Pakistan Journal of Applied Sciences 3 (8-9): 572-578, 2003
ISSN 1607-8926

Irrigated Agriculture Monitoring by Geographic Information System (GIS) and Remote Sensing (RS) Techniques for Southern Part of Indus Basin (Sindh Province, Pakistan)

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Abstract: The rapid growth of population has put a severe strain on soil and water resources in developing countries. Due to lack of proper planning and the shortage in extension service in the agricultural sector, where the major part of water supply is needed, farmers compete in searching for water resources. Thus in this water competition arena, where water is needed for agriculture, industrial, domestic and other needs, irrigation water management is very essential. The irrigation water management is very complex in especially for vast regions, such as Indus Basin 16 million ha wide. Therefore, in addition to present traditional methods of water management, new modern techniques also required to solve the problems for the river basins. As compared to traditional methods, the management practice of irrigated agricultural land by GIS and remote sensing techniques has evident advantage as objectivity, time-saving, low costs and a lot of auxiliary information can be obtained at the same time. GIS/RS techniques are used to monitor Irrigated Agriculture for southern part of Indus (Sindh Province). The screen digitizing method is used to digitize map of Sindh Province. The NDVI is estimated from NOAA-AVHRR satellite data for both kharif and rabi seasons, the agriculture and non-agriculture areas are identified. This will certainly lead to know the uses of water for agriculture and non-agricultural ecosystem in river basins and also proper allocation/distribution of water at different growing stages.

Key words: Geographic information system, remote sensing, NDVI, NOAA-AVHRR

Introduction

Water is not used efficiently in many parts of the world, including Pakistan. As time passes the water is becoming more scarce and its demand is increasing in every sector of life. This causes a great deal of competitive use of water for agriculture, industry, domestic use and forestry etc. On one hand there is a big demand of water in every sector, while on the other side its overuse and the lack of maintenance of water delivery systems have caused a host of socio-economic and environmental and economic problems. The supply of irrigation water for agriculture is also not efficient in Pakistan. The irrigation water is applied to the field without knowing the crop water requirement. This results in excess irrigation in many parts, where as other parts suffer shortage of water during cropping season. The excess irrigation has also led to waterlogging and salinization, which reduces crop production and the value of the land.

Hence, it has been increasingly important to develop water management strategies. One of the first major step, is the delineation of the Indus Basin in different land cover units (agricultural and non-agricultural) which can lead to provides information of major cropping systems. The effective strategies then may be formulated for the distribution and allocation of water among different Irrigated Agriculture zones, for obtaining more productivity while maintaining or improving the environment. Today the concern is not, how many tons of yield are obtained, but the yield response to the volume of water consumed. Our aim is "More Crops Per Drop of Water" Further, it would also be beneficial to know the uses of water for non-agricultural ecosystem in river basins. Having the knowledge of different land use/cover of the area and the proportion of the non-irrigated areas (settlements, degraded lands, etc), water requirements can be calculated and discharge measurements can be better evaluated. It also gives the opportunity to know by whom water is depleted.

The benefits of a GIS/RS approach

The spatial and temporal variability in irrigation causes problems with traditional analytic techniques. A new development in water resource management is the application of GIS/Remote Sensing techniques. The GIS/RS are nowadays indispensable in many different fields of natural resource management, such as water resource management, land use planning, timber management, wildlife habitat analysis, riparian zone monitoring and natural hazard assessment. By Remote Sensing tool the information is provided about irrigated agriculture quantitatively, instantaneously and, above all non-destructively and this can lead to identify different Agricultural crops. In this research study, GIS/RS techniques are used to monitor Irrigated Agricultural land at different growing stages. This will certainly help to assist the in decision making process for supply of irrigation water at different vegetative growing period at different locations and specially distribution of water for Agricultural and non-agricultural areas.

