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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

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A GEOSPATIAL APPROACH TO MANAGING IRRIGATION WATER RESOURCES OF THE BIG ALMATY CANAL

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Abstract. *Relevance.* The article focuses on the geospatial analysis of water resources of the Big Almaty Canal in the Almaty Region of Kazakhstan. The study area is characterized by a diverse landscape, including mountains, hills, valleys, combined with a continental climate featuring hot, dry summers, cold winters, moderate autumns, gradually warming springs. Summer precipitation is limited, generally not exceeding 40 mm, while winter snow accumulation in the surrounding mountains plays a key role in replenishing water resources and supporting irrigation.

Originally, the Big Almaty Canal was constructed to irrigate approximately 174.6 thous.ha of agricultural land. However, due to socio-economic changes, climatic variability, and inefficiencies in water management, the irrigated area has decreased to around 80 thousand hectares. The existing water management system faces challenges related to water shortages, uneven distribution, and suboptimal use of irrigation potential. *Purpose.* This study explores the application of remote sensing techniques to improve water use efficiency and support sustainable irrigation planning.

Methods. Satellite imagery from Sentinel-1, Sentinel-2, and Landsat-8/9, combined with field observations and historical water use data, was applied to assess irrigated lands, classify crops, analyze the water balance. The study identifies geospatial patterns in water resource distribution, evaluates irrigation efficiency, provides recommendations for optimizing water use while accounting for the district's climatic and topographical characteristics.

Results and conclusions. Spatial analysis of actual evapotranspiration (ETa) revealed that calculated water requirements were lower than tabulated values used by BAC (FAO method), while demand-supply assessment indicated a spatial overabundance of water in several areas. Crop coefficients derived from spatially distributed ETrF were lower than FAO standard Kc values. Backscatter analysis showed significant correlation with NDVI, enabling assessment of crop growth stages. Integrating NDVI and SAR backscatter data provides a comprehensive spatial understanding of crop development, enhancing crop monitoring, yield estimation, and precision agriculture practices, and ultimately supporting informed landscape-level decision-making in water resource management.

Keywords: geospatial analysis, remote sensing, water resources, climate, crop water demand, irrigation efficiency

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ГЕОКЕҢІСТІКТІК ТӘСІЛ НЕГІЗІНДЕ ҮЛКЕН АЛМАТЫ КАНАЛЫНЫҢ СУАРУ СУ РЕСУРСТАРЫН БАСҚАРУ

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Аннотация. *Өзектілігі.* Мақала Қазақстанның Алматы облысындағы Үлкен Алматы каналының су ресурстарын геоқкеңістіктік талдауға арналған. Зерттелетін аймақ әртүрлі ландшафтымен сипатталады: таулар, төбелер, өзен аңғарлары және ыстық, құрғақ жазымен, суық қыспен, жұмсақ күзбен және біртіндеп жылынатын көктеммен сипатталатын континенттік климатқа ие. Жазғы жауын-шашын шектеулі, әдетте 40 мм-ден аспайды, ал таулардағы қысқы қар қалыңдығы су қорларын толықтырады және суару үшін маңызды.

Бастапқыда Үлкен Алматы каналы шамамен 174,6 мың га ауыл шаруашылығы жерлерін суарумен қамтамасыз еткен. Алайда, әлеуметтік-экономикалық өзгерістер, климаттық құбылмалылық және су ресурстарын басқарудағы кемшіліктер нәтижесінде суарылатын жер көлемі шамамен 80 мың га-ға дейін қысқарды. Қолданыстағы су пайдалану жүйесі судың жетіспеушілігі, тең бөлінбеуі және суару потенциалын тиімсіз пайдалану сияқты мәселелерге тап болуды. *Мақсаты.* Бұл зерттеу тиімді су пайдалану және тұрақты суару жоспарын жасау үшін қашықтықтан зондтау әдістерін қолдануды қарастырады.

Әдістері. Суарылатын жерлерді бағалау, дақылдарды классификациялау және су балансын талдау үшін Sentinel-1, Sentinel-2 және Landsat-8/9 спутниктік деректері, алқаптық бақылаулар және тарихи су пайдалану деректері қолданылды. Зерттеу су ресурстарының геоқкеңістіктік үлгілерін анықтауға, суарудың тиімділігін бағалауға, климаттық және топографиялық жағдайларды ескеріп, суды пайдалануды оңтайландыру бойынша ұсыныстар жасауға мүмкіндік береді.

Нәтижелері мен қорытындылары. Нақты булану (ETa) кеңістіктік талдауы көрсеткендей, есептелген су қажеттілігі ВАС (ФАО әдісі) кестелік мәндерінен төмен, ал сұраныс пен ұсыныс талдауы кейбір аймақтарда судың артық болуын анықтады. ETrF негізінде есептелген дақыл коэффициенттері ФАО стандартты Kc мәндерінен төмен болды. Радиолокациялық кері шашырау талдауы NDVI-пен айтарлықтай корреляция көрсетті, бұл дақылдардың өсу сатыларын бағалауға мүмкіндік береді. NDVI және SAR деректерін біріктіру дақылдардың дамуын кешенді геокеңістіктік түрде түсінуге, мониторинг дәлдігін, өнімділік бағалауды және егін шаруашылығы тәжірибесін жақсартуға, ландшафттық деңгейде су ресурстарын басқаруды негізді жүргізуге мүмкіндік береді.

Түйін сөздер: геокеңістіктік талдау, қашықтан зондтау, су ресурстары, климат, дақылдардың су қажеттілігі, суды пайдалану тиімділігі

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ГЕОПРОСТРАНСТВЕННЫЙ ПОДХОД К УПРАВЛЕНИЮ ОРОСИТЕЛЬНЫМИ ВОДНЫМИ РЕСУРСАМИ БОЛЬШОГО АЛМАТИНСКОГО КАНАЛА

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Аннотация. *Актуальность.* Статья посвящена геопространственному анализу водных ресурсов Большого Алматинского канала в Алматинской области Казахстана. Территория характеризуется разнообразным ландшафтом горами, холмами, долинами, и континентальным климатом с жарким, сухим летом, холодной зимой, умеренной осенью и постепенно теплеющей весной. Летние осадки ограничены и обычно не превышают 40 мм, тогда как зимний снежный покров в горах восполняет водные ресурсы и поддерживает орошение.

Первоначально канал обеспечивал орошение около 174,6 тыс. га сельскохозяйственных земель. Вследствие социально-экономических изменений, климатической изменчивости и недостатков управления водными ресурсами орошаемая площадь сократилась до примерно 80 тыс. га. Существующая система водопользования сталкивается с проблемами нехватки воды, неравномерного распределения и неоптимального использования ирригационного потенциала. *Цель.* Исследование рассматривает применение методов дистанционного зондирования для повышения эффективности водопользования и устойчивого планирования ирригации.

