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Wheat Crop Growth Monitoring using Multi-Spectral Vegetation Indices in Bhal Region, Gujarat State

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ABSTRACT: The applications of Remote Sensing techniques in the field of agriculture are wide and varied ranging from crop discrimination, inventory, assessment and parameter retrieval and assessing long-term changes and short-term characterization of the crop environment. The spectral crop profile development, as monitored using Vegetations Indices derived using Multi-Spectral Remote Sensing data offers unique advantages in crop identification and crop growth stage estimation. The analysis based on values of Normalized Difference Vegetation Index (NDVI) at regular time interval provides useful information about various crop growth stages and performance of crop in a season. In the present study, Multi-date Landsat-8 data for the Rabi crop season from October-2017 to April-2018, covering Dholka and Dhandhuka Talukas in Ahmedabad District, was downloaded from https://earthexplorer.usgs.gov/. The spectral Vegetation Indices (VIs) namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and short-wave infrared - Water Stress (SWIR - WSI) Index were generated using the NIR, RED and SWIR channel digital data. Field data was collected in the selected sample locations in the study area for identification of wheat and other competing crops grown during rabi season.

Multi-date spectral indices of wheat & cotton were generated at different growth stages. The spectral profiles of these two crops indicate that the crops are well separated at different growth stages since their crop phenology is quite distinct. The Water Stress Index (WSI) and Normalized Difference Vegetation Indices (NDVI) resulted the exactly opposite profiles and their intersection points can also indicate about the spectral emergence and physiological maturity stages of wheat crop. The study revealed that during normal crop season, the NDWI values were positive for both the crops throughout the growing season. The positive values of NDWI were due to higher NIR-Channel reflectance than SWIR-channel, which indicates sufficient quantities of water in the vegetation canopy.

Keywords: Remote Sensing and GIS; Spectral Vegetations Indices; Normalized Difference Vegetation Index (NDVI); Crop growth stages; Normalized Difference Water Index (NDWI), Short-wave infrared - Water Stress (SWIR - WSI) Index

1. INTRODUCTION

From the very beginning, agriculture is one of the most important sectors for India. Agriculture is the only major source of food supply as it is providing regular supply of food to such huge size of population of our country. To full fill these requirements and proper planning for this sector needs relevant and reliable information in timely manner. Planning commission of India recognizes the crucial role of remote sensing (RS) technology in

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generating quality crop statistics (Gupta and Rajan, 2009). India is one of the few select countries which have a reliable system of generating forecast of crop production, methods to evaluate crop health, etc... Using Remote Sensing and other collateral sets of data. Since crop is a very sensitive biological system which is affected by many biotic and abiotic factors, it is essential to have dynamic assessment crop condition so that crop growth cycle can be simulated and reliable forecasts of crop production can be generated and modulated. The chronological sequence of the occurrence of different physiological stages of a crop in its growth cycle forms the crop calendar. Crop calendar is one way of summarizing the information of a crop cycle. Information about crop calendar is essential for monitoring a crop growth for proper management of agriculture.

1.1 Crop Growth Monitoring Using Multi-Temporal Remote Sensing data

Remote sensing sensors provide a regular, consistent and reliable measurement of vegetation response at various growth stages of crop. Therefore, it is ideally suited for monitoring purpose. The spectral response of vegetation, as measured by the Normalized Difference Vegetation Index (NDVI) and its profiles, can provide a new dimension for describing vegetation growth cycle. The analysis based on values of NDVI at regular time interval provides useful information about various crop growth stages and performance of crop in a season. Remote sensing-derived information is used to evaluate spatial and temporal variations in crop growth, crop stress and supports for decision-making for agricultural development (Campbell 1987). The spectral characteristic of vegetation is governed by absorption and scattering. Cellular structure and water content of leaves are detected in near infrared (NIR) and mid-infrared region of wavelength, whereas leaf pigments are detected by visible band (Ripple 1986; Price 1987). Chlorophyll and water content of vegetation are used as major indicator of plant stress. In stressed vegetation, chlorophyll content decreases which results in overall variation in absorption of light by leaf pigments. Consequently, it directly affects spectral signature of plant by decreasing reflection in green band and increasing in blue and red band resulting in changing normal spectral signature of plants. In infrared region, short wave infrared (SWIR) band is sensitive to equivalent water thickness while NIR band is sensitive to variations in dry matter content. NIR and SWIR bands are used to detect effects of drought on vegetation water content and water stress (Ghulam *et al.*, 2008).

1.2 Spectral Vegetation Indices and Water Stress

Vegetation indices (VI) computed from satellite images gives an indication of the presence of vegetation and its health. Several studies on remote sensing applications have proved that VI can be used effectively in crop monitoring as well as in characterizing the vegetation with phenology. Time series profiles of VI derived from satellite data are potential tools to interpret the dynamics and phenological development of vegetation in different areas. The water indices using SWIR band are emerged as more useful indices in extracting information about vegetation water status, water sustainability studies and in drought detection (Kim, 2006). SWIR region is least affected by ozone and Rayleigh scattering; moreover, it is also less affected by water vapour and aerosol content (Vermote *et al.*, 2002). Several spectral indices derived from SWIR and NIR have been used to detect drought effects on vegetation (Tucker 1980).

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The present study demonstrates the use of temporal NDVI data in extracting key phenological information (i.e. spectral emergence, peak vegetative stage and physiological maturity) by interpreting temporal variations in spatial domain to generate crop calendar. The major objective of this study was to monitor the crop growth and crop phenological cycle of wheat and cotton crop using the Multi-date Landsat-8 data - derived spectral vegetation indices. Remote sensing (RS) has stood out as a technique that allows to monitor agricultural crops along their development cycle (Gao *et al.,* 2017). Vegetation indices are contrasts of the reflectance of the spectral bands, and the normalized difference vegetation index (NDVI) is widely used in agriculture, because of its easy application, allowing a fast and efficient detection of variations in the vegetation (Rouse *et al.*, 1974).

2. METHODOLOGY

2.1 Study Area

Ahmedabad District is one of the developed districts of the Vibrant Gujarat. It is located in the middle region of Gujarat and lies between $21^0$58’ to $23^0$3’ North latitudes, $71^0$37’ to $72^0$50’ East Longitudes. The District is surrounded on the north by Mehsana and Gandhinagar district, on the South by Gulf of Cambay and Bhavnagar district, on the East by Kheda district and on the West by Surendranagar district. The total Geographical area of Ahmedabad District is 8087.59 Sq. Km. Ahmedabad is spread across ten talukas - Barwala, Daskroi, **Dholka, Dhandhuka**, Detroj, Sanand, Bavla, Ranpur, Mandal and Viramgam. The present study wascarried out for Dholka and Dhandhuka taluka of Ahmedabad district which are famous for bhalia wheat production in the district, and are the major wheat producing taluks amongst others. The location map of the Ahmedabad District with selected two talukas is given in **Figure-1.**

