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Accounting for Seasonal Land-use Trends in Improving the Predictability of Irrigation Needs in Watersheds

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ABSTRACT

The calculation of water consumption for irrigation is critical in maintaining the water supplies for cultivation in tropical catchments. These water withdrawals change seasonally, depending on the rainy and dry seasons. A land-use map is one of the inputs required by hydrological models used to estimate water withdrawals in the basin. However, land-use maps usually offer stagnant details without reflecting the hydrological seasons, associated crop seasons and activities during the year. This research, therefore, assesses the importance of seasonal land-use maps for measuring water withdrawals in the basin. We have developed a crop calendar for the two main seasons (rainy and dry) for the semi-arid Mohgaon basin, Madhya Pradesh, India. Further, two Landsat 8 images from 2016 (March and December) were used to develop seasonal land-use and land-cover (LULC) maps (March: the non-monsoon season, December: the monsoon season). Classifications for land use were made using 10 land-use and land-cover classes for images from both seasons, which were dependent on the crop calendar. In addition, water withdrawals for irrigation were estimated using LULC maps. There were clear variations in land usage between dry and rainy seasons in rain-fed and irrigated areas. The maximum water withdrawal obtained for irrigating paddy crops was calculated at an average of 800 million m^3/year (i.e., 56.2 cm/year). This research concluded that accurate seasonal land-use maps are important for quantifying the annual water use for irrigation in catchment areas with distinct dry and rainy seasons.

KEYWORDS: Crop calendar, Irrigation, Land-use maps, Water withdrawal.

INTRODUCTION

Several emerging and even developed countries around the world have suffered from water shortages. These shortages may be exacerbated if no organizational activities are undertaken. In responding to this crisis, administrations and water experts have shifted from supply-side to demand-side policies (Thneibat, 2019). Demands for water supply, such as for drinking, irrigation and industrial usage, form a principal basis for the development of societies (Adib and Ahmadeanfar, 2018). Therefore, authorities are required to take corrective actions to maintain the demand and supply ratio in places where rainfall is the major water source. Knowledge of land use and land cover (LULC) is required to consider the hydrological processes of basin-like water movement and climate change (Yesuph and Dagnew, 2019). Topsoil protection refers to woodlands and man-made structures surrounding the land. Land-cover changes do not take place in a single year; they gradually change and correlate with expansions and land use in the area (Alawamy et al., 2020). Land usage, on the other hand, refers to man-made structures and land-managing activities. Human actions can cause transformation, mainly on cultivated soil, over a year based on the season (Singh and Singh, 2017). Hence, data on land-use change is required to measure the usage and withdrawal of water in irrigated areas (Lu et al., 2019) and water loss in terms of evapotranspiration (Morlin Carneiro et al., 2020). These aspects may be measured using Spatial Tools for River Basin Environmental Analysis and Management (STREAM) (Aerts, Kriek and Schepel, 1999), GIS software with a hydrological model tool such as Soil and Water Assessment Tool (SWAT) (Cambien et al., 2020) or *via*

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water balance or water accounting techniques that use remote sensing data was used (Mishra, Rai and Rai, 2020; Karimi et al., 2013). For instance, the water used for various crops can be calculated by the evapotranspiration-precipitation (ET-P) method in the watershed (Pereira and Pires, 2011).

A land-use map is required to classify areas for determining their particular water requirements (Cheema and Bastiaanssen, 2010). Classifying the periodic changes in LULC will assist in improving the estimation of water withdrawals (Talib, 2014). In much of the research, the periodic changes in land use were calculated based on the Normalized Difference Vegetation Index (NDVI) (Xue and Su, 2017; Viana et al., 2019). Altered crops may have equal NDVI standards and outcomes and may fall into the equal NDVI classes, which makes it hard to differentiate between crops that have different water requirements and consumptions (Naser et al., 2020; Sultana et al., 2014). Most of these studies have created land-use maps that lack comprehensive details on seasonal land-use changes (Thomas et al., 2015). An average to the higher resolution of land-use map is required to show a high variation in agricultural land use and water management practices in the Mohgaon basin (Dhawan, 2017). At present, there are regional land-use maps with a resolution of 30 m (Kumar Gaur et al., 2015; Singh and Dubey, 2012).

In this research, we have created the periodical land-use maps to quantify water withdrawals in the Mohgaon basin; a sub-basin of the Upper Narmada river using Landsat 8 images of 30 m resolution as well as the crop calendar for the Mohgaon basin. This study answers the subsequent queries: 1. What are the main land-use classes that vary periodically in the Mohgaon basin? 2. What is the amount of water required for irrigating crops in the Mohgaon basin in different seasons?

This research also includes data that can support decision-makers and river basin management agencies in recommending the issuance of seasonal water-use permits. This would involve considering the diverse volumes of water collected during the monsoon and non-monsoon seasons. The distribution of crop-based water, rather than only volumetric allocation, should be considered by the authorities. However, the production of reliable land-use maps still faces a variety of difficulties, some of which have been highlighted in this research; specifically, the restriction in image analysis during the monsoon season because of cloud cover, hindering the detection of constant changes in land use during the year.

STUDY AREA

The Mohgaon basin is a sub-basin of the Upper Narmada river, having a catchment area of 4067 km^2 (Figure 1). Figure 2 shows rainfall across the basin with heavy precipitation from June to August and short periods of rainfall in September and October. As per Central Water Commission (CWC), June to October are considered as the monsoon season, while November to May are considered as the non-monsoon season. As shown in Figure 1, four rain gauge stations were used to estimate the monthly rainfall in the area. The data used was provided by the Indian Meteorological Department (IMD), Central Water Commission (CWC) and Narmada Control Authority (NCA). The average yearly precipitation varies between 40 and 70 cm/year in the internal area of the basin and between 100 and 120 cm/year in the basin's uplands. Mixed commercial and urban areas are found mainly in the lower part of the basin, where rain-fed agriculture is dominant. In addition, barren lands and dense forests are mainly found in the upper part of the basin; i.e., the highlands. The main crops in the area are soya bean, rice or paddy, wheat, maize and other cereals and pulses.