Методы. Для оценки орошаемых земель, классификации культур и анализа водного баланса использовались спутниковые данные Sentinel-1, Sentinel-2 и

Landsat-8/9, полевые наблюдения и исторические данные о водопотреблении. Исследование выявляет геопространственные закономерности распределения водных ресурсов, оценивает эффективность орошения и формулирует рекомендации по оптимизации водопользования с учетом климатических и топографических условий.

Результаты и выводы. Пространственный анализ фактической эвапотранспирации (ETa) показал, что рассчитанная потребность в воде ниже табличных значений BAC (метод ФАО), а анализ спроса и предложения выявил локальное превышение водных ресурсов. Коэффициенты культур, рассчитанные по ETrF, ниже стандартных Kc ФАО. Анализ радиолокационного обратного рассеяния показал значимую корреляцию с NDVI, позволяя оценивать стадии роста культур. Интеграция NDVI и SAR обеспечивает комплексное пространственное понимание развития посевов, повышает точность мониторинга, оценки урожайности и практик точного земледелия, поддерживая обоснованное управление водными ресурсами на ландшафтном уровне.

Ключевые слова: геопространственный анализ, дистанционное зондирование, водные ресурсы, климат, водопотребность культур, эффективность использования воды

Introduction. Due to the arid and semi-arid climatic zone, the main part of South Kazakhstan agricultural lands need irrigation water systems. The area of the research is Karaturuk region, which belongs to the irrigated area of the Big Almaty Canal shown in Fig.1. The Big Almaty Canal was built in the 1980s to irrigate croplands for 174.6 thousand ha, the length of the canal is 168.2 km. The current irrigated area was reduced to approx. 80 thousands ha due to different social-economic and climatic reasons. One of the main gaps that the water department of Big Almaty Canal has is water use planning for irrigation using remote sensing inputs. The crop inspection is done by field work. Water use plan is based on the farmers orders, reports and field measurements. The research authorities experience the problem of deficit supply or underutilization of created irrigation potential every year. With this background, the present work is taken up to explore the potential of remote sensing in improving the water management in the irrigated command area of Big Almaty Canal project.

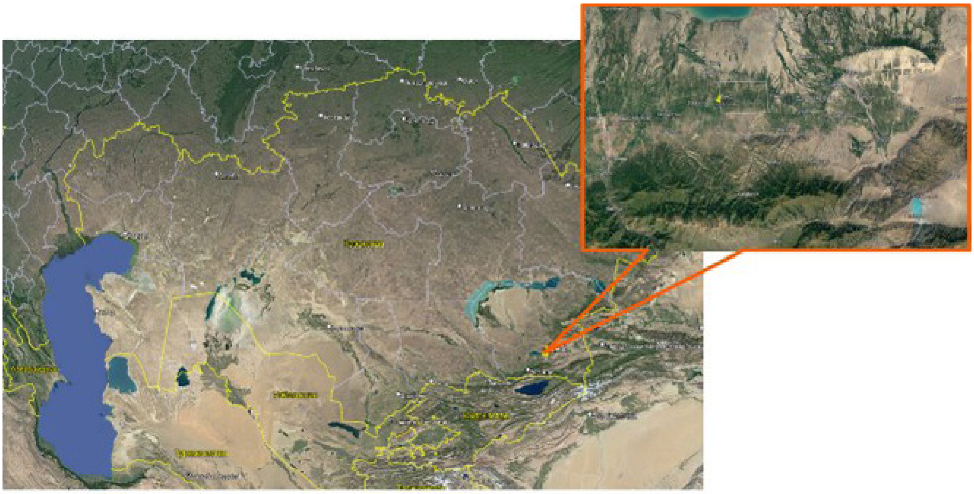


Figure 1 – Location of the Big Almaty Canal

Literary review. Irrigation water management plays a crucial role in agriculture, ensuring efficient water use and sustainable crop production. Understanding the water requirements of crops is fundamental to effective irrigation water management. Crop water use depends on factors such as crop type, growth stage, climate, soil type, and management practices. Evapotranspiration (ET) models, such as the Penman-Monteith, Makkink-Advection equations, are widely used to estimate crop water requirements and guide irrigation scheduling (Cruz-Blanco et al., 2014).

Various irrigation scheduling techniques are employed to optimize water use and improve crop productivity (Ahmed et al., 2023). These include soil moisture-based methods using sensors, such as tensiometers or capacitance probes, as well as plant based methods that consider crop water stress indicators, such as leaf water potential or canopy temperature. Additionally, weather-based methods utilize meteorological data to estimate crop water requirements.

Efficient water delivery systems are crucial for effective irrigation water management. Conventional methods, such as surface irrigation and sprinkler systems, have been widely used. However, more advanced techniques, including drip irrigation and precision irrigation, have gained popularity due to their ability to deliver water directly to the plant root zone, minimizing losses and maximizing water use efficiency (Yingshan et al., 2024).

Advancements in technology have revolutionized irrigation water management. Sensor-based technologies, such as soil moisture sensors and weather stations, provide real-time data for accurate irrigation scheduling (Obaideen et al., 2022). Remote sensing techniques, including satellite imagery and aerial drones, enable monitoring of crop water stress, evapotranspiration, and irrigation efficiency at larger scales. Studies about spatial and temporal distribution of reference (ETo) and actual evapotranspiration (ETa) estimation, crop water requirement and water supply risk during long period of time show the potential of using remote sensing inputs for water irrigation management in arid regions (Mahmoud et al., 2019; Shen et al., 2013).

Water scarcity and environmental concerns have prompted the development of water conservation strategies in irrigation water management. These strategies include deficit irrigation, which involves deliberately applying less water than the crop's full requirement during non-critical growth stages. Additionally, water-saving techniques, such as mulching, crop rotation, and precision irrigation, are employed to minimize water losses and optimize water use (Gabr et al., 2024).

Irrigation water management faces challenges such as water scarcity, climate variability, inadequate infrastructure, and farmer knowledge and adoption barriers. Overcoming these challenges requires a multi-faceted approach, including policy interventions, capacity building, improved infrastructure, and the use of advanced technologies. Integrated water management approaches, such as the use of smart irrigation systems and decision support tools, can also enhance water use efficiency. One proposed adjustment involves lowering the installation depth of the lateral lines. This modification aims to improve the effectiveness of water delivery to the plant roots by siting the irrigation system at a shallower depth. By doing so, it is possible to minimize water losses resulting from evaporation or excessive percolation, thereby enhancing water use efficiency (Ayars et al., 2006).

Sustainable irrigation water management is essential for long-term agricultural productivity and environmental stewardship. Efforts are being made to develop innovative approaches, including precision irrigation, site-specific management, and the use of smart systems driven by artificial intelligence and machine learning algorithms. These advancements aim to optimize water use, minimize environmental impacts, and enhance overall irrigation efficiency (Lakhiar et al., 2024).

Irrigation water management is a critical aspect of agricultural production, ensuring efficient water use and sustainable crop growth. By employing appropriate irrigation scheduling techniques, adopting advanced technologies, and implementing water conservation strategies, farmers can optimize water use, increase crop yields, and mitigate environmental impacts. Continued research and innovation in irrigation water management are crucial for addressing challenges and achieving sustainable agricultural practices.