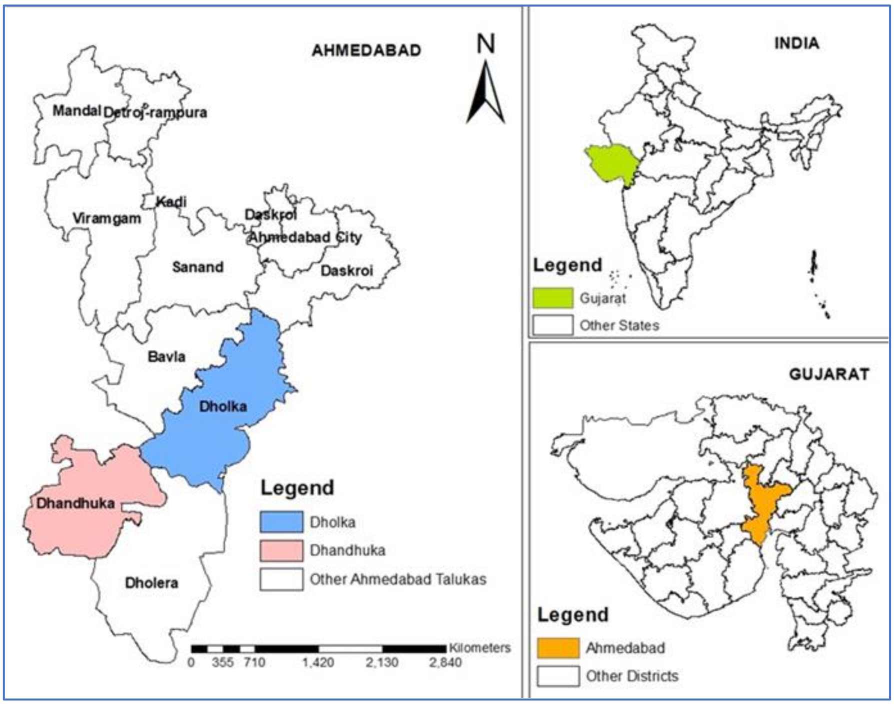

Figure-1 location map of the Ahmedabad District with study area Dholka and Dhandhuka

2.2 Agricultural cropping system of Bhal region

The significant aspect of the rural environment of the Bhal region is that of an agricultural economy in which 90% of the population derives its sustenance from agriculture. Most of the land in the region is cultivated only during the winter season and the land remains fallow in the rest of the months due to flood and drought conditions during monsoon and summer seasons, respectively. Nearly 93% of the farming is rainfed. In coastal and sub-coastal units, cultivation is absolutely impossible during the rainy months due to water-logged conditions. Crops are grown depending on the land condition in relation to flooding during the monsoon and soil moisture conditions during the dry months. In the region most of the crops are sown during rabi and kharif season. The main kharif crops like, Bajra and Paddy are sown in July and harvested during October or November. Rabi crops like, wheat, jowar are grown in October and harvested in March. Lack of irrigation in the region is one of the main causes for the backwardness in agriculture. The major crops cultivated by farmers are cotton, bajra, gram in Kharif and in case of waterlogged area wheat & gram, cumin in rabi season.

The cropping pattern also shows high relationship with the physical and climatic conditions of different ecological units. There is a preponderance of food crops over non-food crops as it occupies 70% of the gross cropped area followed by cash crops (15%), fodder crops (10%) and oilseed (5%), Within the food crops about 60% area is under food grains and the rest of the area is under pulses. In terms of acreage, millets including coarse grain with bajra and jowar are the major crops which are followed by wheat and pulses. In terms of acreage covered under individual crops, there is a distinct variation within the region. Nearly 70% of the total net sown area under wheat crop is mostly concentrated in the northern and north western parts of the region. The north eastern part, with sufficient supply of water through canals and presence of clay soil is better suited for paddy cultivation. A large proportion of land in coastal unit is not suitable for food crops due to the condition of salinity and non-availability of irrigation facility. Hence, this area practices only local variety of cotton and fodder crops (Jowar, Roika, Chikori) only during or after the monsoon season.

2.3 Wheat Area and Production Statistics

Wheat is the one of the staple foods of north Indian population. Analysis of area, production and productivity of wheat during the last decade (1999-00 to 2013-14) indicated that the major wheat producing states that achieved the average productivity of 3t/ha and above are Uttar Pradesh (98.56 lakh ha), Punjab (35 lakh ha), Haryana (25.22 lakh ha), Rajasthan (30.80 lakh ha). The significantly contributing states are Madhya Pradesh (57.92 ha), Bihar (22.57 lakh ha), Jharkhand (1.73 lakh ha), Gujarat (13.51 lakh ha), West Bengal (3.35 lakh ha) and Uttarakhand (3.48 lakh ha) are with the productivity category range of 2-3 t/ha. Maharashtra (10.97 lakh ha), J&K (2.93 lakh ha) and HP (3.56 lakh ha) are largely rainfed wheat growing states and have little more than 1.5 t/ha productivity. These States contribute about 99% of total wheat production in the country. In the study area, the area under wheat varies greatly from 0.42% to 65.8% by the number of factors influencing wheat cultivation in Ahmedabad district. The best quality of wheat, locally called 'Daudkhani or Bhalia' is produced mostly in Dhandhuka and Dholka talukas. The important feature of this variety is that it grows on the moisture condition of soil available during the post-monsoon season. The area under wheat cultivation in Ahmedabad district and Gujarat State from 1989-90 to 2015-

16 is given in **Figure-2**, which clearly indicates that the area under wheat cultivation in Ahmedabad district has increased by almost 100% within last 30 years with the area of 125600 ha in 2016-17.

2.4 Data Analysis

The data analysis methodology was divided into four stages. First steps include the collection and processing of Raster and Vector Data. Landsat-8 OLI images from USGS Earth Explorer have been downloaded for winter season of 2018-19. The data analysis flow chart adopted for Wheat Growth Pattern Analysis is given in **Figure-3**. In the pre-processing section, Landsat data of different dates was layer-stacked of different bands and then subsets of satellite data were extracted covering the study area. Layer stacking is a process for combining multiple band digital data into single image. Then Radiometric correction was applied to convert DN to radiance. At last, the Atmospheric correction applied to the Satellite Imaging Model to eliminate or reduce the influence of solar and atmospheric illumination. Standard atmosphere, aerosol type, solar zenith angle and ground elevation range were some of the major inputs used in this model.