METHODOLOGY

Water consumption in the Mohgaon basin depends on three factors: farming activities, types of crops and available water, briefed in a crop calendar (Wichelns, 2016; Table 1) of the basin, which was created using the data gathered by the Government of Madhya Pradesh. These information sources and the administration’s performance helped create the crop calendar for the Mohgaon basin. Land-use maps of the area were digitized and 10 land-use types were taken into consideration, including paddy, soya bean and wheat, which consume a significant amount of water.

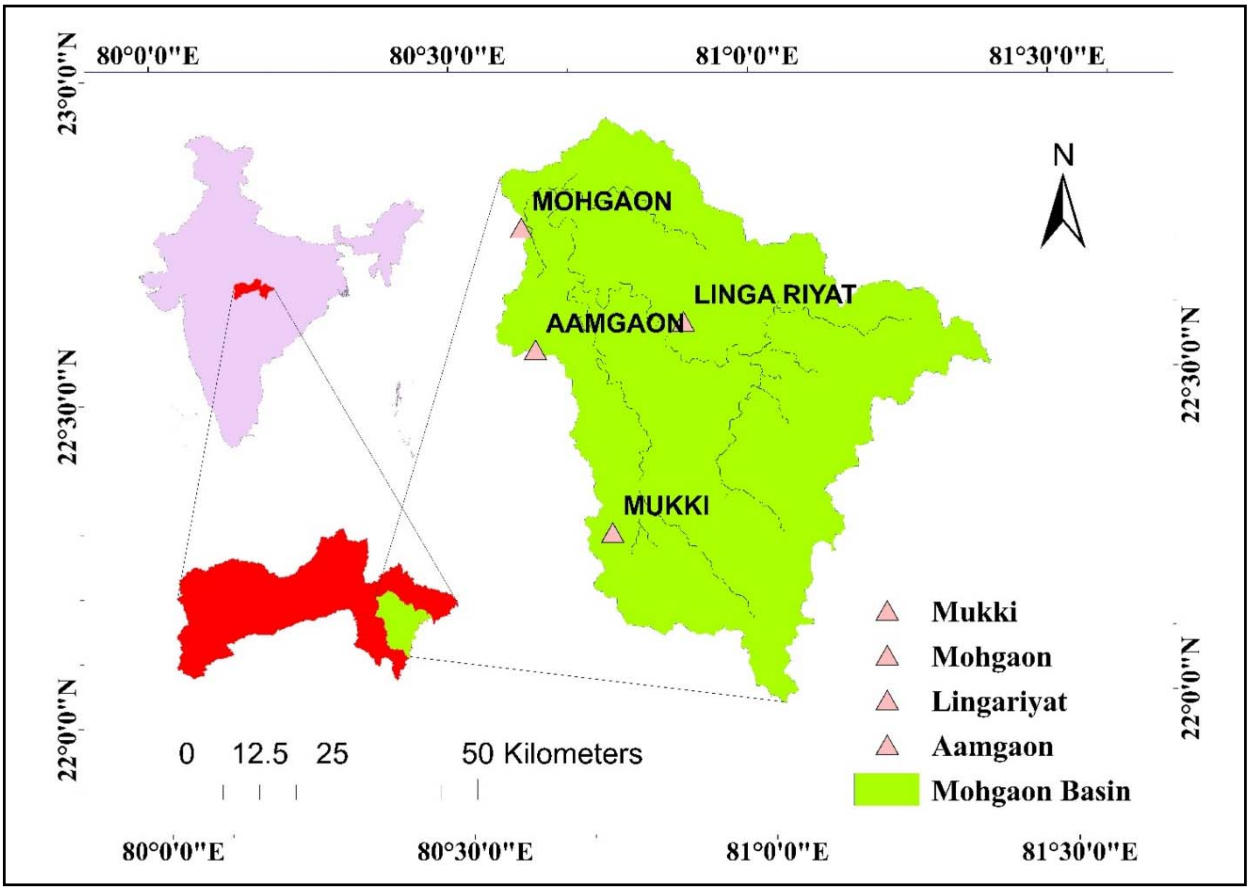

Figure (1): Study area

Land-use Images

Two images (Landsat 8 OLI/TIRS) of the Mohgaon basin for March and December (2016) were designated and taken from the US Geological Survey website. These images were then processed (composite, mosaic and mask) and prepared for analysis.

Normalized Difference Vegetation Index (NDVI)

NDVI maps were formed from band 4 (RED) and near-infrared band 5 (NIR) of the images (Xu, 2014; Jiang et al., 2006; Maglana et al., 2020). The NDVI was calculated using Equation (1).

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad (1)$$

Image Classification and Seasonal Land-use Change

Two images of the area were used for maximum likelihood supervised classification, a technique that uses a prepared identity with a known identity to classify pixels with an unidentified identity (Egorov et al., 2015), which helps calculate the number of pixels to assess the increase and decrease in the area for each class (Liu, 2003). This tool was widely used to identify changes in land use in the area. In this research, land use has been classified into main 6 types; grasslands, shrublands, dance forests, agricultural land, barren land and water bodies. Agriculture land is further classified into the main 5 major crops; soya bean, paddy, wheat, cereals and maize.