Spectral vegetation indices

The irrigation conditions at ground can not directly be indicated by spectral radiances measured by satellites. The several levels of interpretation must be made between satellite spectral radiance and irrigation decision making. Vegetation Indices (VIs) are, due to their simplicity, best for rapidly assessing whether or not an area is cropped. It is a common spectral index that identifies the presence of chlorophyll. The different vegetation indices do exist to monitor crop growth. Some the most commonly use Vegetation Indices (VIs) are; NDVI (Normalized Difference Vegetation Index), SR (Simple Ratio), (SAVI) Soil Adjusted Vegetation Index, OSAVI (Optimized Soil Adjusted Vegetation Index) etc. The scientific investigations indicate that global vegetation can be derived from the satellite data. In this contest NOAA-AVHRR satellite data allow the monitoring of very extensive areas at very reasonable cost showing the temporal variability of vegetation resources by using Vegetation Indices (Justice ***et al.***, 1986).

Research area

The name of the province Sindh given to the province stands for river Indus and it lies between the 23 and 29 north latitude and the 67 and 70 parallel east longitude. The length of Sindh province from south to north is about 580 km and width is about 275 km from east to west, with maximum width of 440 km. It covers an area of about 137200 Sq.km. The Sindh province is bordered with Rann of Kachh in south, Rajastan in east, Punjab province in north-east and Baluchistan in north west. In the extreme west are the barren Kirthar mountain, to the east is the Indian desert valley terminating in deltaic in the south-west. The mighty river Indus is flowing from the worlds highest mountains into the Arabian Sea.

The Indus Plain is the most prosperous agricultural region of Pakistan, with an area of about 21 Mha and which is made up of fertile alluvium thousand of feet thick, transported and deposits by pre-historic river system. It extends 1050 to 1130 km from rim of the Potwar Plateau southward to the Arabian Sea. The Province of the Punjab is in its northern zone, while the southern zone is mainly comprises by the Province of Sindh.

An average gradient of Indus Plain is about 19 cm per km towards the sea and is divided into the upper and lower plain. The upper Indus plain is divided into a number of doabs, meaning the land lying between the two rivers. The lower Indus plain has been formed by the meandering and shifting courses of Indus River.

Materials and Methods

The Vegetation index is composed of reflectance in red spectral region (0.62 to 0.70 μm) and a portion (0.7 to 1.1 μm) of near-infrared spectral region. Spectral satellite measurements in the

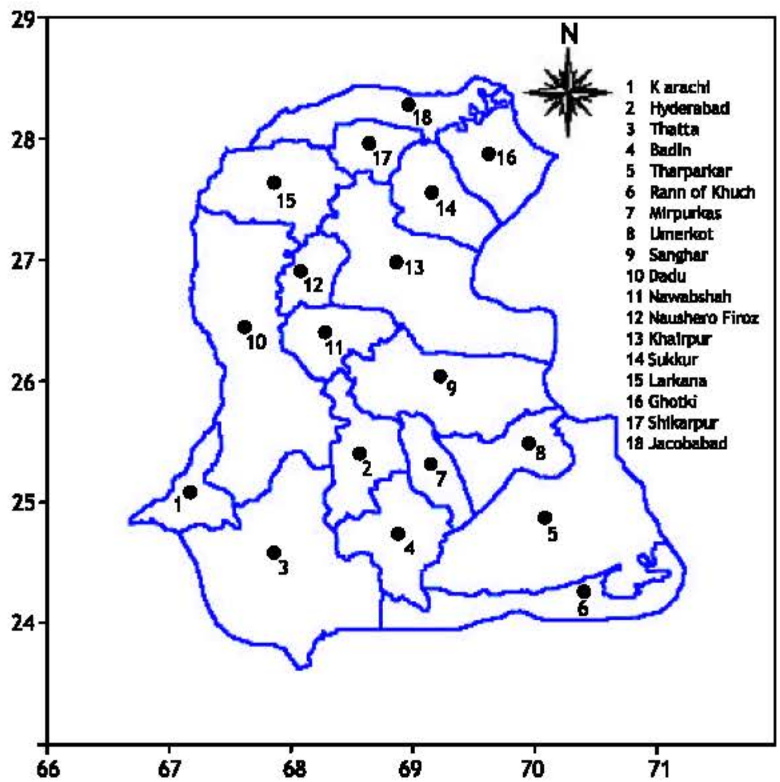

Fig. 1: District map of Sindh province (study area)