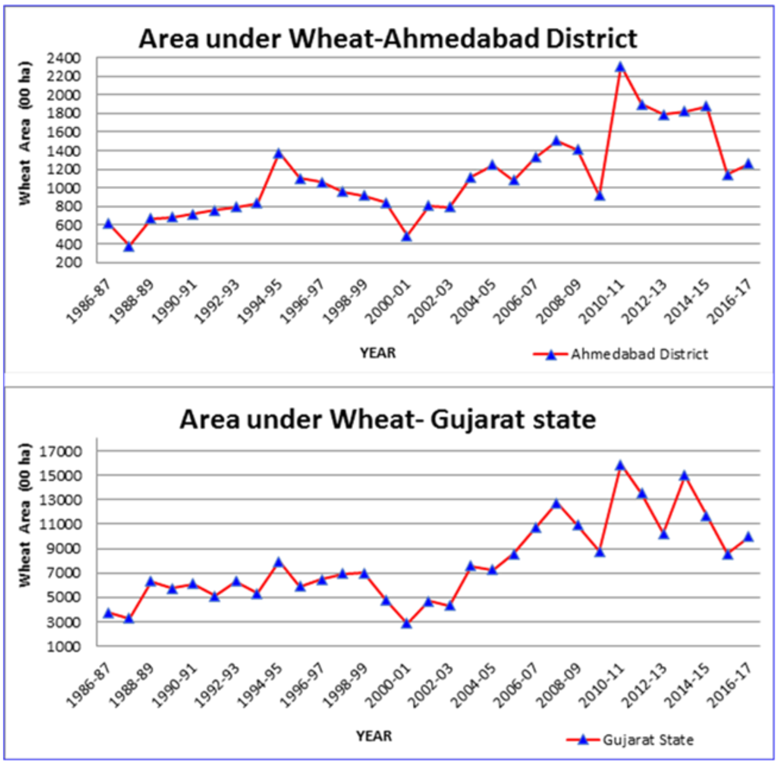

Figure-2: Area under Wheat in Ahmedabad District and Gujarat State
(Data Source: Deptt. of Agriculture, Govt. of Gujarat)

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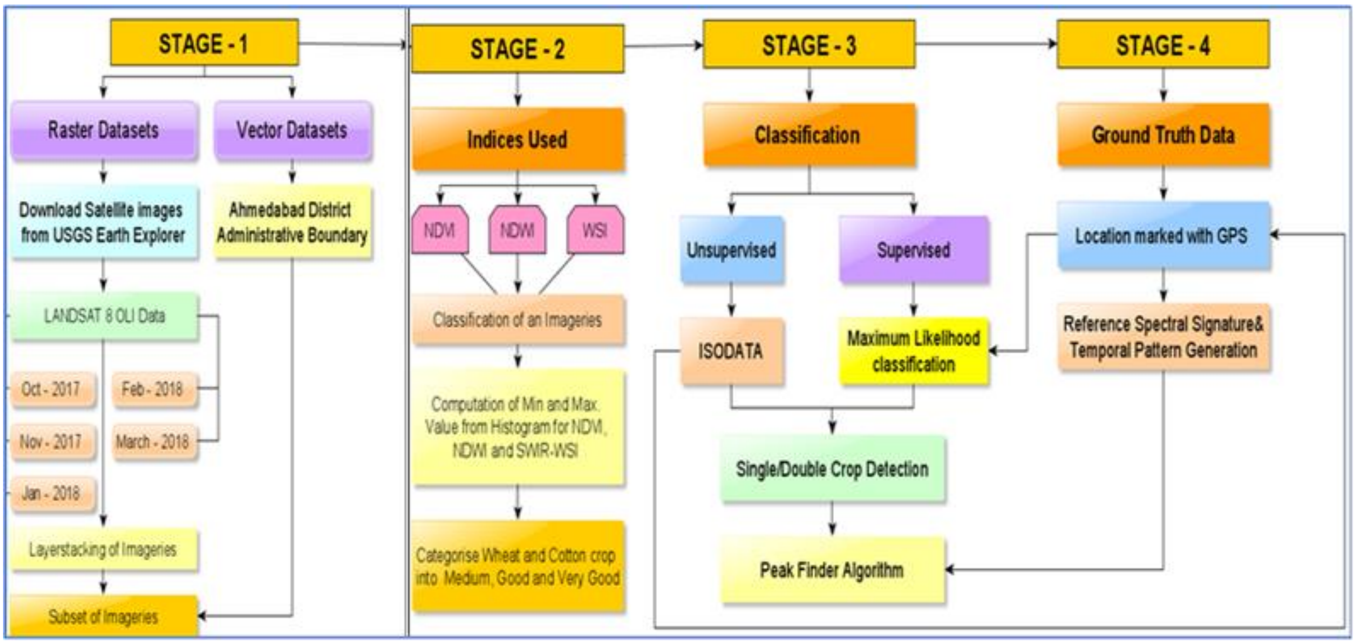

Figure-3: Methodology Flow-chart for Wheat Growth Analysis

2.5 Satellite Data used

In the present study, Multi-date, multi-spectral digital data from Landsat-8 OLI for the Rabi crop season from October-2017 to March-2018, covering Dholka and Dhandhuka Talukas in Ahmedabad District, were downloaded from https://earthexplorer.usgs.gov/. The administrative boundaries like district, taluka and village boundaries of Dholka and Dhandhuka taluka were generated and used for extracting satellite data covering the study area in Ahmedabad District, Gujarat State. All raw images were pre-processed (geo-referencing, resampling, atmospheric correction) to get reflectance data in same WGS-84 geo-matric datum. **T**he Landsat-8 satellite launched on 11-February-2013 carries two instruments: the OLI and the Thermal Infrared Sensor (TIRS). The OLI instrument provides enhancement from prior ETM+sensor, with the addition of two new spectral bands: a deep blue VIS channel (band 1) and a new infrared channel (band-9). The TIRS instrument has two spectral bands (bands-10 and 11). The Landsat data in the VIS, NIR, and MIR channels of OLI sensors have a spatial resolution of 30×30m (Louati, Saïdi, & Zargouni, 2014). The details of Landsat digital data acquired are given in **Table-1.** The multi-date Landsat-8 digital data of winter season of 2017-18 covering Dholka and Dhandhuka Taluka are given in **Figure-4**.

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Table-1: Details of Landsat-8 Multi-spectral Data acquired during 2017-18

Sr. No.	Satellite / Sensor	Spatial Resolution (m)	Path /Row	Acquisition Date
1	Landsat-8 / OLI	30	149/44	04-Oct-2017
2.	Landsat-8 / OLI	30	149/44	20-Oct-2017
3.	Landsat-8 / OLI	30	149/44	05-Nov-2017
4.	Landsat-8 / OLI	30	149/44	08-Jan-2018
5.	Landsat-8 / OLI	30	149/44	24-Jan-2018
6.	Landsat-8 / OLI	30	149/44	25-Feb-2018
7.	Landsat-8 / OLI	30	149/44	13-Mar-2018
8.	Landsat-8 / OLI	30	149/44	29-Mar-2018

2.6 Ground Truth Data Collection

Field data collection was carried out in the selected areas for Dhandhuka taluka in Ahmedabad district. Field data on crops grown, crop growth stage, Crop variety, Global Positioning System (GPS) location, field size, etc. was collected. The other competing crops observed in the district were cotton, Jowar, Roika, Chikori. The GPS measurements of wheat and cotton sites in the various parts of the taluka were used to identify the wheat and cotton crop on the Multi-date Landsat-8 data. The GPS measurements of selected sites in taluka of Ahmedabad district along with field photographs were recorded. Some of the field photographs of crops at different growth stages are given in **Figure-5**.

