Irrigated areas of India derived using MODIS 500 m time series for the years 2001–2003


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ABSTRACT

The overarching goal of this research was to develop methods and protocols for mapping irrigated areas using a Moderate Resolution Imaging Spectroradiometer (MODIS) 500 m time series, to generate irrigated area statistics, and to compare these with ground- and census-based statistics. The primary mega-file data-cube (MFDC), comparable to a hyper-spectral data cube, used in this study consisted of 952 bands of data in a single file that were derived from MODIS 500 m, 7-band reflectance data acquired every 8-days during 2001–2003. The methods consisted of (a) segmenting the 952-band MFDC based not only on elevation-precipitation-temperature zones but on major and minor irrigated command area boundaries obtained from India’s Central Board of Irrigation and Power (CBIP), (b) developing a large ideal spectral data bank (ISDB) of irrigated areas for India, (c) adopting quantitative spectral matching techniques (SMTs) such as the spectral correlation similarity (SCS) R²-value, (d) establishing a comprehensive set of protocols for class identification and labeling, and (e) comparing the results with the National Census data of India and field-plot data gathered during this project for determining accuracies, uncertainties and errors. The study produced irrigated area maps and statistics of India at the national and the subnational (e.g., state, district) levels based on MODIS data from 2001–2003. The Total Area Available for Irrigation (TAAI) and Annualized Irrigated Areas (AIAs) were 113 and 147 million hectares (MHa), respectively. The TAAI does not consider the intensity of irrigation, and its nearest equivalent is the net irrigated areas in the Indian National Statistics. The AIA considers intensity of irrigation and is the equivalent of “irrigated potential utilized (IPU)” reported by India’s Ministry of Water Resources (MoWR). The field-plot data collected during this project showed that the accuracy of TAAI classes was 88% with a 12% error of omission and 32% of error of commission. Comparisons between the AIA and IPU produced an R²-value of 0.84. However, AIA was consistently higher than IPU. The causes for differences were both in traditional approaches and remote sensing. The causes of uncertainties unique to traditional approaches were (a) inadequate accounting of minor irrigation (groundwater, small reservoirs and tanks), (b) unwillingness to share irrigated area statistics by the individual Indian states because of their stakes, (c) absence of comprehensive statistical analyses of reported data, and (d) subjectivity involved in observation-based data collection process. The causes of uncertainties unique to remote sensing approaches were (a) irrigated area fraction estimate and related sub-pixel area computations and (b) resolution of the imagery. The causes of uncertainties common in both traditional and remote sensing approaches were definitions and methodological issues.

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Irrigated Area Maps and Statistics of India Using Remote Sensing and National Statistics

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Abstract: The goal of this research was to compare the remote-sensing derived irrigated areas with census-derived statistics reported in the national system. India, which has nearly 30% of global annualized irrigated areas (AIAs), and is the leading irrigated area country in the World, along with China, was chosen for the study. Irrigated areas were derived for nominal year 2000 using time-series remote sensing at two spatial resolutions: (a) 10-km Advanced Very High Resolution Radiometer (AVHRR) and (b) 500-m Moderate
Resolution Imaging Spectroradiometer (MODIS). These areas were compared with the Indian National Statistical Data on irrigated areas reported by the: (a) Directorate of Economics and Statistics (DES) of the Ministry of Agriculture (MOA), and (b) Ministry of Water Resources (MoWR). A state-by-state comparison of remote sensing derived irrigated areas when compared with MoWR derived irrigation potential utilized (IPU), an equivalent of AIA, provided a high degree of correlation with R² values of: (a) 0.79 with 10-km, and (b) 0.85 with MODIS 500-m. However, the remote sensing derived irrigated area estimates for India were consistently higher than the irrigated areas reported by the national statistics. The remote sensing derived total area available for irrigation (TAAI), which does not consider intensity of irrigation, was 101 million hectares (Mha) using 10-km and 113 Mha using 500-m. The AIAs, which considers intensity of irrigation, was 132 Mha using 10-km and 146 Mha using 500-m. In contrast the IPU, an equivalent of AIAs, as reported by MoWR was 83 Mha. There are “large variations” in irrigated area statistics reported, even between two ministries (e.g., Directorate of Statistics of Ministry of Agriculture and Ministry of Water Resources) of the same national system. The causes include: (a) reluctance on part of the states to furnish irrigated area data in view of their vested interests in sharing of water, and (b) reporting of large volumes of data with inadequate statistical analysis. Overall, the factors that influenced uncertainty in irrigated areas in remote sensing and national statistics were: (a) inadequate accounting of irrigated areas, especially minor irrigation from groundwater, in the national statistics, (b) definition issues involved in mapping using remote sensing as well as national statistics, (c) difficulties in arriving at precise estimates of irrigated area fractions (IAFs) using remote sensing, and (d) imagery resolution in remote sensing. The study clearly established the existing uncertainties in irrigated area estimates and indicates that both remote sensing and national statistical approaches require further refinement. The need for accurate estimates of irrigated areas are crucial for water use assessments and food security studies and requires high emphasis.