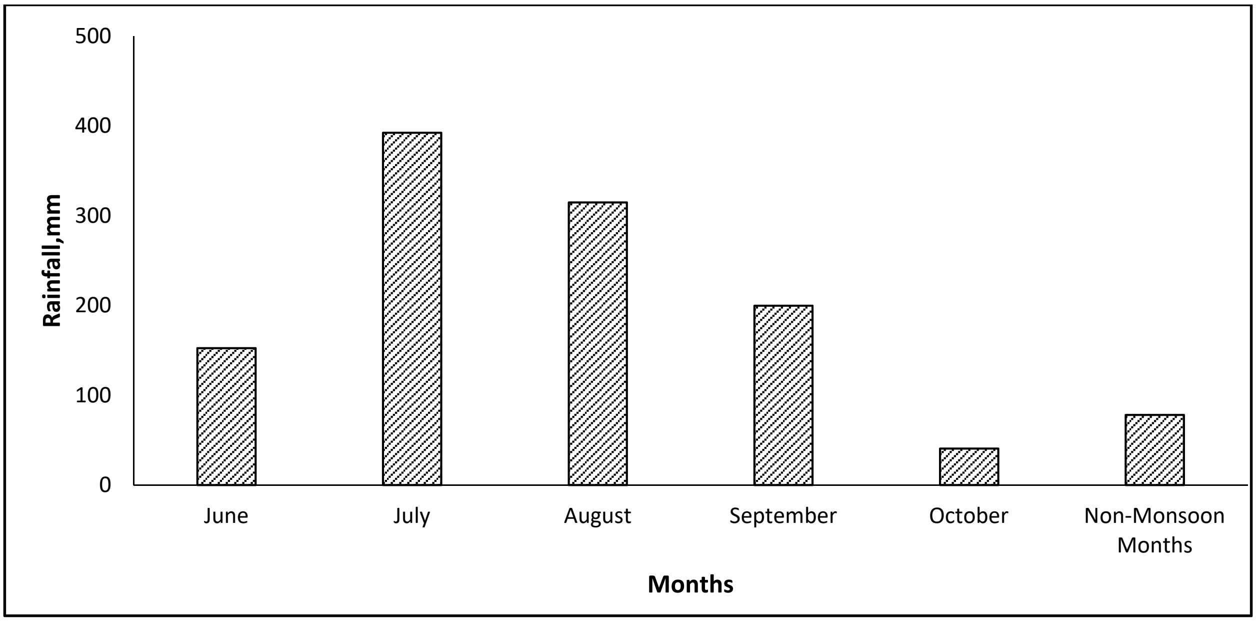

Figure (2): Average rainfall in the area

Statistical Accuracy

The percentage of seasonal changes in LULC and NDVI was equated to check whether there is a similar change in pattern with the seasons. The Kappa coefficient (Tang et al., 2015) was found to be 0.84 for the area.

Water Requirement Using Land-use Maps

A water balance approach was used to calculate the volume of water used for irrigation (water withdrawals) with help of precipitation as well as evapotranspiration (Foster, Mieno and Brozović, 2020). Moreover, the precipitation map of the study area and the monthly and annual precipitation were examined. The Nash–Sutcliffe efficiency coefficient (NSE) and coefficient of determination (R^2) were calculated to measure the alignment between them. The station's results showed strong alignment with a cumulative NSE and R^2 of 0.81 and 0.79, respectively.

Evapotranspiration (ET) data was collected from the Indian Meteorological Department (IMD) and the ET product was created from the ET monitor at a 250 m resolution. We then equated the water balance ET (W_{BET}), which was obtained from Equation (2) (Stella, 2019), with the available observed ET:

$$W_{BET} = P - Q - \Delta S \qquad (2)$$

P, Q and ΔS are the average yearly rainfall, discharge and variation in storage. The variation in storage was assumed to be negligible ($\Delta S = 0$).

Further, the coefficient of determination was found between the water balance ET (predicted) and observed ET, which is satisfactory ($R^2 = 0.8781$) and presented in Figure 3. The estimation of water withdrawal for the irrigated crops in the Mohgaon basin was carried out with the help of a validated precipitation map and ET map. The procedure for estimating water withdrawals calculated using the water requirement of the irrigated surface is described below (Weerasinghe and Griensven, n.d.; van Eekelen et al., 2015).

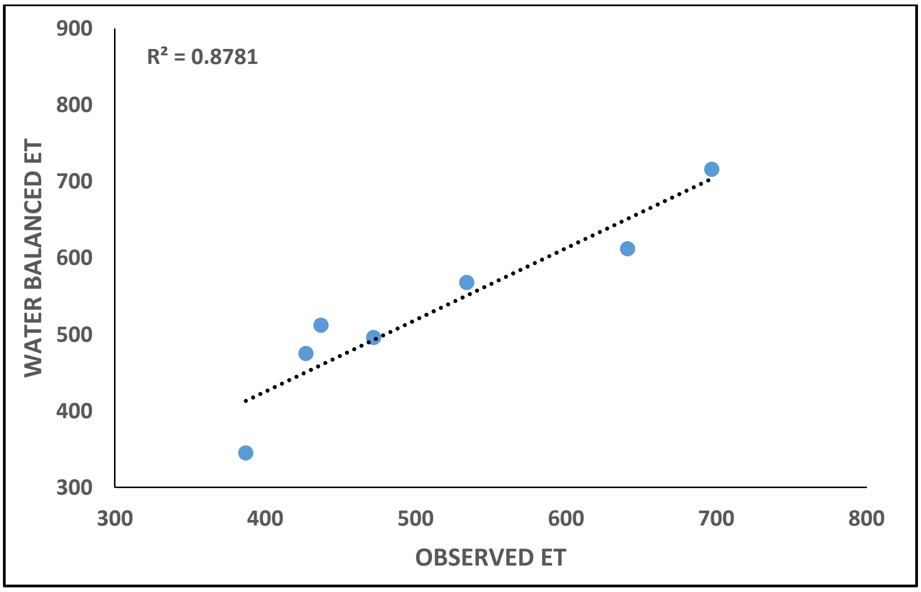

Figure (3): Comparison of observed ET and water balanced ET

The total ET is expressed as:

$$\text{ET} = \text{ET precipitation} + \text{ET incremental} \qquad (3)$$

$ET_{precipitation}$ is the amount of water that evaporated from areas where no extra water was supplied and $ET_{incremental}$ is the volume of water that evaporated due to withdrawals. The $F_{ET/R}$ ratio is required for the determination of precipitation, since the rainwater does not penetrate and can be stored and accessed for uptake by plants. Therefore, $ET_{incremental}$ is the difference between the total ET and $ET_{precipitation}$ (Sensing and Water, n.d.):

$$ET_{Incremental} = ET - F_{ET/R} * P \qquad (4)$$

Here, P is the total yearly precipitation, while ET is the total yearly water evaporated. The incremental ET from the lands is not equal to that pulled out from the aquifers, rivers and streams. The irrigation efficiency of the Mohgaon basin varies from 35% to 50% (CWC, India). In this research, 30% irrigation efficiency is assumed as the ratio of the ET total and water requirement (Equation (5)):

$$\text{Water requirement} = \left(\frac{\text{ET Incremental}}{\text{Efficiency}}\right) * \text{Area}. \qquad (5)$$

This ensures that 70% of the water removed is diverted into rivers and lakes or evaporates and is not consumed by active irrigation. A description of the processes (Weerasinghe and Griensven, 2019) for calculating water requirement for irrigation is provided in Figure 4.