2.7 Generation of Spectral Vegetation Indices (SVI)

The various Spectral Vegetation indices namely, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Water Stress Index (WSI) were computed. The Minimum, Maximum and Mean Histogram values for three spectral indices were computed for wheat areas and finally classified into Medium, Good and Very Good based on the field data collected at various selected locations in the study area.

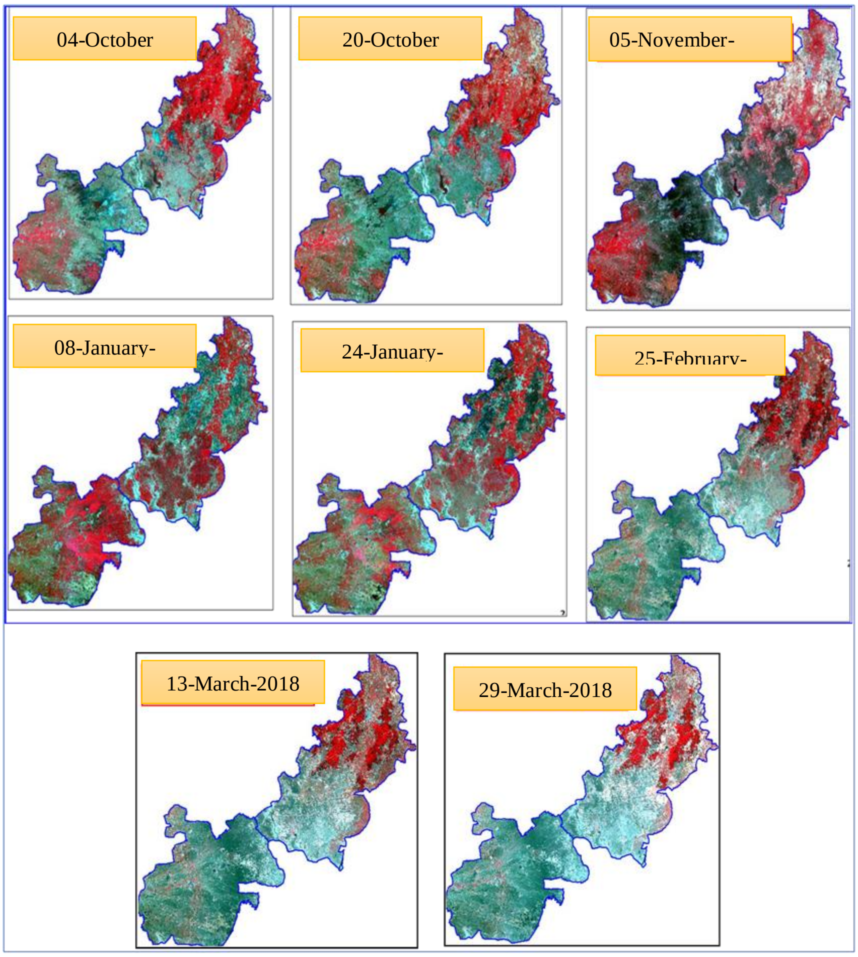

Figure-4: Multi-date Landsat-8 covering Dholka and Dhandhuka Talukas

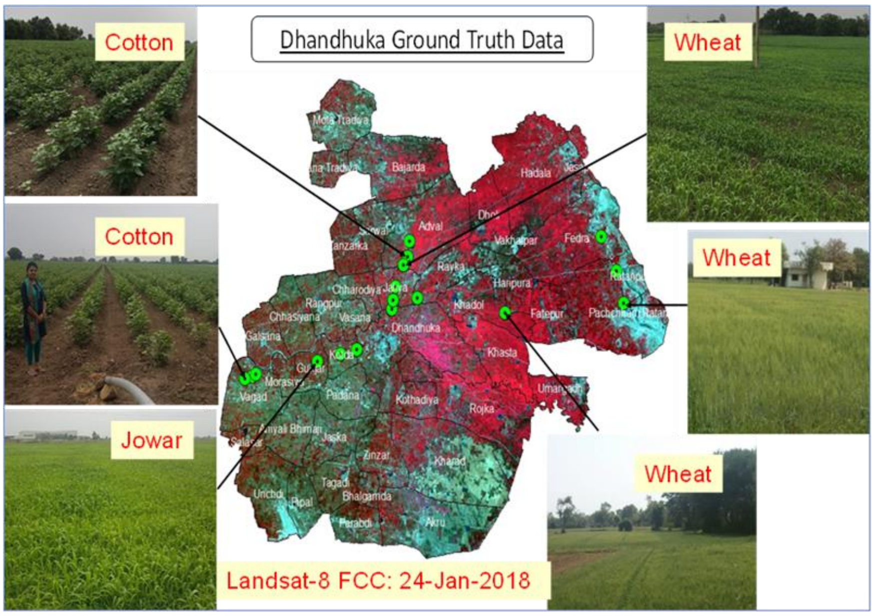

Figure-5: Field Photographs of Wheat and other crops in Dhandhuka Taluka

2.7.1 Normalized Difference Vegetation Index (NDVI)

Normalised Difference Vegetation Index (NDVI) utilises the absorptive and reflective characteristics of vegetation in the red and near infrared portions of the electromagnetic spectrum. Therefore, changes in the NDVI time-series indicate changes in vegetation conditions proportional to the absorption of photosynthetically active radiation (Sellers, 1985). Therefore, NDVI was used in the present study. For each 8-day composite, we calculated NDVI using surface reflectance values from the red (620–670 nm), NIR (841– 875 nm) bands using following equation:

NDVI = NIR – RED / NIR + RED

where, NIR and Red represent reflectance in NIR and Red region of electromagnetic spectrum, respectively. The NDVI is found to be an effective measure for crop growth assessment and monitoring. Satellite data are radiometrically normalized to compensate for changes in radiation caused by differences in illumination, atmospheric conditions, sun zenith angle, sensor and satellite characteristics, time of data acquisition, etc. (Jonna *et al.*, 1994).

2.7.2 Generation of Normalized Difference Water Index (NDWI)

NDWI refer to remote sensing-derived indexes related to liquid water: NDWI is used to monitor changes related to water content in water bodies, using green and NIR wavelengths, defined by McFeeters (1996);

NDWI = (GREEN (band 3) – NIR (band 5) / (GREEN (band 3) + NIR (band 5)

The NDWI is a remote sensing-based indicator sensitive to the change in the water content of leaves. Value of NDWI ranges between -1 to +1.

2.7.3 Generation of Short-Wave Infrared-Water Stress Index (SWI-WSI)

Two configurations of a water stress index, SIWSI(6,2) and SIWSI(5,2) are derived on a daily basis from the MODIS satellite data using the information from the near infrared (NIR) channel 2 (841–876 nm) and the shortwave infrared channel 5 (1230–1250 nm) or 6 (1628–1652 nm), respectively, which are wavelength bands at which leaf water content influence the radiometric response. The indices are compared to in situ top layer soil moisture

It is well known that large absorption by leaf water occurs in these wavelengths and therefore, short-wave infrared (SWIR) reflectance is negatively related to leaf water content (Tucker, 1980, Ceccato *et al.*, 2002). The largest of these regions is 1.3 – 2.5 μm interval (SWIR) where the amount of water available in the internal leaf structure largely controls the spectral reflectance (Tucker, 1980).