**Keywords:** GIAM, irrigated areas, India, remote sensing, irrigation statistics.

1. Introduction

Irrigation is known to consume nearly 75 percent of all freshwater used by humans, yet the availability of exclusive irrigated area maps, which provide sub-national, national, continental, and global level statistics, are rare and inconsistent from one country or region to another. Irrigated areas are sometimes part of Land-Use/Land-Cover (LULC) maps with a single class or two. The biggest limitation of the existing irrigated area maps and statistics has been the failure to account for: (a) irrigation intensity, (b) irrigation source, (c) irrigated crop types, and (d) precise location of irrigated areas. Irrigation intensity and irrigation crop types have a huge influence in the quantum of water consumed. Knowledge about the irrigation source is a must to determine patterns of resource use and
Irrigated Areas of India Derived from Satellite Sensors and National Statistics: A Way Forward from GIAM Experience

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5.1 INTRODUCTION

India continues to be a predominantly agrarian economy with the majority of its population depending on agriculture for their livelihood. The contribution of the agriculture sector is about 25% of the gross domestic product (GDP). India, with a geographical area of about 328 Mha, experiences diversified climatic conditions. Spatiotemporal variability in rainfall and the availability of groundwater resources have a direct impact on the irrigation system of the country. In the last 50 years, there has been a phenomenal expansion in irrigation development in India, resulting in an increase in gross irrigation area from 22.5 Mha in 1951 to about 76.3 Mha by the end of the year 2001 [1]. At the same time, the Net Irrigated Areas (NIA) in the country has increased from 21.2 Mha to about 57.2 Mha. India has about 27.5% of the global Gross Irrigated Area (GIA), which is second only to China with a corresponding ratio of 31.5% [2,3]. Many experts opined that, to meet the ever-increasing demand of the food grains in the country, a major contribution to the increase in production is attributable to the expansion of the irrigation facility. As per the estimates of the Ministry of Agriculture (MoA), a 1% increase in the irrigated area would increase production by 4 million tons (if the area and production technology and fertilizer use increase at the same rate as in the recent past). Keeping in view the importance
of irrigated agriculture in the national food production, the dynamics of irrigated areas needs to be monitored periodically in order to map the irrigated areas for their effective management. The complexities are more in mapping irrigated areas in India, where subsistence agriculture, diversity in crop types and calendar, and small landholdings prevail.

Spatial data on the distribution of irrigated areas and their dynamics are a prerequisite for effective planning, management, and monitoring at the local, regional, and national level for overall agricultural development in the country. In order to accomplish this, it is first necessary to obtain reliable data on spatiotemporal patterns of irrigated areas. As a part of agricultural statistics, the Directorate of Economics and Statistics (DES), under the MoA, reports the irrigated area statistics every year. Traditionally, village patwari (grassroots-level revenue department officials) report irrigation statistics as a part of agricultural statistics that are, in turn, compiled at different levels, like the village, tehsil, district, state, and national. It is a rigorous, time-consuming, and resources-intensive process. The major limitation in the existing statistical data lies in the visualization of the spatial pattern of irrigated areas of any given administrative unit. The other limitations are the lack of representation of irrigation intensity and information on both the irrigated crop types and the precise location of irrigated areas. Given the huge implications of irrigated areas on water use, food production, and population growth, the availability of precise irrigated area maps and statistics and information on their spatial distribution are invaluable in the planning and management of irrigated agriculture in the country.

In view of the existing status of water resources and increasing demands for water to meet the requirements of the growing population of the country, a holistic and well-planned, long-term strategy is needed for sustainable water resources management in the irrigation sector in India. The availability of spatiotemporal data on sourcewise irrigated areas will be of immense help in monitoring and planning the different irrigation sources in the country. Recent studies indicate that the number of tube wells in India has increased from about 100,000 in the early 1960s to anywhere between 19 and 26 million by early 2000 [4]. This has resulted in an increase in the area irrigated by tube wells alone to be about 42% of all irrigated areas in India. Sinha [5] reported that the irrigated areas in India had reached 100 Mha by the year 2000. Shah et al. [6,7] have observed about the massive overexploitation of groundwater in most parts of India, and have also mentioned that most of the groundwater potential is already exploited.

Recently, there have been two major efforts in mapping irrigated areas at national and global scales. One is Global Irrigated Area Mapping (GIAM) by the International Water Management Institute (IWMI) [3,8] and the other is the Global Map of Irrigated Area (GMIA) by the Food and Agriculture Organization of the United Nations and the University of Frankfurt (FAO/UF) [9,10]. The IWMI GIAM (http://www.iwmigiam.org) effort is overwhelmingly remote-sensing-based and the FAO/UF GMIA (http://www.fao.org/AG/agL/aglw/aquastat/main/index.stm) effort is based on national statistics combined with GIS techniques. In the present study, an attempt has been made to analyze the irrigated areas of India, derived from national statistics and based on satellite sensors from the GIAM project. It helps to diagnose their similarities and dissimilarities to strategize the way forward for systematic mapping of irrigated areas in the country.