The seasonal map of December, representing the wet season, was used to extract the ET and P values for wet months (June, July, August, September and October), while the map of March was used to extract the values in the non-monsoon season.

RESULTS AND DISCUSSION

Crop Calendar

The crop calendar gives a demonstration of the monthly managing activities, such as sowing, raising and harvesting of crops (Table 1), which distinguishes irrigated and rain-fed crops; this was not possible in previous research. Crops such as paddy and wheat have unique monthly management activities set out in their cultivation cycle.

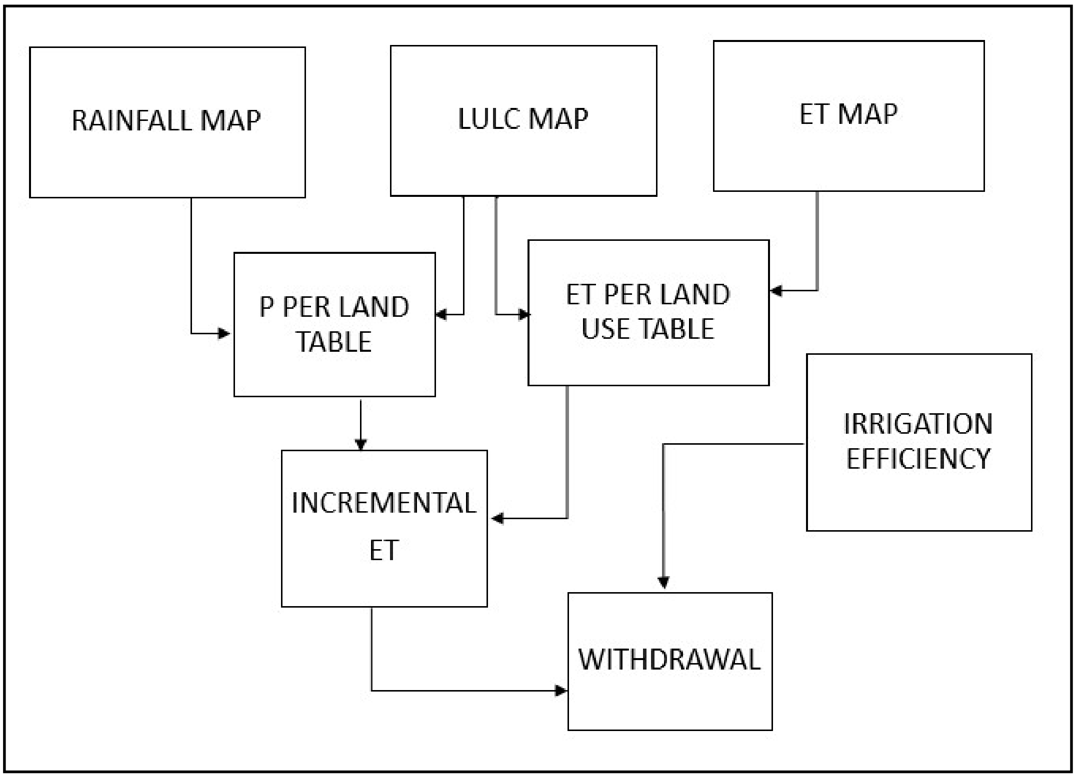

Figure (4): Data analysis of water withdrawals

NDVI Analysis for the Mohgaon Basin

NDVI tests the volume and potency of plants on the soil. NDVI values commonly vary from -1.0 to 1.0, with negative values showing clouds and water, while positive values near zero show plain earth (Hashim, Abd Latif and Adnan, 2019). The NDVI values for the Mohgaon basin show a strong change of usage between the two crop seasons (Figure 5). The use of periodic land use is necessary to distinguish agricultural land-use groups present in the region.

Change in Land Use

LULC groups were plotted for monsoon and non-monsoon in the Mohgaon basin (Figure 6). Comparing the monsoon season (December 2016) to the non-monsoon (March 2016), it was noted that 4.5 % of the paddy-grown area, 2 % of the soya bean fields and 3.5 % of wheat-grown areas were transformed to bare soil. Simultaneously, the irrigated mixed crops, such as maize, bajra and cereals, increased by 1.5 % in March. The detailed findings are summarized in Table 2. Figure 7 indicates the shift in the percentage of large-scale cultivation to unused land in the Mohgaon basin from the monsoon season to the non-monsoon season. It further shows the percentage reduction in grasslands and shrublands from monsoon season to non-monsoon season. This effect demonstrates a major decline in the ratio of rain-fed paddy to that in non-monsoon season.

Water Withdrawal

If the ET value approaches P, this would mean that an additional water supply has been used for drainages, such as field or surface water abstraction. The annual water requirement for irrigated land was estimated using the land-use map for the amount of water required per irrigated usage.

Figure 8 reveals water requirements for different crops ranging from 50 to 800 million m^3. The figure also showed the water needs for irrigated crops in non-monsoon seasons, since the catchment was located in a semi-arid region.

Table 1. Crop calendar for Mohgaon basin

Crops	JAN.	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Maize Rain Feed							Sowing	Mid	Mid	Mid	Harvesting	Harvesting
Bazra Rain Feed							Sowing	Mid	Mid	Mid	Harvesting	Harvesting
Paddy Rain Feed							Sowing	Mid	Mid	Mid	Harvesting	Harvesting
Pulses Irrigated	Mid	Mid	Harvesting								Sowing	Mid
Soya Bean Rain Feed							Sowing	Mid	Mid	Harvesting	Harvesting	
Wheat Irrigated	Mid	Mid	Harvesting								Sowing	Mid
Cereals Rain Feed							Sowing	Mid	Mid	Harvesting	Harvesting	
Maize Irrigated	Sowing	Mid	Mid	Mid	Harvesting							
Bazra Irrigated	Sowing	Mid	Mid	Mid	Harvesting							
Paddy Irrigated	Sowing	Mid	Mid	Mid	Harvesting							
Pulses Rain Feed						Sowing	Mid	Mid	Mid	Harvesting		
Soya Bean Irrigated	Sowing	Mid	Mid	Mid	Harvesting							
Wheat Rain Feed						Sowing	Mid	Mid	Mid	Harvesting		
Cereals Irrigated	Sowing	Mid	Mid	Mid	Harvesting							