Materials and methods. For the pilot project a command area of 6,000 hectares located in the Karaturuk region (Fig. 2) was taken to do our research and analysis to find out potential use of remote sensing inputs to improve irrigation water management.

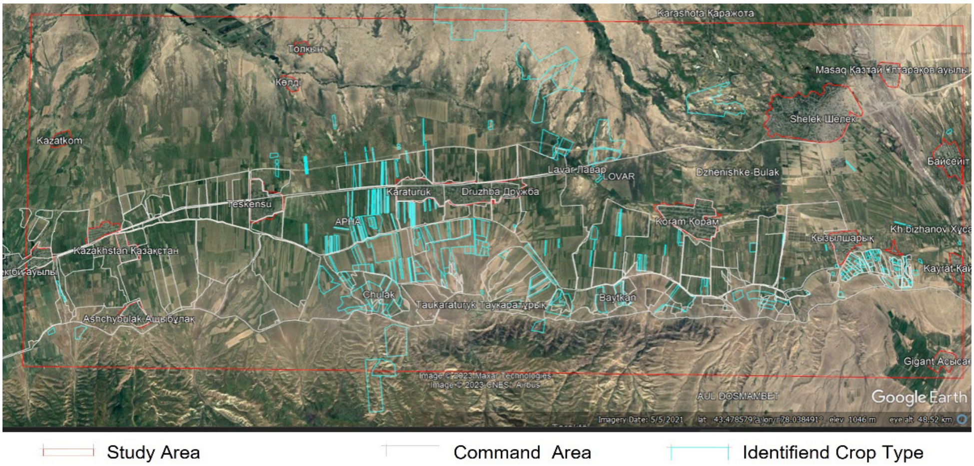


Figure 2 – Command area in Karaturuk region

According to the farmers table record for 2022 dominant crop types which are cultivated in the command area are: Alfalfa (35,17%), Maize (33,17%), Orchards/ Apples, (24,97%). Farmers follow the crop calendar which is common to South and South-East Kazakhstan. Sowing period starts from the end of March-beginning of April, harvesting period is the end of July-August.

The Big Almaty Canal in Enbekshikazakh District and is located in the Almaty region of Kazakhstan. Enbekshikazakh District is situated in the southeastern part of the Almaty region. It is bordered by the Almaty region's Talgar District to the west and the Almaty District to the north. The district also shares borders with Kyrgyzstan to the south and China to the southeast. The area is characterized by a diverse landscape that includes mountains, hills, and valleys.

Enbekshikazakh District experiences a continental climate. According to the meteorological Data from CERES/MERRA2 and Persiann Precipitation models shown in Fig.3 summers are generally warm and dry, while winters are cold. Summers are generally warm, with average temperatures ranging from 20°C to 27°C. It can get hot during the day, especially in July and August, with temperatures occasionally exceeding 35°C. The region receives relatively low precipitation during the summer months up to 40 mm. Autumn (September to November) brings cooler temperatures, with average highs ranging from 10°C to 20°C in September and dropping to 0°C to 10°C by November. The amount of rainfall increases during this season. Winters (December to February) in Enbekshikazakh District are cold, with average temperatures ranging from 0°C to -10°C (14°F to -4°F). The area experiences snowfall, and the mountains surrounding the district are often covered in snow. Spring (March to May) is characterized by a gradual increase in temperatures. March is still cold, with temperatures ranging from 0°C to 5°C, but by May, the average highs reach 15°C to 25°C. Precipitation levels start to decrease in the spring.

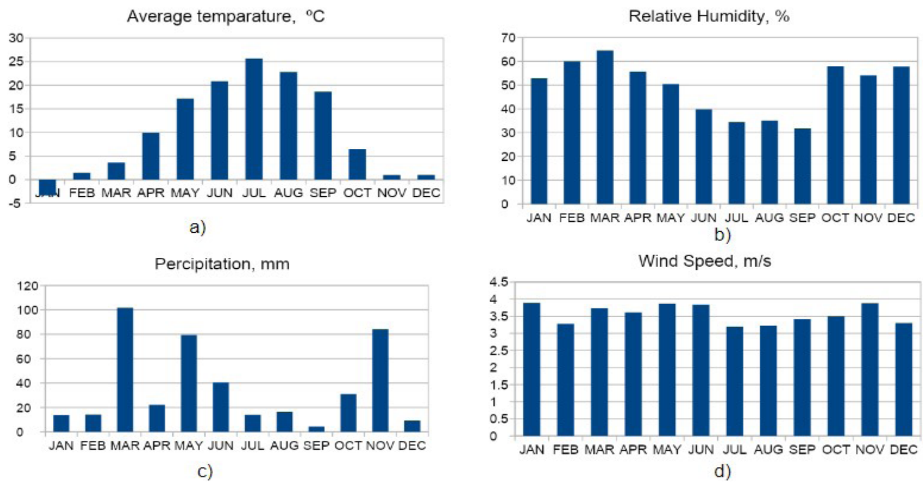


Figure 3 – Graphs of Meteo Data

The soil composition in Enbekshikazakh District can vary, depending on the specific location and elevation (Pachikin et al., 2014). The region encompasses different soil types, including. Chernozem soils are characterized by their high fertility and dark color. They are rich in organic matter and nutrients, making them suitable for agriculture. As the district includes mountainous areas, there are various mountain soils found at different elevations. These soils are influenced by factors such as slope, parent material, and climate. Solonchaks are saline soils that contain high levels of salt. They are typically found in low-lying areas with poor drainage. Sierozems are soils with a relatively high clay content. They can vary in fertility depending on their drainage and organic matter content.

Methodology. The research methodology is illustrated in Fig.4 as a Flow Chart, which presents the main stages of data collection, processing, and analysis used in this study.

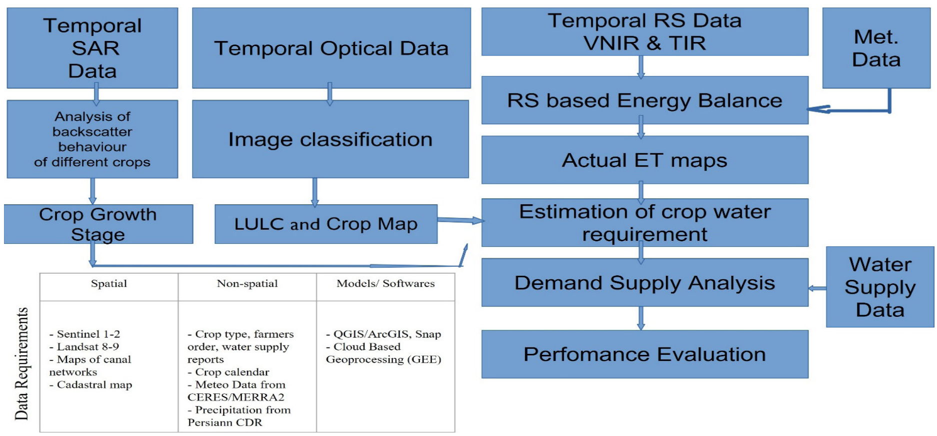


Figure 4 – Flow Chart of the methodology

Image Classification. Optical imagery of Sentinel-2 was used for image classification. Image series from the period of March and September was used. Optimal method combining field samples is unsupervised classification k-means due to few field samples with the pure crop classes and irrationally scattered among study area.