Table 1: The data used for the Kharif and Rabi seasons

Kharif season	Rabi season
13 May 1998	05 Nov 1998
27 Jun 1998	12 Dec 1998
30 July 1998	16 Jan 1999
25 Aug 1998	02 Feb 1999
30 Sept 1998	28 March1999
29 Oct 1998	23 Apr 1999

red and infra red channels were atmospherically corrected for interference from aerosols (e.g., Paltridge and Gutman 1991). AVHRR channels 1 (red) and 2 (near infrared) provides information which may lead to different Vegetation Indices (VIs). In the red and near-infrared parts of the spectrum, these Vegetation Indices (VIs) are related to the contrasting reflectance's of green biomass. In the red part of the electromagnetic spectrum, the reflectance of the bare soil is usually higher than for the green vegetation. The reason is that, visible light is absorbed by chlorophyll in the plant leaves. The green vegetation has a high reflectance in the near-infrared part of the spectrum. In contrast, the bare soils do not have a significantly higher reflectance in this wave length range.

As NDVI is the most commonly used and still seems to be leading Vegetation index in the remote sensing community, therefore to monitor the Irrigated Agriculture for southern part of Indus Basin (Sindh Province), the NDVI has been estimated from NOAA-AVHRR satellite data for rabi and kharif seasons. The Sindh province map comprising different districts is also been digitized by screen digitized method (Fig. 1). This gives an idea for vegetation growth at different stages for the different district.

Pre-processing of satellite data (NOAA-AVHRR)

Data selection and acquisition

In the framework of this research study, twelve (12) month scenes of NOAA-14, (Table 1) both Karif (summer) and Rabi (winter) periods have been pre-processed.

The daily global imagery is obtained by NOAA Polar Orbiting Environmental Satellites. These data are transmitted to the Command and Data Acquisition (CDA) stations. The daily global imagery is obtained by NOAA Polar Orbiting Environmental Satellites. These data are transmitted to the Command and Data Acquisition (CDA) stations.

The CDA stations relay the data to the National Environmental Satellite, Data and Information Service (NESDIS), located in Suitland, Maryland, for processing and distribution.

Integrated land and water information system (ILWIS)

ILWIS, GIS/RS based software with image processing capabilities, has been used in data processing. The software has been developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands. ILWIS allows the user to input, manage, analyse and present geographic data. The information about spatial and temporal patterns and processes on the earth surface can also be generated from the data.

NDVI calculations

Albedos of AVHRR channels 1 and 2 from the top of atmosphere T^{OA} were converted to surface bidirectional reflectance by using an atmospheric correction method (***Malik*** 1998). This model was developed by using Holben's approach for atmospheric corrections. After correction, the temporal NDVI for rabi and kharif, from bidirectional reflectances were calculated and the values for NDVI are in practice between 1 (high biomass) and -1 (water).

$$NDVI = (rnir - red)/(rnir + red)$$

where;

rnir, is the measured surface reflectance in the near infrared band.

red, is the measured surface reflectance visible band.

Results and Discussion

After pre-processing the satellite data (Atmospheric and Geo-metric corrections) the Vegetation Index, NDVI is calculated for kharif and rabi seasons and the statistical analysis also perform. In order to see the temporal variation the NDVI are also plotted (Fig. 2). The results of twelve (12) months from May 98 to April 99 of the NDVI are in the Table 2 and 3.

The results of NDVI estimations for the kharif (summer season) shows increasing trend from May 1998 to July 1998.