SOWING STAGE — MID STAGE — HARVESTING STAGE

Table 2. Change in the area covered in in Mohgaon basin

LULC CLASSIFICATION	AREA COVERED IN PERCENTAGE	
	DECEMBER	MARCH
BARREN LAND	12.51	24.02
GRAZED SHRUB LAND	0.49	0.62
CEREALS	2.41	2.45
DENSE FOREST	32.44	32.11
MAIZE	0.31	1.57
PADDY	10.34	6.61
GRASS LAND	1.34	0.94
SOYA BEAN	24.20	22.29
WATER BODIES	5.28	2.29
WHEAT	10.68	7.10
TOTAL	100	100

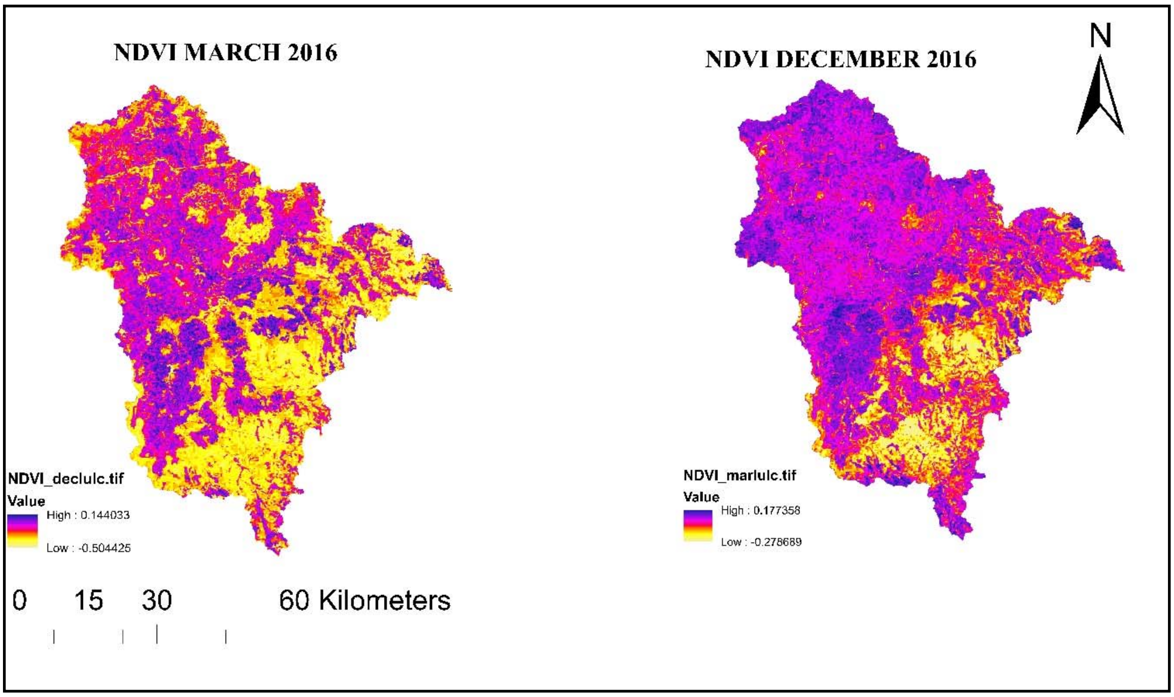

Figure (5): Distribution of NDVI for March 2016 and December 2016 for Mohgaon basin

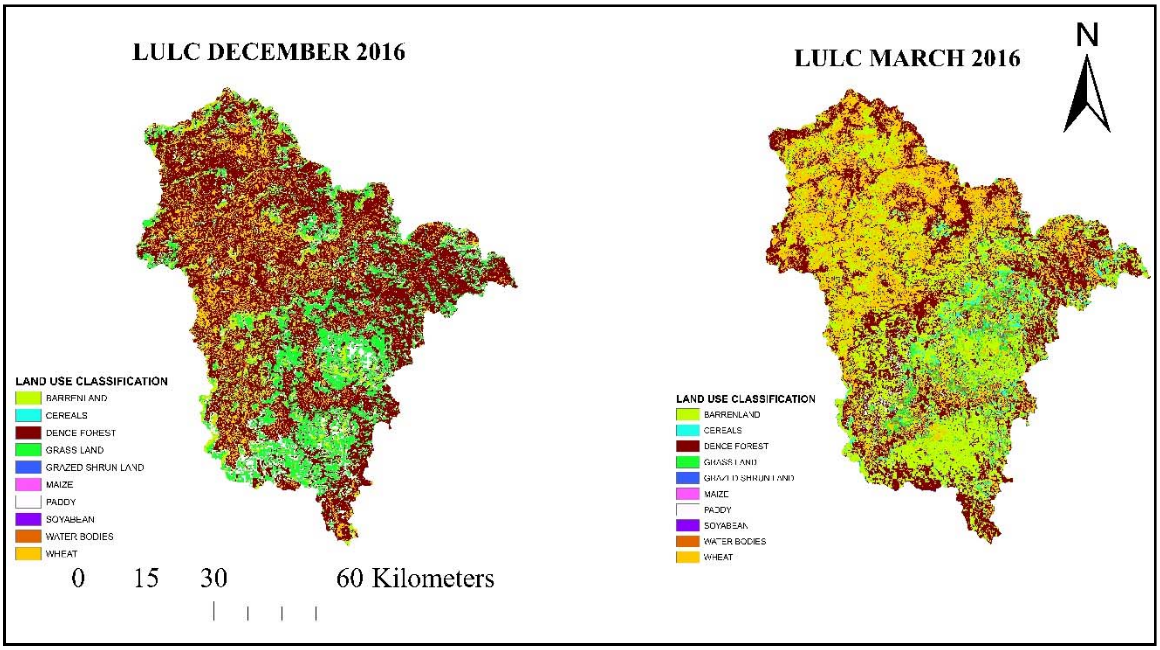

Figure (6): Distribution of LULC class of March and December 2016

For this land use, separate zones were used for each season to forecast water requirements; Figure 8 shows the various water requirements for individually irrigated land uses. The outcome showed that a considerable volume of water was removed in March. The water requirements for irrigated paddy and soya bean are up to 800 million m^3/year (56.2 cm/year), (including water used in germination, raising seedlings, transplanting, vegetative growth, flowering and beginning maturity to harvest), followed by wheat, which uses up to 520 million m^3 / year (45.3 cm/year).