Unsupervised classification is a widely used technique in image analysis and pattern recognition. The K-means algorithm is one of the most popular methods for unsupervised classification due to its simplicity and efficiency.

The K-means algorithm is an iterative clustering technique that aims to partition a dataset into K distinct clusters, where K is a user-defined parameter. The method operates by iteratively assigning data points to the nearest cluster centroid and updating the centroids based on the mean values of the assigned points. The process continues until convergence is achieved (Abbas et al., 2016).

One of the key strengths of the K-means method is its simplicity and computational efficiency. The algorithm is easy to understand and implement, making it accessible to researchers and practitioners. It also scales well to large datasets, making it suitable for processing high-resolution imagery. Additionally, K-means does not require labeled training data, making it useful for unsupervised analysis.

K-means clustering has some limitations and challenges as well. One major limitation is its sensitivity to the initial seed or centroid selection, which can result in different clustering outcomes. The algorithm is also sensitive to outliers and noise, which can significantly affect the clustering results. Another challenge is determining the optimal value of K, which can be subjective and require domain expertise.

Output with 20 clusters were validated with the field data for dominant crop identification and Google Map as reference to identify water bodies, barren lands and non-crop vegetation. Accuracy Assessment using the merged samples from the field data and Google Map showed 0.89 overall accuracy.

Actual Evapotranspiration. Actual Evapotranspiration (ETa) is a measure of the total amount of water that is lost from an ecosystem through the processes of evaporation and transpiration. Evapotranspiration is a key component of the water cycle and plays a crucial role in the redistribution of water in the atmosphere, soil, and plants (Labedzki, 2011).

Evaporation refers to the process by which water changes from a liquid state to a vapor state. It occurs when water on the Earth's surface, such as rivers, lakes, or soil, absorbs energy from the sun and turns into water vapor. Transpiration, on the other hand, is the process by which plants absorb water through their roots and release it into the atmosphere through tiny openings called stomata on their leaves (Brouwer et al., 1986).

Actual Evapotranspiration takes into account both evaporation from the soil and water surfaces as well as transpiration from plants. It represents the total water loss from an ecosystem, including natural vegetation, crops, and other land surfaces.

The measurement and estimation of Actual Evapotranspiration can be done using various techniques and tools, such as weather stations, satellite imagery, and hydrological models. These methods take into account factors such as temperature, humidity, wind speed, solar radiation, plant characteristics, and soil moisture content to estimate the amount of water that is being evaporated and transpired (Brouwer et al., 1986).

Actual Evapotranspiration is influenced by several factors, including climatic conditions, vegetation type and density, soil properties, and land use. It is an important parameter for understanding and managing water resources, agricultural productivity, and ecosystem health. By quantifying the amount of water lost through evapotranspiration, scientists and water resource managers can make informed decisions regarding irrigation scheduling, crop water requirements, water allocation, and ecological conservation.

Accurate estimation of Actual Evapotranspiration is crucial for sustainable water management, especially in regions where water resources are limited or prone to drought. By monitoring and understanding the evapotranspiration processes, it is possible to optimize water use, improve irrigation efficiency, and mitigate the impacts of water scarcity on ecosystems and human activities.

EEFlux (Earth Engine Evapotranspiration Flux) is a variant of the METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration) model that operates within the Google Earth Engine system. It was developed through a collaboration between the University of Nebraska-Lincoln, Desert Research Institute, and the University of Idaho, with funding support from Google. EEFlux processes individual Landsat scenes from 1984 to the present and covers nearly all land areas worldwide. It utilizes NLDAS (National Land Data Assimilation System) gridded weather data in the United States and CFSV2 (Climate Forecast System Version 2) gridded weather data globally to calibrate the surface energy balance for each image.

To calculate actual evapotranspiration (ET), EEFlux employs a residual approach based on the surface energy balance equation: ET is derived as the difference between net radiation (Rn) and the combined soil heat flux (G) and sensible heat flux (H). The thermal band of Landsat is used to drive the surface energy balance, while the shortwave bands are utilized to estimate vegetation quantities, albedo, and surface roughness.

EEFlux provides valuable information about evapotranspiration at a high spatial resolution, facilitating the assessment of water usage and vegetation health over extensive areas. By harnessing the capabilities of the Google Earth Engine platform, it can efficiently process and analyze large volumes of satellite imagery and meteorological data.

Crop growth stages are typically categorized into distinct phases, such as germination, vegetative growth, flowering, fruiting, and senescence. FAO separates four crop growth stages: initial stage, crop-development, mid-season and late season.

Each stage has unique characteristics that can be identified using different Remote Sensing data approaches.

Normalized Difference Vegetation Index (NDVI) is a widely used vegetation index derived from remote sensing data, primarily using visible and near-infrared spectral bands. It quantifies the amount and vigor of green vegetation. During different crop growth stages, NDVI values change, providing insights into vegetation health and development. NDVI values are typically low during the initial stages of crop growth, increase as vegetation cover expands, and reach a peak during the maximum photosynthetic activity stage. Subsequently, NDVI values may decline as the crop matures and senescence. By analyzing temporal NDVI patterns, it is possible to identify and monitor different crop growth stages (Berger et al., 2019).

By analyzing SAR images that can also acquire different growth stages, it is possible to develop classification algorithms to identify and track these stages. SAR is an active remote sensing technology that uses microwave signals to illuminate the target area and measures the backscattered energy to generate high-resolution images. The backscattered radar signal is influenced by various factors, including the properties of the target surface, such as roughness, composition, and moisture content, as well as the incident angle and polarization of the radar wave. Backscatter analysis involves the study of these signals to extract valuable information about the target characteristics and environmental conditions.