SWI-WSI = (SWIR - NIR) / (SWIR + NIR)

3. RESULT AND DISCUSSION

3.1 Multi-temporal profiles of Spectral Vegetation Indices of Wheat Crop

The spatial and temporal variation of crop growth based on the spectral Vegetation Indices (VIs) namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Short-Wave Infrared - Water Stress (SWIR - WSI) Index were generated using the NIR, RED and SWIR channel digital data covering Dholka and Dhandhuka talukas of Ahmedabad district for the Rabi crop season from October-2017 to March-2018 using Multi-date Landsat-8 digital data. The locations of wheat and cotton crops along with other land use classes were identified on the Landsat-8 OLI images and VI images based on the field data & GPS measurements. The polygons of homogeneous sample areas having more than 100 pixels were marked on these images. Using these polygons of sample areas, the histograms of Digital Number (DN) values in four Landsat-8 OLI bands i.e. 3, 4, 5, and 6 were generated and then average DN values for each cover type have been computed. The mean, minimum, maximum and standard deviations of the NDVI, NDWI and SWIR-WSI were computed for all image data sets. To understand the trends of the indices, the mean values of the selected sites were plotted. Multi-date spectral indices of wheat & cotton were generated at different growth stages. The spectral profiles of these two crops (wheat and cotton) indicated that these two crops are well separated at different growth stages since their crop phenology is quite distinct. The values of different spectral indices computed using the mean values of different spectral bands from sowing to maturity of wheat crop in Dhandhuka Taluka are given in **Table-2**. The mean Spectral Indices namely NDVI, NDWI and SWIR-WSI are given in **Table-3** of wheat from sowing to maturity in Dhandhuka. The Spectral Growth Profiles of Wheat in Dhandhuka Taluka were plotted **(Figure-6)** using mean values SVIs given in Table-3.

Table-2: Mean spectral band values and Scaled Spectral Indices and from sowing to maturity of wheat in Dhandhuka

Dhandhuka Wheat										
Sr.No.	**Date**	**Days**	**Category**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**	**NDWI**	**SWIR-WSI**
1	05-Nov-17	5	Dhandhuka Wheat 1	768.469	832.791	1154.205	1122.911	115.574	100.962	98.046
			Dhandhuka Wheat 2	855.312	945.031	1350.29	1572.7	117.067	91.967	107.033
2	21-Nov-17	21	Dhandhuka Wheat 1	653.303	659.871	1273.277	1105.45	131.033	106.333	92.669
			Dhandhuka Wheat 2	810.12	837.922	1508.523	1507.831	128.022	99.488	99.517
3	07-Dec-17	37	Dhandhuka Wheat 1	3180.746	3173.982	3709.514	3228.721	114.25	109.044	89.956
			Dhandhuka Wheat 2	818.082	627.245	1959.898	1367.212	151.051	117.285	81.715
4	08-Jan-18	69	Dhandhuka Wheat 1	706.563	530.048	3774.767	1642.823	174.766	138.77	60.232
			Dhandhuka Wheat 2	569.263	440.466	2578.143	1224.165	170.236	135.08	63.92
5	24-Jan-18	85	Dhandhuka Wheat 1	752.64	674.58	3507.095	1622.762	166.824	135.929	63.072
			Dhandhuka Wheat 2	749.581	798.768	2586.461	1504.085	152.312	125.953	73.047
6	25-Feb-18	117	Dhandhuka Wheat 1	804.73	995.445	1541.719	1470.048	120.953	101.801	97.204
			Dhandhuka Wheat 2	1204.203	1572.187	2677.788	2275.468	125.572	107.746	91.254
7	13-Mar-18	133	Dhandhuka Wheat 1	756.73	941.614	1389.781	1379.204	118.661	99.826	99.183
			Dhandhuka Wheat 2	1307.548	1698.644	2716.29	2533.795	122.472	102.871	96.129
8	29-Mar-18	149	Dhandhuka Wheat 1	840.928	1045.659	1454.749	1472.091	115.857	98.904	100.099
			Dhandhuka Wheat 2	1407.755	1803.33	2628.86	2564.831	118.042	100.637	98.363

Similarly, the Values of different spectral indices computed using the mean values of different spectral bands from sowing to maturity of wheat crop in Dholka Taluka are given in **Table-4**. The mean Spectral Indices namely NDVI, NDWI and SWIR-WSI given in **Table-5**

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of wheat from sowing to maturity in Dholka were used plot the Spectral Growth Profiles of Wheat in Dholka Taluka **(Figure-7).**

Table-3: Spectral Indices of Wheat from sowing to maturity of wheat in Dhandhuka

Dhandhuka		Wheat 1			Wheat 2		
Date	**Days**	**NDVI**	**NDWI**	**SWIR-WSI**	**NDVI**	**NDWI**	**SWIR-WSI**
05-Nov-17	5	0.15574	0.00962	-0.01954	0.17067	-0.08033	0.07033
21-Nov-17	21	0.31033	0.06333	-0.07331	0.28022	-0.00512	-0.00483
07-Dec-17	37	0.1425	0.09044	-0.10044	0.51051	0.17285	-0.18285
08-Jan-18	69	0.74766	0.3877	-0.39768	0.70236	0.3508	-0.3608
24-Jan-18	85	0.66824	0.35929	-0.36928	0.52312	0.25953	-0.26953
25-Feb-18	117	0.20953	0.01801	-0.02796	0.25572	0.07746	-0.08746
13-Mar-18	133	0.18661	0.00174	-0.00817	0.22472	0.02871	-0.03871