The grouping of the images and changes in the crop calendar have confirmed the benefits in the study of land-use transition and the emergence of a systematic classification of land uses in the Mohgaon basin. The observations also emphasized the importance of the use of data for land-use classification. However, there are major geographical differences in the distribution of shrublands in the area. NDVI helps recognize unusual plant occurrences and their relationship to periodic differences. More variations between NIR (high) and RED (low) mean a greater vegetation response at a given site. The NDVI map shows intermittent differences between the dry and rainy seasons.

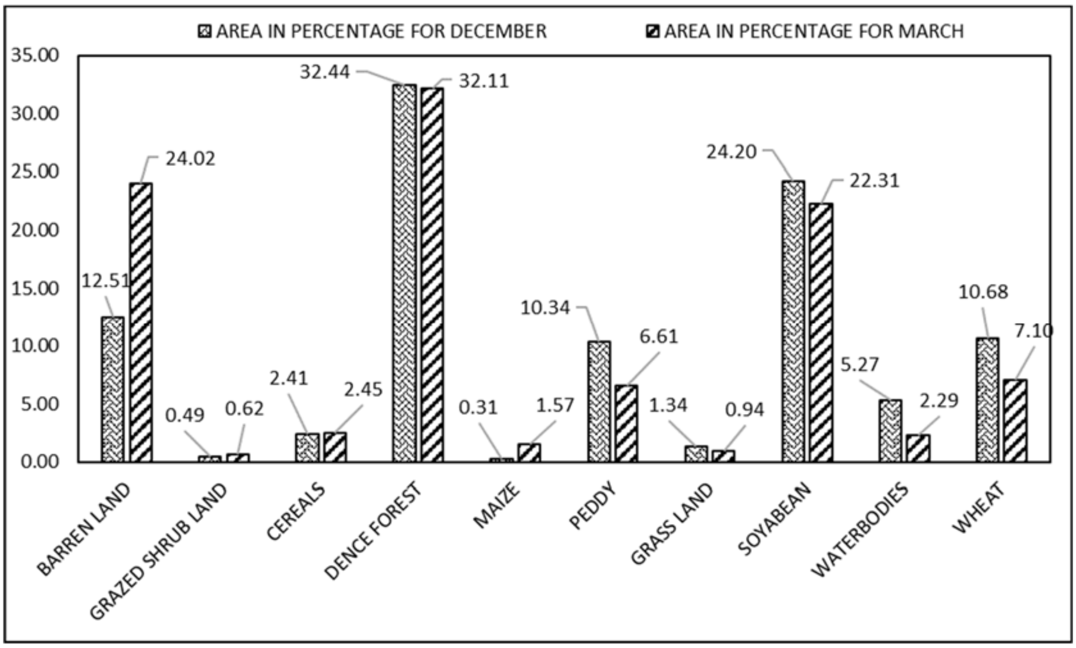

Figure (7): Seasonal change in the Mohgaon basin

Land-use charts used in this study have been used to measure water withdrawals for irrigation purposes. The precise estimation of water requirements is important for the catchment authority. The calculation of the water amount using instruments such as flow meters is costly and not suitable in the long term, although no such instruments were installed in the Mohgaon basin region. Remote sensing is a cost-effective option to direct measurements.

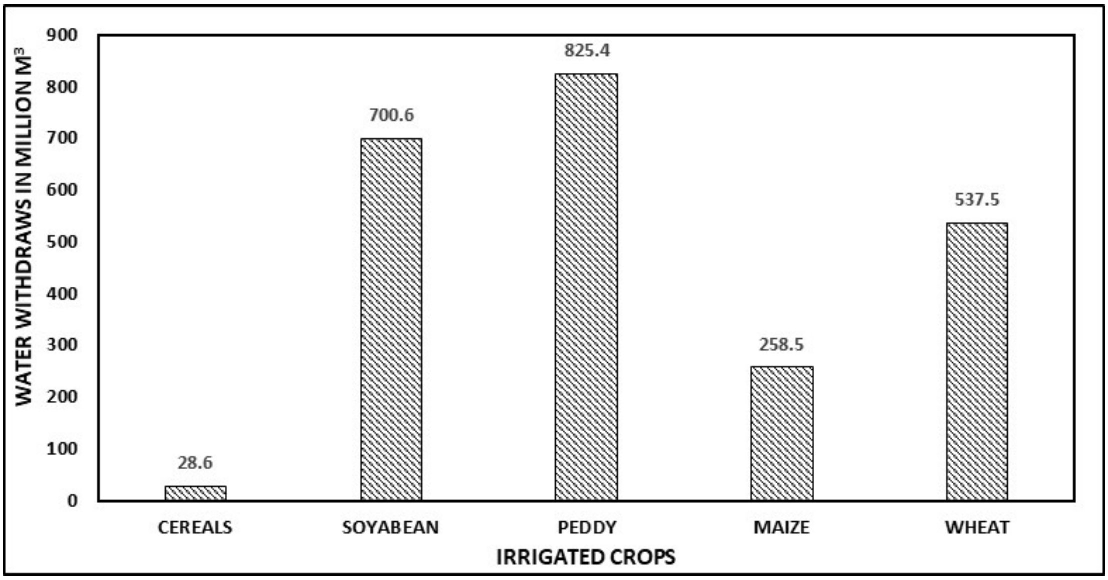

Figure (8): Water withdrawal for irrigated crops

Furthermore, the area of irrigated crops rises from the rainy season to the dry season, which is clearly explained in land-use maps. The increase in the irrigated areas during the dry season increases the use of surface and groundwater. The crop will take six months to harvest; thus, during the dry seasons, there will be fewer areas for agriculture. In this research, the irrigated crops demonstrated variations in the amount of water withdrawn between the two seasons.

A land-use map is the precise estimation of irrigation requirements in an area. However, it can be difficult to read and analyze due to cloud cover, especially if it is for the rainy season. As the rainy season is from June to September, the water estimation cannot be precisely explained, due to the cloud cover. The pictorial representation of the rainy season may also contribute to errors, which may delay sowing and consequently, crops mature later in the rainy season. This can also justify the lack of precision in the classification of irrigated mixed crops.