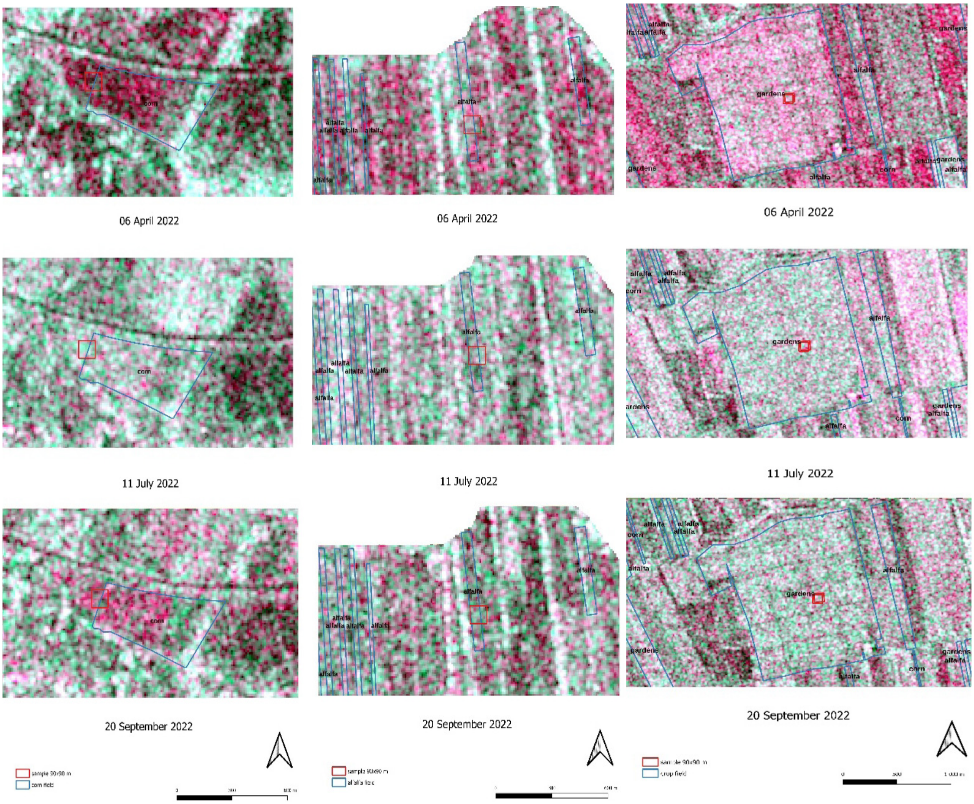
In SAR imagery, the intensity of the backscattered signal is typically represented by different shades of gray or color, where brighter pixels indicate higher backscatter values. By analyzing the variations in backscatter across the image, important information about the target, such as topography, vegetation, land cover, soil moisture, and changes over time can be derived.

Backscatter analysis often involves comparing different SAR images acquired under varying conditions, such as different frequencies, polarizations, or temporal intervals. By analyzing the changes in backscatter patterns, we can monitor land surface changes, detect vegetation growth, assess deforestation, monitor agricultural practices, track urban development, and even detect changes in the Earth's surface due to natural disasters or geological processes.

Crop growth monitoring and assessment are critical for effective agricultural management and decision-making. Remote sensing technologies, such as synthetic aperture radar (SAR), offer valuable insights into crop development by analyzing the backscattered radar signals.

To do crop growth monitoring we chose 5 samples from croplands where only one crop type is cultivated shown in Fig.5. Time series of NDVI derived from Sentinel-2 and SAR images VH polarization band of Sentinel-1 (Fig.6) were used to get NDVI and backscatter values.

Figure 5 – Location of samples



a) Corn fields b) Alfalfa fields c) Orchards(gardens)
Figure 6 – Samples of different croplands taken from Sentinel-1 image series to backscatter analysis

Backscatter Signatures for Crop Growth Stages Different crop growth stages exhibit specific backscatter signatures due to changes in canopy structure, moisture content, and biomass. During the early growth stages, crops have lower biomass and less developed canopies, resulting in lower backscatter values. As the crops progress towards maturity, canopy density increases, leading to higher backscatter values.

To derive crop growth stages from backscatter analysis, a time series of SAR images is required. These images should cover the entire crop growth cycle to capture the changes in backscatter values at different stages. Preprocessing techniques, including radiometric calibration, speckle filtering, and geometric correction, are applied to the SAR data to enhance the accuracy of the analysis (Abdikan et al., 2018).

While backscatter analysis provides valuable insights, it has certain limitations. Factors like weather conditions, crop types, and field variability can influence the backscatter response, leading to challenges in classification accuracy. Further research is needed to refine classification algorithms, integrate multi-sensor data, and develop crop-specific models to improve the reliability and applicability of backscatter analysis for deriving crop growth stages.

Backscatter analysis of SAR data offers a non-destructive and efficient method to derive crop growth stages. By analyzing the backscattered radar signals, crop development can be monitored and assessed, enabling precise agricultural management practices. With ongoing advancements in remote sensing technologies and machine learning algorithms, backscatter analysis holds great potential for enhancing crop monitoring and improving agricultural productivity.

Integrating NDVI and SAR backscatter analysis enhances the understanding of crop growth stages. The combination of optical (NDVI) and radar (SAR) data provides complementary information on vegetation characteristics. NDVI is sensitive to chlorophyll content and leaf area, while SAR backscatter captures structural and moisture-related variations. By fusing these datasets, it is possible to overcome limitations posed by cloud cover, obtain more accurate and consistent crop growth information, and improve crop monitoring and management.

While NDVI and SAR backscatter analysis offer valuable insights into crop growth stages, there are some challenges to consider. Factors such as soil moisture, crop type, crop density, and phenological variations can influence the interpretation of NDVI and SAR backscatter data. Additionally, calibration and validation of the data against ground-based measurements are essential to ensure accurate results. Moreover, the availability and cost of acquiring SAR data may limit its widespread use compared to optical data sources.

The results and analysis are shown in Results and Discussion sections.

Crop water requirement and irrigation water requirement. The crop coefficient (Kc) is a dimensionless parameter used in agriculture and irrigation to estimate the water requirements of a specific crop at a given stage of its growth. It relates the actual evapotranspiration (ETa) of the crop to the reference evapotranspiration

(ETo), which represents the water requirements of well-watered, uniformly growing grass or reference crop.

The crop coefficient takes into account the unique characteristics and growth stages of different crops, as well as the environmental conditions, to adjust the reference evapotranspiration and estimate the actual water needs of the specific crop. It provides a multiplier or adjustment factor to determine the crop's water requirement relative to the reference crop.

The crop coefficient varies throughout the different growth stages of a crop, reflecting the changing water demands as the crop develops. It is typically highest during periods of active growth and transpiration and lower during periods of slower growth or dormancy.

Crop coefficients are often determined through empirical measurements or research studies specific to a particular crop and region. They can also be obtained from published guidelines and databases developed by agricultural organizations, research institutions, or governmental agencies.

The crop coefficient is used in the calculation of crop water requirements using the following equation 1:

$$\text{Crop water requirement } (ET_c) = K_c \times ET_o \quad (1)$$

where ET_c is the crop water requirement, K_c is the crop coefficient, and ET_o is the reference evapotranspiration.

By applying the appropriate crop coefficient to the reference evapotranspiration, farmers and irrigation specialists can estimate the irrigation needs of a particular crop during each growth stage. This information is valuable for efficient irrigation scheduling, water management, and optimizing crop production while avoiding water stress or over-irrigation.

It is important to note that crop coefficients are specific to particular crops, and different crops may have different coefficients for each growth stage.

Additionally, local climatic conditions, soil properties, and management practices can influence the crop coefficient values. Therefore, it is recommended to consult local agricultural experts, research institutions, or agricultural extension services to obtain accurate and region-specific crop coefficient values for precise irrigation management.

Performance Evaluation and Demand Supply Analysis. Conducting a demand-supply analysis in irrigation water management involves considering the unique aspects of water availability, crop water requirements, and local water management practices. Local water management authorities and agricultural experts can provide specific data and guidance for conducting a comprehensive analysis in your specific area of interest.