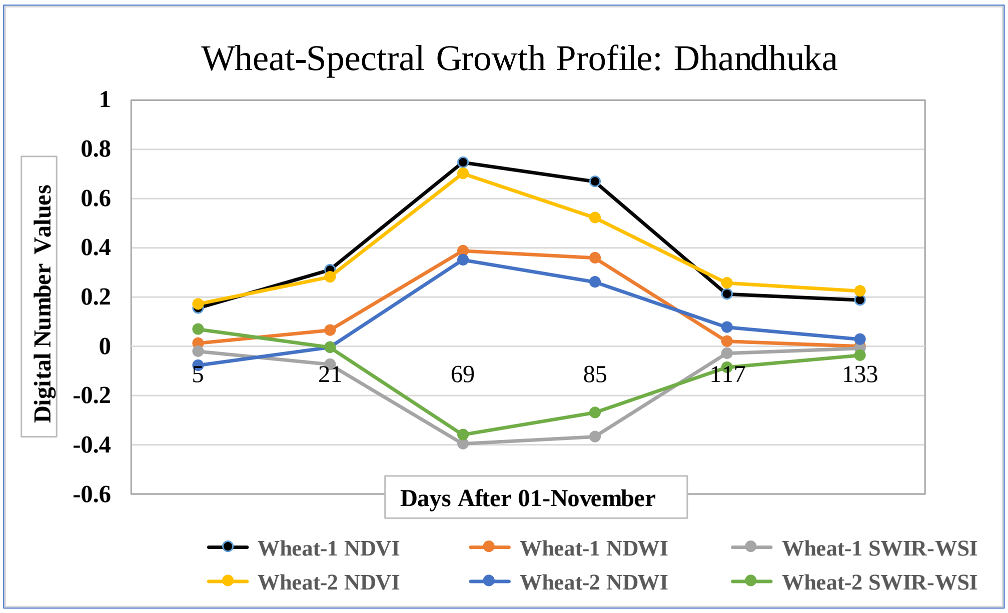

Figure-6: Spectral Growth Profiles different SVI of Wheat in Dhandhuka Taluka

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Table-4: Mean spectral band values and Scaled Spectral Indices and from sowing to maturity of wheat in Dholka

Dholka Wheat									
Sr.No	Date	Category	Band 3	Band 4	Band 5	Band 6	NDVI	NDWI	SWIR-WSI
1	05-Nov-17	Dholka Wheat 1	945.23	1058.758	1753.804	1989.183	123.821	93.018	105.982
		Dholka Wheat 2	887.49	966.213	1553.199	1862.72	122.787	90.454	108.546
2	21-Nov-17	Dholka Wheat 1	882.58	968.696	1702.696	1832.4	126.408	95.683	103.318
		Dholka Wheat 2	834.29	894.505	1636.694	1832.148	128.745	93.863	105.137
3	07-Dec-17	Dholka Wheat 1	839.36	759.501	1967.186	1650.962	143.531	108.326	90.68
		Dholka Wheat 2	767.24	688.102	1772.88	1590.438	143.486	104.877	94.127
4	08-Jan-18	Dholka Wheat 1	618.35	423.108	3223.017	1414.713	176.113	138.378	60.622
		Dholka Wheat 2	666.09	552.884	2637.37	1569.516	164.759	124.847	74.153
5	24-Jan-18	Dholka Wheat 1	558.86	426.373	3050.656	1269.356	174.93	140.734	58.266
		Dholka Wheat 2	714.59	685.275	2652.981	1594.852	158.241	124.287	74.713
6	25-Feb-18	Dholka Wheat 1	854.9	1028.747	2327.979	1794.297	138.987	112.87	86.13
		Dholka Wheat 2	917.51	1127.269	2062.065	2013.618	128.699	100.343	98.66
7	13-Mar-18	Dholka Wheat 1	1141.3	1499.293	2883.117	2673.174	131.351	103.416	95.587
		Dholka Wheat 2	1066.2	1339.097	2243.981	2398.188	124.764	95.477	103.532
8	29-Mar-18	Dholka Wheat 1	1370.4	1812.027	3159.715	3022.941	126.48	101.581	97.421
		Dholka Wheat 2	1151.1	1456.16	2248.861	2502.94	120.773	93.31	105.692

Table-5: Spectral Indices of Wheat from sowing to maturity of wheat in Dholka

Dholka		Wheat 1			Wheat 2		
Date	Days	NDVI	NDWI	SWIR-WSI	NDVI	NDWI	SWIR-WSI
05-Nov-17	5	0.2382	-0.06982	0.05982	0.22787	-0.09546	0.08546
21-Nov-17	21	0.2641	-0.04317	0.03318	0.28745	-0.06137	0.05137
08-Jan-18	69	0.7611	0.38378	-0.39378	0.64759	0.24847	-0.25847
24-Jan-18	85	0.7493	0.40734	-0.41734	0.58241	0.24287	-0.25287
25-Feb-18	117	0.3899	0.1287	-0.1387	0.28699	0.00343	-0.0134
13-Mar-18	133	0.3135	0.03416	-0.04413	0.24764	-0.04523	0.03532

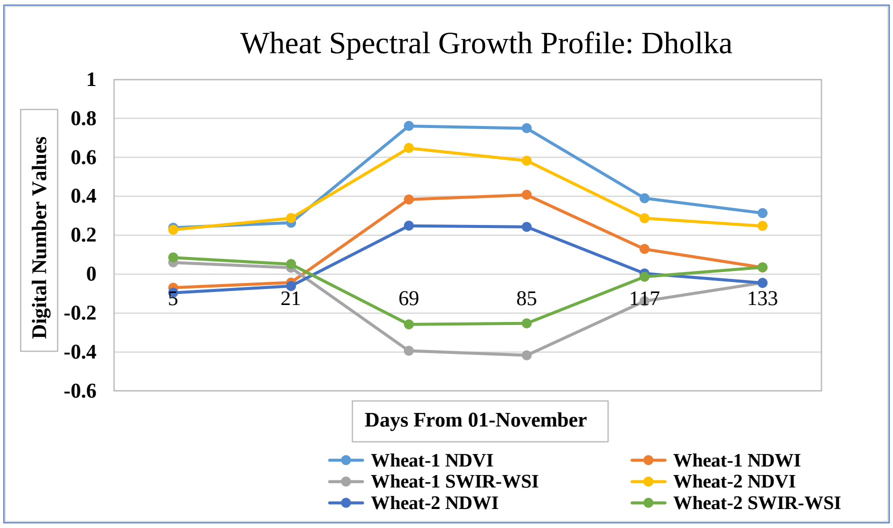

Figure-7: Spectral Growth Profiles of different SVI of Wheat in Dholka Taluka

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The Water Stress Indices (SWIR-WSI) and Normalized Difference Vegetation Indices (NDVI) computed from growing season of wheat resulted in the exactly opposite profiles. As (SWIR-WSI) results in negative values because of comparatively higher reflectance in NIR spectral region, and lower reflectance due to absorption because of moisture content, in the SWIR spectral region in SWIR-WSI equation. It is well known that large absorption by leaf water occurs in these wavelengths and therefore, short-wave infrared (SWIR) reflectance is negatively related to leaf water content (Tucker, 1980). The largest of these regions is 1.3 – 2.5 µm interval (SWIR) where the amount of water available in the internal leaf structure largely controls the spectral reflectance (Tucker, 1980). As the SWIR-WSI values increase (high negative values), which indicates increase in vegetation water content and as these values approaches '0' (zero), indicating drying of the vegetation.

Whereas, NDWI and NDVI values are positive values because of comparatively higher reflectance in Green visible spectral region, and lower reflectance due to absorption because of moisture content, in the NIR spectral region in these two equations. The spectral profiles of SWIR-WSI and NDWI during sowing to crop emergence and at the end of the crop season, cross each other at '0' (zero), on both the sides which indicate the spectral emergence after sowing and spectral maturity at the end of the crop season. The study revealed that during normal crop season, the NDWI values were positive for both the crops throughout the growing season. The positive values of NDWI were due to higher Green-Channel reflectance than NIR-channel, which indicates sufficient quantities of water in the vegetation canopy. It has also been found that all three indices used in this study were found sensitive to vegetation water content.

