP, Kafatos M. Crop yield estimation model for Iowa using remote sensing and surface parameters. *International Journal of Applied Earth Observation and Geoinformation*. 2006;8(1):26-33.

- Prasad B, Carver BF, Stone ML, Barbar MA, Raun WR, Klatt AR. Genetic analysis of indirect selection for winter wheat grain yield using spectral reflectance indices. *Crop Science*. 2007;47:1416-1425.
- Rondeaux G, Steven M, Baret F. Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*. 1996;55:95-107.
- Rouse JW, Haas RH, Schell JA. and Deering DW. Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS Symposium, NASA. 1973;351(1):309-317.
- Seckler D, Amerasinghe U, Molden D, de Silva R, Barker R. World water demand and supply, 1990 to 2025: scenarios and issues. Research Report 19, International Water Management Institute, Colombo, Sri Lanka. 1998;40 pp.
- Serrano L, Filella I, Peñuelas J. Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. *Crop Science*. 2000;40:723-731.
- Simonneaux V, Duchemin B, Helson D, Raki E, Olioso A, Chehbouni A. The use of high-resolution image time series for crop classification and evapotranspiration estimates over an irrigated area in central Morocco. *International Journal of Remote Sensing*. 2008;29:95-116.
- Starbuck MJ, Tamayo J. Monitoring vegetation change in Abu Dhabi Emirate from 1996 to 2000 and 2004 using Landsat satellite imagery. *Arab Gulf Journal of Scientific Research*. 2007;25:71-80.
- Stimson HC, Breshears TDD, Ustin SL, Kefauver SC. Spectral sensing of foliar water conditions in two co-occurring conifer species: *Pinus edulis* and *Juniperus monosperma*. *Remote Sensing of Environment*. 2005;10:23-32.
- Thelin GP, Heimes, FJ. Mapping Irrigated Cropland from Landsat Data for Determination of Water Use from the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming; US Geological Survey Professional Paper; USGS: Washington, DC, USA. 1987.
- Thenkabail PS, Mariotto I, Gumma MK, Middleton EM, Landis DR Huemmrich KF. Selection of Hyperspectral Narrowbands (HNBs) and Composition of Hyperspectral Two band Vegetation Indices (HVIs) for Biophysical characterization and Discrimination of crop types using field reflectance and hyperion/EO-1 data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 2013;68:427-439.
- Thiruvengadachari S, Sakthivadivel R. Satellite remote sensing techniques to aid irrigation system performance assessment: a case study in India. Research Report 9, International Water Management Institute, Colombo, Sri Lanka. 1997;23pp.

Thiruvengadachari Satellite sensing of irrigation patterns in semiarid areas-An Indian study. Photogrammetry Engineering and Remote Sensing.1981;45:1493-1499.

Vegetation Indices to Drive Digital Agri Solutions. EOS Data Analytics, eos.com. 2022

Wallace JF, Caccetta PA, Kiiveri HT. Recent developments in analysis of spatial and temporal data for landscape qualities and monitoring. Australian Ecology. 2004;29:100-107.

Zarco-Tejada PJ, Rueda CA, Ustin SL. Water content estimation in vegetation with MODIS reflectance data and model inversion methods. Remote Sensing of Environment. 2003;85:109-124.

Zarco-Tejada PJ, Ustin SL. Modeling canopy water content for carbon estimates from MODIS data at land EOS validation sites. In: Proceeding of the 2001 international geoscience and remote sensing symposium. 2001;(1):342-344.

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