Performance evaluation involves assessing the efficiency and effectiveness of water use practices and systems.

Assessing the available water supply sources for irrigation may include surface water from rivers, reservoirs, or canals, as well as groundwater from wells or other sources. Consider the quantity of water available from each source and any limitations or constraints that may affect the supply, such as water rights, infrastructure capacity, or environmental considerations. Due to the time limit we were unable to include those sources.

Evaluation of the water demand for irrigation purposes considers factors such as crop water requirements, evapotranspiration rates, irrigation efficiency, and cropping patterns. Analyze the total water demand for the specified area and identify any variations in demand throughout the year based on crop cycles or seasonal patterns. Equations 2 and 3 were used for demand supply analysis:

$$\text{Demand} = \frac{\text{ETa}}{\text{Irrigation Efficiency}} \tag{2}$$

$$\text{Demand} - \text{Supply Efficiency} = \frac{\text{Demand} \cdot 100}{\text{Irrigation Supply}} \tag{3}$$

Results and Discussion. The K-means algorithm is a widely used unsupervised classification method with numerous applications in image analysis and pattern recognition. While it has some limitations, such as sensitivity to initialization and outliers, advancements and extensions have been proposed to overcome these challenges. For this research we derived an output of 20 clusters and validated using the field data for dominant crop identification and Google Map as reference to identify water bodies, barren lands and non-crop vegetation.

Accuracy Assessment using the merged samples from the field data and Google Map showed 0.89 overall accuracy.

Figure 7 shows the final LULC map used to crop water requirement and irrigation water requirement estimation.

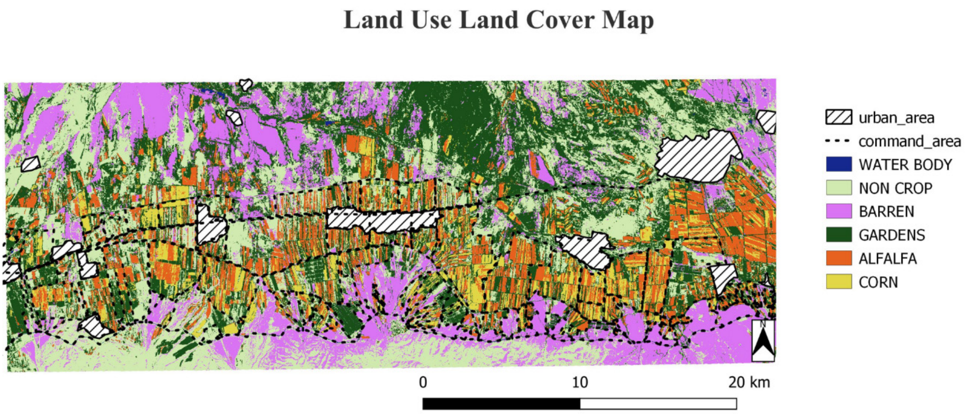


Figure 7 – LULC map of the dominant crops

Actual Evapotranspiration map. Actual Evapotranspiration Map for our study area was generated using Landsat 7 and 8 Thermal bands dataset for the chosen period as for crop classification. Using the EEFlux (https://eeflux-level1.appspot.com) platform based on Google Earth Engine algorithm we derived 13 ETa and ETrF maps. In the Fig. 8 and 9 ETa and ETrF monthly maps are shown.

A reference for general equations for EEFlux, based on those of METRIC is available at: http://www.intechopen.com/books/evapotranspiration-remote sensing-and-modeling/operational-remote-sensing-of-et-and-challenges which is an Intech book chapter compiled by Dr. Ayse Kilic (Irmak) of the Univ. Nebraska-Lincoln and associates at the University of Idaho and Desert Research Institute in 2012 (Allen et al., 2007).

ETrF is the "fraction of alfalfa reference ET" and is similar to the alfalfa reference-based crop coefficient. ETrF generally should vary from 0 to 1.0 or 1.1. ETrF is developed by EEFlux during the energy balance process. The standard calibration (std. calib.) uses the built in automated calibration of EEFlux (which will be revised and improved over time).

Standardized Penman-Monteith equation. ETrF is similar to the traditionally used "crop coefficient" ETrF = ETact / Etr.