There are several disadvantages of using the crop calendar developed in this research. The harvesting dates for crops, such as irrigated paddy, vary from lowlands to highlands. Therefore, farmers and higher authorities need a wide range of interviewees to minimize errors and suspicions. This research must involve field verification during the dry seasons and the gathering of details about the rainy season from farmers in each agricultural land-use class. For more precise outcomes, soil verification must be carried out in both seasons. In the same way, the examination of water intake must be conducted for one year. Besides, the irrigation efficiency of 30 percent assumed in this research may lead to errors, as the irrigation efficiency may vary based on soil type and crop type.

CONCLUSIONS

In this research, land-use groups were plotted out using two images of Landsat 8 from March 2016 and December 2016. The critical varying land uses included the cultivation of irrigated and mixed irrigated crops. The ground cover in the catchment area is changing rapidly. The measure of irrigated areas for paddy ranged from 6.61 percent in March (non-monsoon season) to 10.34 percent in December (monsoon season), whereas the percentage of irrigated areas for wheat ranged from 7.1 % in March (non-monsoon season) to 10.68 % in December (monsoon season). The percentage of irrigated areas for soya beans ranged from 22.3 % in March (non-monsoon season) to 24.2% in December (monsoon season) and land use for maize ranged from 1.5% in March (non-monsoon season) to 0.37% in December (monsoon season).

The estimates of water requirement are expressively changed by using LULC maps based on the estimated maximum irrigated paddy withdrawals of 800 million m^3 per year (56.2 cm/year); however, using LULC maps could overestimate the water requirement for irrigation in the catchment area. However, the opposite is also valid. Unfortunately, there are no tests or measured values for each irrigated agricultural land use in this catchment area to authenticate our results.

However, this research demonstrates that the use of land-use maps would increase the quantification of water requirement based on the reflection of the varying area of irrigated land over the year by surveys and site visits. Additionally, detailed research on LULC maps offers valuable information on hydrological models, water accounting schemes, land-use policies and policy decisions. The seasonal distribution of water in the basin can also be measured with the help of detailed seasonal land-use maps.

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REFERENCES

Adib Arash, and Iman Ahmadeanfar. (2018). "Comparative study of SDP and DP methods for optimal water release from reservoirs: A case study on the Dez dam, Iran." Jordan Journal of Civil Engineering, 12 (1), 22-34.

Aerts, J. C.J.H., Kriek, M., and Schepel, M. (1999). "STREAM (spatial tools for river basins and environment and analysis of management options): Set-up and requirements". Physics and Chemistry of the Earth-Part B: Hydrology, Oceans and Atmosphere, 24 (6), 591-595. https://doi.org/10.1016/S1464-1909(99) 00049-0.

Alawamy, Jamal Suliman, Siva K. Balasundram, Ahmad Husni Mohd Hanif, and Christopher Teh Boon Sung. (2020). "Detecting and analyzing land-use and land-cover changes in the region of Al-Jabal Al-Akhdar, Libya using time-series Landsat data from 1985 to 2017." Sustainability (Switzerland), 12 (11). https://doi.org/10.3390/su12114490.

Cambien, Naomi, Sacha Gobeyn, Indira Nolivos, Marie Anne Eurie Forio, Mijail Arias-Hidalgo, Luis Dominguez-Granda, Felix Witing, Martin Volk, and Peter L.M. Goethals. (2020). "Using the soil and water assessment tool to simulate the pesticide dynamics in the data-scarce Guayas river basin, Ecuador." Water (Switzerland), 12 (3), 1-21. https://doi.org/10.3390/w12030696.

Cheema, M.J.M., and Bastiaanssen, W.G.M. (2010). "Land-use and land-cover classification in the irrigated Indus basin using growth phenology information from satellite data to support water management analysis." Agricultural Water Management, 97 (10), 1541-1552. https://doi.org/10.1016/j.agwat.2010.05.009.

Delft, FAO, and IHE. (2020). "Water accounting in the Nile river basin". Rome.

Dhawan, Vibha. (2017). "Water and agriculture in India." Background Paper for the South Asia Expert Panel during the Global Forum for Food and Agriculture, 28. https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf.

Eekelen, M.W. van, W.G.M. Bastiaanssen, C. Jarmain, B. Jackson, F. Ferreira, P. van der Zaag, A. Saraiva Okello et al. (2015). "A novel approach to estimate direct and indirect water withdrawals from satellite measurements: A case study from the Incomati basin." Agriculture, Ecosystems and Environment, 200, 126-142. https://doi.org/10.1016/j.agee.2014.10.023.

Egorov, A.V., Hansen, M.C., Roy, D.P., Kommareddy, A., and Potapov, P.V. (2015). "Image interpretation-guided supervised classification using nested segmentation." Remote Sensing of Environment, 16, 135-147. https://doi.org/10.1016/j.rse.2015.04.022.

Elizabeth, A., and Robert, E. (2013). "Water balance estimates of evapotranspiration rates in areas with varying land use." Evapotranspiration-An Overview, 1-22. https://doi.org/10.5772/52811.

Foster, T., Mieno, T., and Brozović, N. (2020). "Satellite-based monitoring of irrigation water use: Assessing measurement errors and their implications for agricultural water management policy." Water Resources Research, 56 (11). https://doi.org/10.1029/2020WR028378.

Hashim, H., Abd Latif, Z., and Adnan, N.A. (2019). "Urban vegetation classification with NDVI threshold value method with very high resolution (VHR)-pleiades imagery." International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42 (4/W16), 237-240. https://doi.org/10.5194/isprs-archives-XLII-4-W16-237-2019.

Jiang, Zhangyan, Alfredo R. Huete, Jin Chen, Yunhao Chen, Jing Li, Guangjian Yan, and Xiaoyu Zhang. (2006). "Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction." Remote Sensing of Environment, 101 (3), 366-378. https://doi.org/10.1016/j.rse.2006.01.003.

Karimi, P., Bastiaanssen, W.G.M., Molden, D., and Cheema, M.J.M. (2013). "Basin-wide water accounting based on remote sensing data: An application for the Indus basin." Hydrology and Earth System Sciences, 17 (7), 2473-2486. https://doi.org/10.5194/hess-17-2473-2013.