The vegetation values are less in the months of April and May, as they are the seeding and germination periods for kharif crops (rice and cotton).

The maximum values of vegetation are in the months of June and July, because they are Vegetative periods also for sugarcane crop. The values start to drop in August and September as its reproductive period and in late September and October the harvesting starts (Table 1).

Table 2: NDVI statistical analysis for Kharif season

Date	Max	Mean	Std.dev
10-May-98	0.608	0.13	0.15
27-Jun-98	0.876	0.23	0.16
30-Jul-98	0.717	0.21	0.16
25-Aug-98	0.685	0.19	0.16
30-Sept-98	0.636	0.16	0.16
29-Oct-98	0.627	0.15	0.13

Table 3: NDVI statistical analysis for Rabi season

Date	Max	Mean	Std.dev
05-Nov-98	0.566	0.20	0.16
12-Dec-98	0.634	0.16	0.14
16-Jan-99	0.683	0.19	0.15
02-Feb-99	0.841	0.26	0.19
28-Mar-99	0.564	0.17	0.13
23-Apr-99	0.532	0.12	0.11

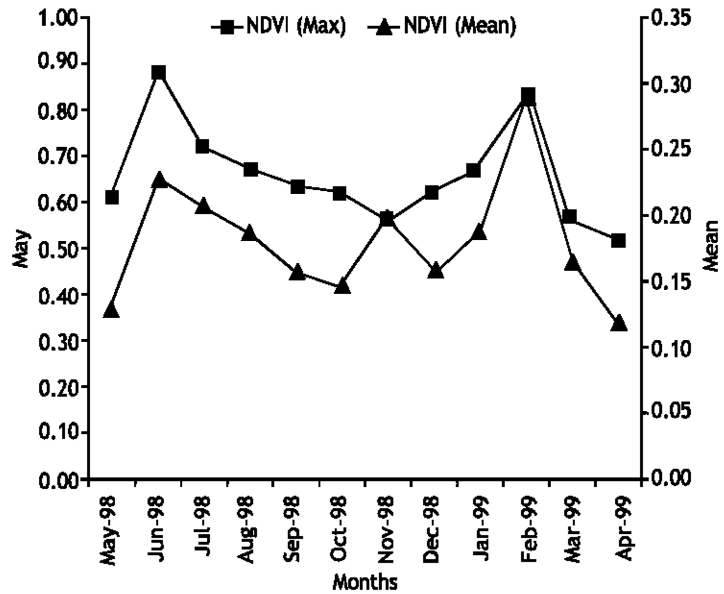

Fig. 2: NDVI temoral profile

The results of Rabi (winter) season shows also increasing trend from Nov 1998 to Feb 1999. The highest vegetation values are in January and February 1999, as they are the vegetation and reproductive periods of Rabi crop (Wheat and Mustered) (Table 3). The vegetation values start to decrease in March and April 1999, because of harvesting period.

The results of study shows that the NOAA-AVHRR (Satellite data) provides the opportunity to monitor the dynamics of Irrigated Agriculture. The Information on pixel by pixel basis can be obtained to identify Irrigated Agriculture by means of public domain satellite data NOAA-AVHRR. Moreover, this approach is very useful in that temporal phenomenon such as seasonality of the vegetation can be displayed and understood. Thus by using this approach, the quality of existing boundaries of agro-climatic zones, in dynamic terms of the time series of AVHRR, can be improved. In particular, NDVI can be used as indicator of growth cycles, of the spatial variability and earliness or lateness of vegetation growth. The present research study has several benefits to develop water management strategies, decision making process and water use planning. As by using this information of different Irrigated Agriculture zones, effective strategies can be formulated by allocation of proper use of water in Indus Basin. The information can be very useful for multi-temporal classification of NOAA-AVHRR, for the water use at different growing stages. Further, this whole approach can be applied to whole or any river basin which is advent in the arena of global water resources analysis.

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