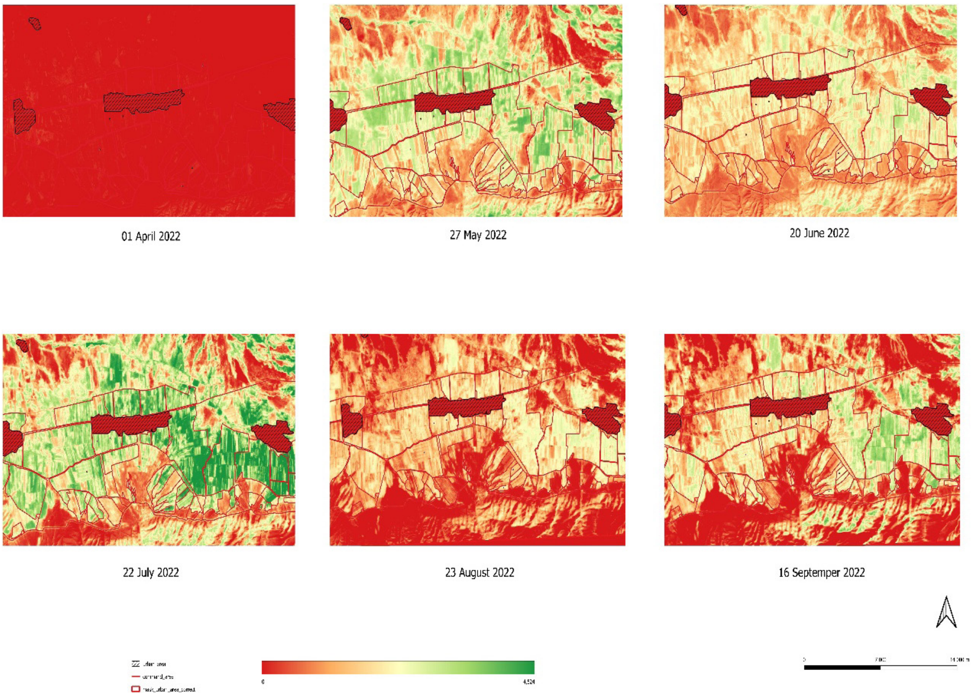


Figure 8 – Monthly ETa maps

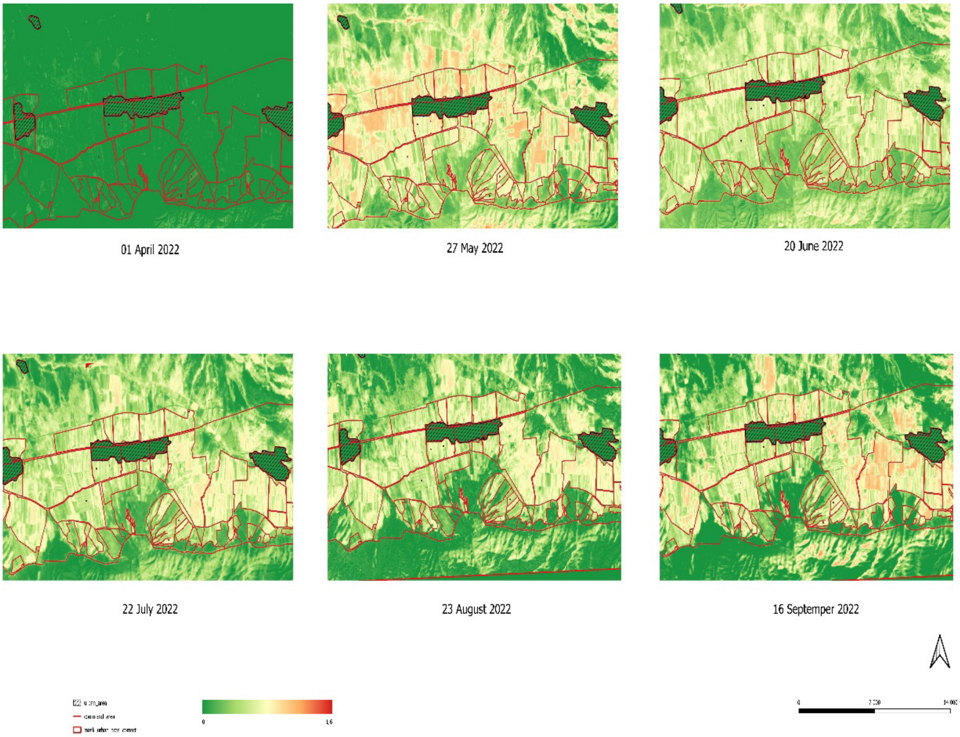


Figure 9 – Monthly ETrF maps

Crop Growth stage of the dominant crops. Analyzing NDVI coefficients in the fields of alfalfa Fig. 10 a) we can see 3 times of high values which means maximum photosynthetic activity or mid season stage. So we can suppose in the command area alfalfa has 3 cycles of growing during the irrigation season or 180 days, while backscatter coefficient behavior (Fig. 10d) is similar during all growth stages. We can explain it because of the height of the crop and frequency of the C band of Sentinel-1 has less penetration capacity. Graphs of NDVI and backscatter values in the fields of corn (Fig.10c and f) show good differentiation in all of the 4 growth stages and matching the time periods. Beginning of April during the 30 days is the initial stage, the next 50 days till mid of June is the crop development stage, following 60 days until mid of August is the Middle season stage of the corn and rest 40 days till end of September is the late season stage.

The analysis of the graph in the orchards (apples) (Fig.10b and e) fields need field validation, because NDVI can show us the minimum and maximum photosynthetic activities, which makes it difficult to differentiate phenological stages of apple trees. The reason is that during the whole irrigation period trees have leaves and without field observation it is hard to predict the harvesting period according to NDVI and backscatter values.

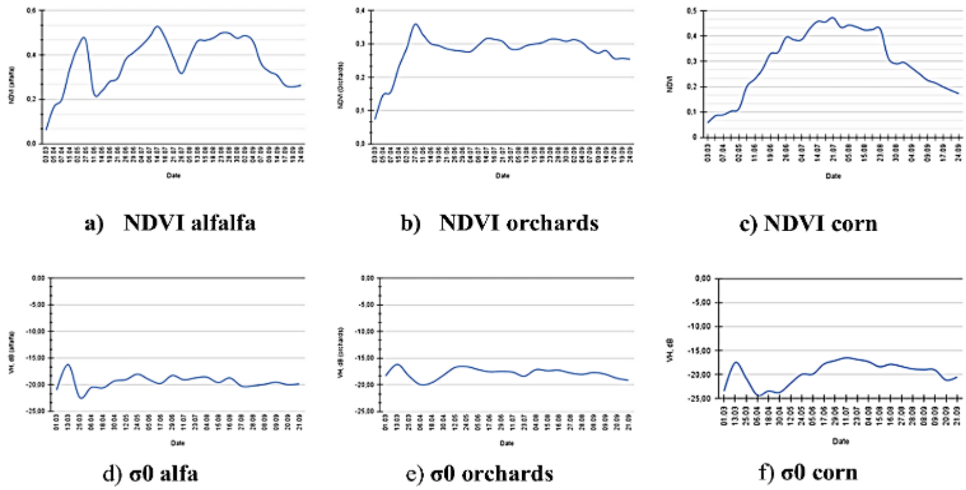


Figure 10 – Graphs of NDVI and backscatter coefficients in the chosen crop fields

Based on derived ETa maps interpolation could be done to estimate crop water requirement (CWR). To do that we need to find two ETa values from the existing close dated maps and taking the middle date as a center, give a value from the nearest dated map to the dates where ETa maps are not available. Summarizing the interpolated values during the month gives us Crop Water Requirement as shown in the Table 1.

Table 1 – Crop Water Requirement estimated by ETa with the comparison of given table

	Corn, mm/ha	Alfalfa, mm/ha	Garden, mm/ha
BAC	552,6	822,4	736,8
ETa	310,25	351,06	317,10

Estimated values are less than the given table from the BAC which could mean the command area needs less water for the irrigation.

Using water supply information for 2022 from the BAC we can estimate irrigation water requirement (IWR) according to the farmers irrigated area and ratio between actual supplied water and IWR shows us the water demand supply. Ideally 90-100% shows the rational water supply, below 50% - over supply more than 50% - oversupply or water deficit.

Table 2 gives information about the crop fields which we took as samples. This estimation was done for 99 out of 163 irrigated lands, because 99 farmers cultivate only a single type of crop among the dominant classes.

Table 2 – Information according the samples derived by ETa Maps and the BAC data

	Corn	Alfalfa 1	Alfalfa 2	Garden 1	Garden 2
Planned, m^3	142336	62303	37382	3538873	524691
Actual supplied, m^3	288307	67382	49842	4424720	254636

IWR, m^3	79913	26595	15957	1523041	225814
Water demand, %	27,72	39,47	32,02	34,42	88,68
Crop land ID	400049	303102	301930	4294	24070

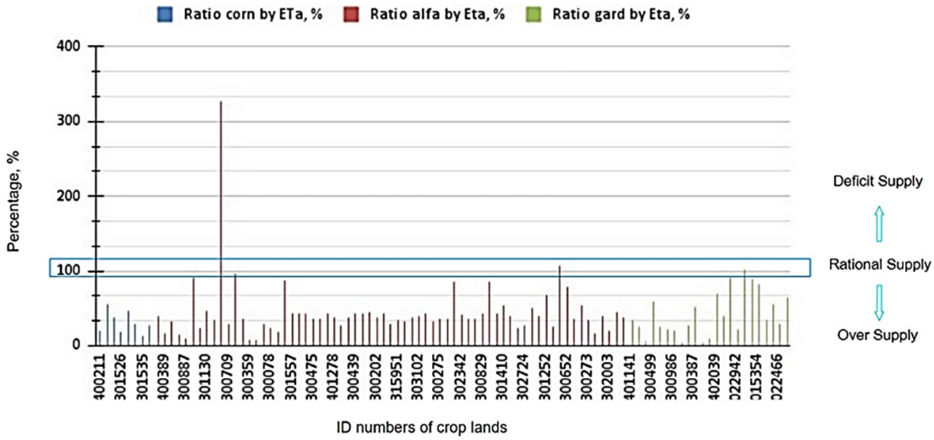


Figure 11 – Demand Supply Analysis for all the croplands

Fig.12 and Fig.13 represent the demand supply analysis of the command area for alfalfa and for the corn fields respectively estimated using CWR derived by ETa and tabled BAC data. It is observed that by ETa water distribution in the study area is more than is required for crop irrigation compared by BAC values, which shows a more balanced and rational distribution.