Kumar Gaur, Mahesh, Moharana, P.C. Pandey, C.B., Chouhan, J.S., and Prachi Goyal. (2015). "High-resolution satellite data for land-use/land-cover mapping: A case study of Bilara Tehsil, Jodhpur district." Annals of Arid Zones, 54 (3&4), 125-132.

Liu, Xiong. (2003). "Supervised classification and unsupervised classification." CFA Harvard Edu., 1-12. http://www.cfa.harvard.edu/~xliu/presentations/SRS1_project_report.PDF.

Lu, Yuting, Penghai Wu, Xiaoshuang Ma, and Xinghua Li. (2019). "Detection and prediction of land-use/land-cover change using spatiotemporal data fusion and the cellular automata Markov model." Environmental Monitoring and Assessment, 191 (2). https://doi.org/ 10.1007/ s10661-019-7200-2.

Maglana, Jesi Martin R., Hazel Olive O. Parmes, Aaron Charles C. Yu, Ricardo L. Fornis, and Aure Flo A. Oraya. (2020). "An attempt to classify landcover of the Butuanon river catchment using Landsat images covering the years from 1993 to 2019 for rainfall-runoff modeling." AIP Conference Proceedings 2278. https://doi.org/10.1063/5.0015027.

Mishra, Prabuddh Kumar, Aman Rai, and Suresh Chand Rai. (2020). "Land-use and land-cover change detection using geospatial techniques in the Sikkim Himalaya, India." Egyptian Journal of Remote Sensing and Space Science 23 (2), 133-143. https://doi.org/ 10.1016/j.ejrs.2019.02.001.

Morlin Carneiro, Franciele, Carlos Eduardo Angeli Furlani, Cristiano Zerbato, Patricia Candida de Menezes, Lucas Augusto da Silva Gírio, and Mailson Freire de Oliveira. (2020). "Comparison between vegetation indices for detecting spatial and temporal variabilities in soybean crop using canopy sensors." Precision Agriculture, 21 (5), 979-1007. https://doi.org/10.1007/s11119-019-09704-3.

Naser, Mohammed A., Raj Khosla, Louis Longchamps, and Subash Dahal. (2020). "Using NDVI to differentiate wheat genotypes' productivity under dryland and irrigated conditions." Remote Sensing, 12 (5). https://doi.org/10.3390/rs12050824.

Pereira, Andre, and Luiz Pires. (2011). "Evapotranspiration and water management for crop production." Evapotranspiration: From Measurements to Agricultural and Environmental Applications. https://doi.org/10.5772/20081.

Singh, Rinku, and Singh, G.S. (2017). "Traditional agriculture: A climate-smart approach for sustainable food production." Energy, Ecology and Environment, 2 (5), 296-316. https://doi.org/10.1007/s40974-017-0074-7.

Singh, Vimla, and Alok Dubey. (2012). "Land-use mapping using remote sensing and GIS techniques in Naina-Gorma basin, part of Rewa district, MP, India." International Journal of Emerging Technology and Advanced Engineering, 2 (11), 151-156.

Stella, Juan M. (2019). "Mathematical methodology to calculate the rate of water storage." International Journal of Hydrology, 3 (1), 11-16. https://doi.org/10.15406/ijh.2019.03.00156.

Sultana, Syeda Refat, Amjed Ali, Ashfaq Ahmad, Muhammad Mubeen, M. Zia-Ul-Haq, Shakeel Ahmad, Sezai Ercisli, and Hawa Z.E. Jaafar. (2014). "Normalized difference vegetation index as a tool for wheat yield estimation: A case study from Faisalabad, Pakistan." Scientific World Journal, 2014. https://doi.org/10.1155/2014/725326.

Talib, Ammara. (2014). "Impacts of land cover and climate change on water resources in Suasco river watershed." University of Massachusetts – Amherst, 13 (4), 881-889.

Tang, Wan, Jun Hu, Hui Zhang, Pan Wu, and Hua He. (2015). "Kappa coefficient: A popular measure of rater agreement." Shanghai Archives of Psychiatry, 27 (1), 62-67. https://doi.org/10.11919/j.issn.1002-0829. 215010.

Thneibat, Mujahed. (2019). "Consumer perceptions of water-saving devices in water-scarce regions." Jordan Journal of Civil Engineering, 13 (4), 508-520.

Thomas, T., Gunthe, S.S., Sudheer, K.P., and Ghosh, N.C. (2015). "Analysis of monsoon rainfall variability over Narmada basin in central India: Implication of climate change." Journal of Water and Climate Change, 6 (3), 615-627. https://doi.org/10.2166/wcc.2014.041.

Viana, Cláudia M., Sandra Oliveira, Sérgio C. Oliveira, and Jorge Rocha. (2019). "Land-use/land-cover change detection and urban sprawl analysis: Spatial modeling in GIS and R for earth and environmental sciences". Elsevier, Inc. https://doi.org/10.1016/b978-0-12-815226-3.00029-6.

Weerasinghe, Imeshi, and Ann Van Griensven. (2019). "Accounting for seasonal land-use dynamics to water withdrawals". Water, 11 (2471).

Wichelns, Dennis. (2016). "Managing water and soils to achieve adaptation and reduce methane emissions and arsenic contamination in Asian rice production." Water (Switzerland), 8 (4). https://doi.org/10.3390/w8040141.

Xu, Dandan. (2014). “Comparing NDVI extracted from Landsat 8 imagery with that from Landsat 7 imagery.” American Journal of Remote Sensing, 2 (2), 10. https://doi.org/10.11648/j.ajrs.20140202.11.

Xue, Jinru, and Baofeng Su. (2017). “Significant remote sensing vegetation indices: A review of developments and applications.” Journal of Sensors, 2017. https://doi.org/10.1155/2017/1353691.

Yesuph, Asnake Yimam, and Amare Bantider Dagnew. (2019). “Land-use/cover spatiotemporal dynamics, driving forces and implications at the Beshillo catchment of the Blue Nile basin, north-eastern highlands of Ethiopia.” Environmental Systems Research, 8 (1). https://doi.org/10.1186/s40068-019-0148-y.