SWIR-WSI (Water Stress Indices) ranges from 0 to -1 and high WSI value shows the effect of crop water stress. In the month of November, VIs (Vegetation Indices) images showed the indication of crop water stress due to poor growth of Wheat-1 in Dhandhuka, Whereas Wheat-2 showed high value of water stress due to late sowing. As per temporal profiles of WSI shown in Figure-6 and Figure-7 for Dhandhuka and Dholka Talukas respectively, in the year 2017-18, wheat-1 crop in November month showed values of -0.01 and 0.05 for Dhandhuka and Dholka, respectively. Wheat crop of Dholka has shown higher values in the month of November as compared to wheat crop in Dhandhuka, which indicates late sowing of wheat in Dholka taluka in November month. In the month of February, WSI values again increased and has reached to -0.02 and -0.13 of Dhandhuka and Dholka due to senescence and so less vegetation water content. Lowest water stress values in Dhandhuka observed was -0.39 in start of January month and in Dholka it was -0.41 in the end of January month, this indicated sufficient amount of moisture content with good vegetative growth of wheat. Between the months of November to February; Water Stress indices of Dholka and Dhandhuka are continues declining with lowest numbers of -0.36 and -0.25 respectively, which indicates sufficient and good amount of moisture content.

These three vegetation indices namely, Normalized Difference Vegetation Indices (NDVI), Normalized Difference Water Indices (NDWI) and Water Stress Indices (SWIR-WSI) are showing the trend of wheat crop growth monitoring starting from sowing stage to the harvesting stage of the crop cycle through its spectral profiles of the particular crop. Not only these indices are used to analyse the crop growth, but also to detect whether the crop has been suffering from water stress or not.

3.2 Multi-temporal profiles of NDVI, NDWI and SWIR-WSI of Cotton Crop

Gujarat has long been known for the fine G. herbaceum cotton; it had been growing from the days of yore. The famous muslins of ancient India own their origin to this type of cottons. The cottons known as Oomras to the trade included G. arboreum cottons or bengelense or indicum origin grown in the Mathio track of Gujarat, possessing coarse loamy soil, called gorat. These cottons are sown in June-July and harvested in the month of October-December. Cotton is another important cash crop grown along with the wheat in the Bhal region. Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Water Stress Index (SWIR-WSI) generated only for the winter season from November to March are showing the trend of cotton crop growth monitoring starting from third picking stage of cotton to the harvesting stage of the crop cycle through its higher numbers of NDVI and NDWI; which is gradually declining to the harvest period of cotton.

The Values of different spectral indices computed using the mean values of different spectral bands from sowing to maturity of cotton crop in Dhandhuka Taluka are given in **Table-6.** The mean Spectral Indices namely NDVI, NDWI and SWIR-WSI given in **Table-7** of cotton from third picking stage to maturity in Dhandhuka were used plot he Spectral Growth Profiles of Cotton Crop in Dhandhuka Taluka (**Figure-8**).

Table-6: Mean spectral band values and Scaled Spectral Indices During Winter Season of Cotton in Dhandhuka

Dhandhuka Cotton										
Sr.No.	Date	Days	Category	Band 3	Band 4	Band 5	Band 6	NDVI	NDWI	SWIR-WSI
1	05-Nov-17	5	Dhandhuka Cotton	730.73	583.16	3342.07	1679.78	169.68	132.50	66.50
2	21-Nov-17	21	Dhandhuka Cotton	669.88	577.78	3140.58	1664.38	168.40	130.16	68.84
3	08-Jan-18	69	Dhandhuka Cotton	638.72	666.57	2363.04	1711.19	155.32	115.53	83.47
4	24-Jan-18	85	Dhandhuka Cotton	756.53	899.02	2227.16	2005.40	141.83	104.92	94.08
5	25-Feb-18	117	Dhandhuka Cotton	808.23	1010.05	1905.03	1908.08	128.84	98.24	100.76
6	13-Mar-18	133	Dhandhuka Cotton	826.91	1052.75	1815.56	1904.02	125.09	96.36	102.64

Table-7: Spectral Indices of Cotton During Winter Season of Cotton in Dhandhuka

Dhandhuka Cotton					
Sr.No.	Date	Days	NDVI	NDWI	SWIR-WSI
1	05-Nov-17	5	0.69682	0.32496	-0.33496
2	21-Nov-17	21	0.68397	0.30159	-0.31159
3	08-Jan-18	69	0.55323	0.15534	-0.16534
4	24-Jan-18	85	0.41832	0.04917	-0.05917
5	25-Feb-18	117	0.28841	-0.01762	0.00762
6	13-Mar-18	133	0.25087	-0.03637	0.02639

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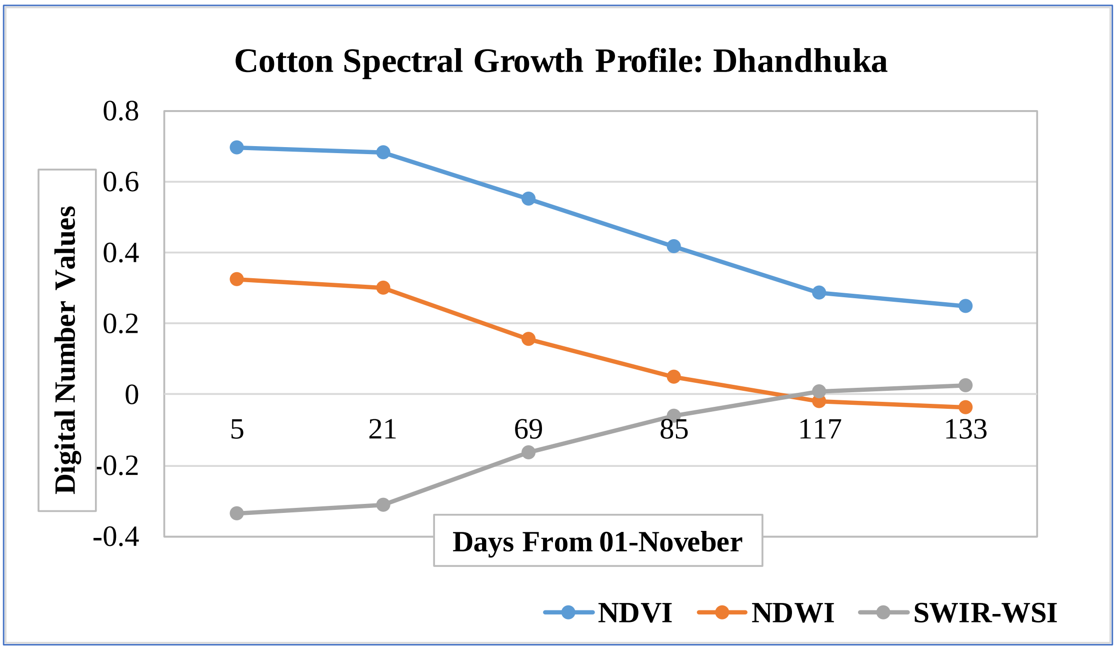

Figure-8: Spectral Growth Profiles of Cotton in Dhandhuka Taluka

The Values of different spectral indices computed using the mean values of different spectral bands from sowing to maturity of cotton crop in Dholka Taluka are given in **Table-8.** The mean Spectral Indices namely NDVI, NDWI and SWIR-WSI given in **Table-9** of cotton from third picking stage to maturity in Dhandhuka were used plot he Spectral Growth Profiles of Cotton Crop in Dholka Taluka (**Figure-9**).