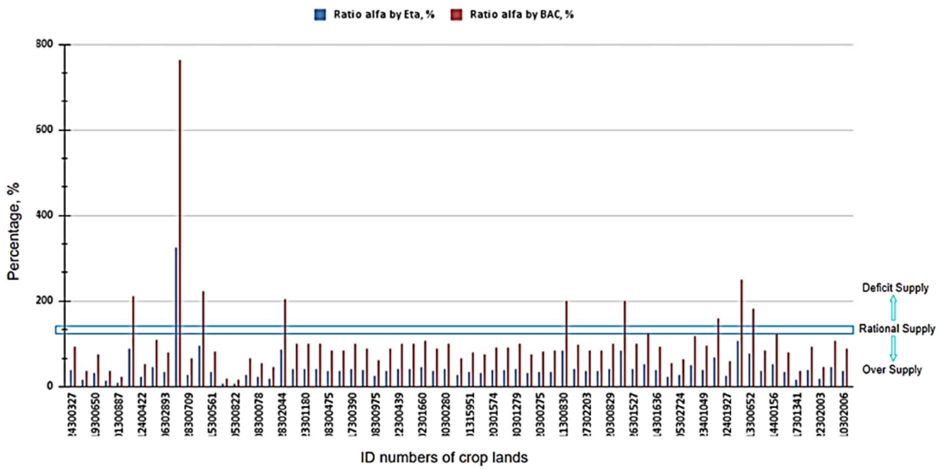


Figure 12 – Demand Supply Analysis for alfalfa fields by ETa and BAC

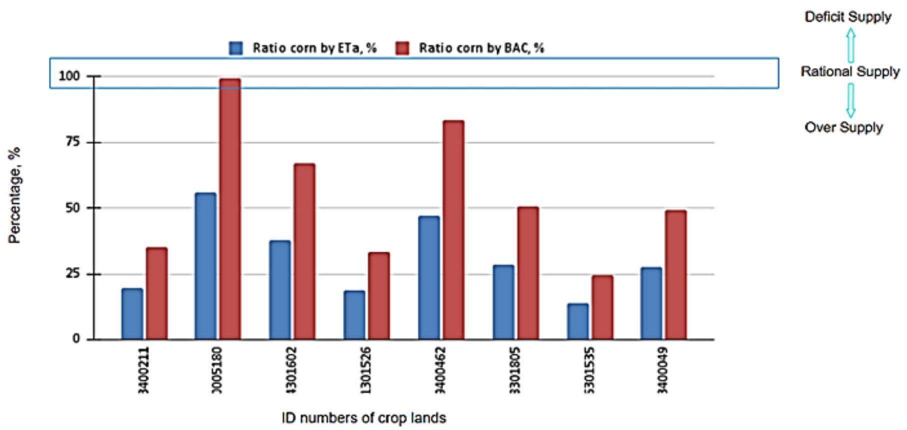


Figure 13 – Water Demand Supply for corn fields by ETa and BAC

In Fig.14 and Tables 3 and 4 we can see the difference between crop coefficient (Kc) values given by FAO and estimated using ETrF maps.

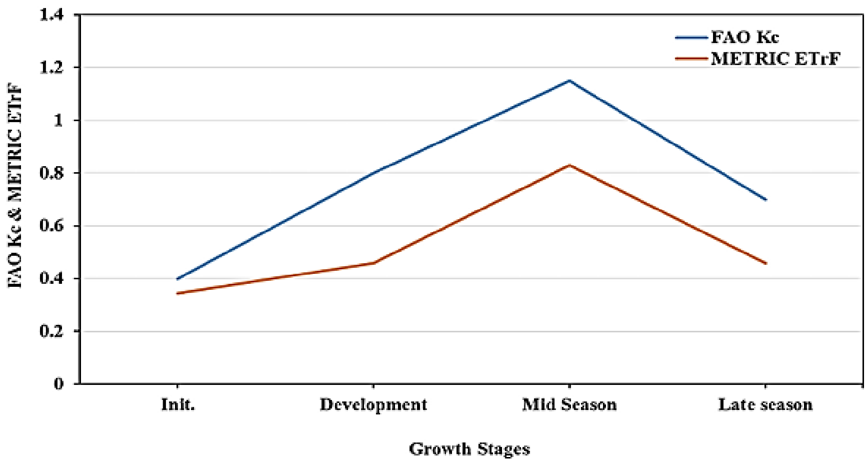


Figure 14 – Crop Coefficient Graph

Table 3 – Kc of Corn

Corn (180 days)	30	50	60	40
Growth stage	Initial	Crop development	Mid.season	Late season
FAO	0.4	0.8	1.15	0.7
ETrF	0.345	0.458	0.83	0.458

Table 4 – Kc of Alfalfa

	Alfalfa
FAO	0.95
ETrF	0.6

With the derived results we can assume that FAO based coefficients are not suitable for the command area and should be validated with the field observations based methods. This difference might be due to FAO uses universal approaches to estimate coefficients. Additionally long period analysis with the same methodology recommended, which might show the time series changes during the years. Water loss might happen due to the irrigation method, condition of the canal canal infrastructure for water supply, farmers expertise and experience in water planning estimation.

Conclusion. Aimed objectives are done and parameters for irrigation water management were estimated using Remote sensing inputs. Water Requirement derived from ETa is less than tabled water requirement method used by BAC (FAO method). Demand supply analysis shows over supply of water. Crop coefficients derived from ETrF are less than FAO K_c.

Backscatter analysis shows correlation with NDVI to analyze crops at different growth stages. In conclusion, combining NDVI and SAR backscatter analysis enables a comprehensive understanding of crop growth stages by leveraging the strengths of both techniques. Integrating these data sources can improve crop monitoring, yield estimation, and precision agriculture practices, ultimately enhancing decision-making in agricultural management.

Recommendations. Using ML for crop classification and more samples in training dataset. Same analysis is suggested to do for a 5-10 years period to find out coefficient crop water requirement and irrigation water requirement. Crop coefficient as well could be estimated and updated. Using TomoSAR techniques to estimate biomass and yield in corn irrigated lands. This might give a view of the relation and understanding between oversupplied and water deficit periods.

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