Table-8: Mean spectral band values and Scaled Spectral Indices During Winter Season of Cotton in Dholka

Dholka Cotton										
Sr.No.	Date	Days	Category	Band 3	Band 4	Band 5	Band 6	NDVI	NDWI	SWIR-WSI
1	05-Nov-17	5	Dholka Cotton	756.57	601.139	3412.253	1823.823	169.329	129.696	69.304
2	21-Nov-17	21	Dholka Cotton	815.709	824.975	2604.392	2218	148.848	106	93
3	08-Jan-18	69	Dholka Cotton	648.81	513.962	3013.987	1669.785	169.797	127.722	71.278
4	24-Jan-18	85	Dholka Cotton	614.494	480.557	3550.582	1588.861	174.772	136.937	62.063
5	25-Feb-18	117	Dholka Cotton	706.987	769.063	2240.696	1869.734	147.747	108.671	90.329
6	13-Mar-18	133	Dholka Cotton	864.975	1070.72	2423.051	2371.987	138.595	100.797	98.203

Table-9: Spectral Indices of Cotton During Winter Season of Cotton in Dholka

Dholka Cotton					
Sr.No.	**Date**	**Days**	**NDVI**	**NDWI**	**SWIR-WSI**
1	05-Nov-17	5	0.69329	0.29696	-0.30696
2	21-Nov-17	21	0.48848	0.06	-0.07
3	08-Jan-18	69	0.69797	0.27722	-0.28722
4	24-Jan-18	85	0.74772	0.36937	-0.37937
5	25-Feb-18	117	0.47747	0.08671	-0.09671
6	13-Mar-18	133	0.38595	0.00797	-0.01797

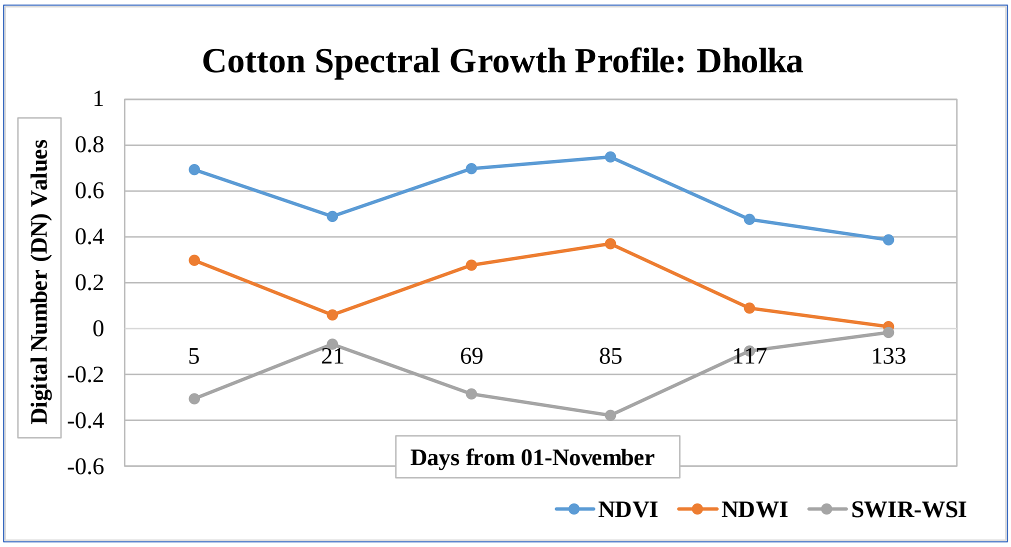

Figure-9: Spectral Growth Profiles of Cotton in Dholka Taluka

Even in the cotton crop, the Water Stress Indices (WSI) and Normalized Difference Water Indices (NDWI) resulted the exactly opposite profiles and they are indicating maturity of cotton crop. The study revealed that during the months of December, cotton crop matures and it is ready to be harvested, the NDWI values were positive. The positive values of NDWI were due to higher NIR-Channel reflectance than Green-channel, which indicates sufficient quantities of water in the vegetation canopy. At the maturity stage of cotton (24-Jan), the NDWI values for Dholka and Dhandhuka were 0.369 and 0.049, respectively.

For the cotton crop, both the talukas indicating a different result of spectral reflectance. According to the result found for Dhandhuka taluka cotton crop had been at the maturity stage in the month of December with the highest values of NDVI and NDWI. There after the declining curve indicates the harvesting of the cotton; whereas for the month of November, Dholka taluka results found to be different reason being the late sowing of the cotton crop in Dholka. According to the Water Stress indices number the cotton crop in Dholka had been found to suffered from water stress during the month of November. High SWIR-WSI (Water Stress Indices) shows the effect of crop water stress. The values of WSI for the month -0.3

and -0.07 are clearly indicating the water stress due to lack of water supply to the crop. January month NDVI and NDWI curve is going upwards for Dholka cotton which indicates the maturity and harvesting stage. During maturity stage the crop showing no signs of water stress.

4. CONCLUSION

This study explores monitoring crop growth of wheat and Cotton using NIR and SWIR-based Indices derived from multi temporal Landsat data of Dhandhuka and Dholka taluka of Ahmedabad district, Gujarat State. Following are the major conclusions based on the results obtained from this study:

- All three indices; Normalized Difference Vegetation Indices (NDVI), Normalized Difference Water Indices (NDWI) and Water Stress Indices (SWIR-WSI) were found to be very useful in detecting vegetation growth and water stress.
- Multi-date spectral indices of wheat & cotton were generated at different growth stages. It has been observed that, the spectral profiles of these two crops (wheat and cotton) indicate that the crops are well separated at different growth stages since their crop phenology is quite distinct.
- It can be inferred that SWIR-WSI have ability to capture water stress accurately and it could be used in monitoring of crop water stress on regular basis.
- The positive values of NDWI were due to higher NIR-Channel reflectance than SWIR-channel, which indicates sufficient quantities of water in the vegetation canopy.
- NDVI profiles of crop were generated using the multi-temporal NDVI values from sowing till maturity; it can reflect the change of crop NDVI from sowing to maturation and harvesting.
- The Water Stress Index (WSI) and Normalized Difference Vegetation Indices (NDVI) resulted the exactly opposite profiles and their intersection points can also indicate about the spectral emergence and physiological maturity stages of wheat crop.

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