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Performanance Evaluation of the Cauvery Irrigation System, India, Using Remote Sensing and Gis Technology

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ABSTRACT
Evaluation of any irrigation project involves the assessment of area, improved by the project. Irrigated agriculture will play a major role in determining the future food security of most Asian countries, and it will also be the major contributor to the additional food production required as world population expands. Therefore, it is important to raise the agricultural performance of low productivity/ irrigation systems, while sustaining the performance of more-productive systems. In many countries, and particularly in India, accurate evaluation of irrigation system performance and sustainability is hampered by lack of adequate, reliable, and timely irrigation statistics. Usually, performance indicators such as yield, cropping intensity, and irrigation intensity are measured at an aggregated level, often at the state or national levels. Data at project level are rarely collected. If collected, they frequently are unreliable or not easily accessible. It is in this context emerging technologies in irrigation management, applied remote sensing and geographic information system (GIS) techniques to study the Cauvery Irrigation System and to analyze agricultural performance issues. The diagnostic analysis of the operation of the Cauvery canal command area in south side India reported here was the result of collaborative research by the National Remote Sensing Agency. Satellite remote sensing was utilized to obtain data on basic agronomic characteristics and crop yield. Hydrologic analysis based on ground data was carried out, aided by GIS and supplemented with output data from a distributed computer model that simulates the spatiotemporal behaviour of canal water, soil water, and groundwater. The salient findings from this research are reported here and in Remote Sensing and Hydrologic Models for Performance Assessment in Irrigation Circle, India. The Cauvery Irrigation System is above average in agricultural performance compared with other irrigation systems in Tamilnadu.
KEYWORDS: Cauvery Irrigation System, Cropping Intensity, Hydrologic Analysis, Tamilnadu, Crop Yield.

I. INTRODUCTION

Irrigated agriculture will play a major role in determining the future food security of most Asian countries, and it will also be the major contributor to the additional food production required as world population expands (Svendsen and Rosegrant 1994). Therefore, it is important to raise the agricultural performance of low productivity irrigation systems, while sustaining the performance of more productive systems. In many countries, and particularly in India, accurate evaluation of irrigation system performance and sustainability is hampered by lack of adequate, reliable, and timely irrigation statistics.

Usually, performance indicators such as yield, cropping intensity, and irrigation intensity are measured at an aggregated level, often at the state or national levels. Data at project level are rarely collected. If collected, they frequently are unreliable or not easily accessible (Murray- Rust and Merrey 1994). It is in this context that IWMI, as part of its ongoing research program on the use of emerging technologies in irrigation management, applied remote sensing and geographic information system (GIS) techniques to study the Cauvery Irrigation System and to analyze agricultural performance issues.

The diagnostic analysis of the operation of the Cauvery canal command area in northwest India reported here was the result of collaborative research by the National Remote Sensing Agency, Hyderabad, India, the Haryana State Irrigation and Water Resources Department, Chandigarh, India, and the International Water Management Institute Hydrologic analysis based on ground data was carried out, aided by GIS and supplemented with output data from a distributed computer model that simulates the spatiotemporal behaviour of canal water, soil water, and groundwater. The salient findings from this research are reported here and in Remote Sensing and Hydrologic Models for Performance Assessment in Sirsa Irrigation Circle, India (Bastiaanssen et al. 1998).

The Cauvery Irrigation System is above average in agricultural performance compared with other irrigation systems in Haryana (Economic and Statistical Organization 1995). Currently, Cauvery contributes about 40 percent of Haryana's wheat production and 6 percent of national production. Through its warabandi principle (see box) of rigid rotational water distribution, Cauvery is designed to deliver water equitably to farmers over an extended area. But farmers' success in growing a high proportion of wheat and reaching high production levels is being achieved by pumping groundwater.

These two studies demonstrate the potential of remote sensing and GIS for evaluating the performance of irrigation systems under two of India's major food crops. Multispectral satellite data can be used to derive information on cropped area, cropping pattern and calendar, and crop productivity in irrigation systems (Thiruvengadachari and Sakthivadivel 1997).

Specific objectives of the Cauvery system study were, first, to generate disaggregated data on total irrigated area, area under major crops, and wheat productivity and, second, to integrate satellite-derived data with ground-measured data to identify factors that constrain agricultural performance and threaten the sustainability of the agricultural production system. A critical issue that this research addresses is whether present practices for allocating and distributing canal water supplies can continue without detriment to agricultural production and the groundwater regime.

II. STUDY AREA

2.1 CAUVERY SUB BASIN

Tamil Nadu is heavily dependent on monsoon rains, and thereby is prone to droughts when the monsoons fail. The climate of the state ranges from dry sub-humid to semi-arid. The state has three distinct periods of rainfall; (i) South West monsoon from June to September, with strong southwest winds; (ii) North East monsoon from October to December, with dominant northeast winds; and (iii) Dry season from January to May. The Cauvery Delta forms the lower part of the Cauvery River System and has complex water systems with issues of surface and groundwater, coastal instability and salinity intrusion.

The normal annual rainfall of the state is about 945 mm of which 48% is through the North East monsoon, and 32% through the South West monsoon. Since the state is entirely dependent on rains for recharging its water resources, monsoon failures lead to acute water scarcity and severe drought [Nathan, 1995]. The Cauvery Delta lies at the bottom of the Cauvery river basin. The river Cauvery is the fourth largest river of southern region and flows from north west to south east.

Cauvery Delta lies in the eastern point of Tamil Nadu between 10:00 N to 11:30 N Latitude and between 78.15 E to79.45 E Longitude. Cauvery Delta zone consist of four districts of Nagappatinam, Thanjavur and Thrivarur and parts of the district Trichy, Cuddalore and Puddubbottai in Tamil Nadu. Cauvery Delta zone has a total geographical land area of 1.45 million Ha which is equivalent 11% of the area of Tamil Nadu state On its total course of about 800 km, the Cauvery travels through the states of Karnataka, Tamil Nadu, Kerala and a Union Territory of Pondicherry before falling into the Bay of Bengal.

The Cauvery has a total drainage area of 81,155 sq km (2.5% of the total geographical area of the country). Of this 42 % lies in Karnataka, 54 % in Tamil Nadu, 3.5 % in Kerala and the rest in the Karaikkal region of Pondicherry. The overall basin map is shown in Figure 2. Cauvery river originates in the Mercara District of Karnataka in the Brahmagiri range of hills in the Western Ghats at an elevation of 1341 m above mean sea level.

River enters the state of Tamil Nadu where Metter dam (1934) impounds 95.6 TMC of water for use in the Cauvery Delta area. At Upper Anicut, about 177 kms from Metter dam the river splits into two branches the northern branch in called the Coleroon, a flood carrier and the southern branch in the main Cauvery which carries water for irrigation. The Grand Anicut (Barrage) is constructed on the main Cauvery river. At Grand Anicut complex, the river Cauvery splits into two branches Cauvery and Vennar .

These two rivers act as the main irrigation canals with the help of head regulators provided on the both the rivers separately. These rivers in turn, divide and sub divide into number of branches which form network all over delta and distributes the Cauvery water in the vast irrigation system. These channels also carry the drainage water and act as irrigation cum drainage channels in the lower delta. The northern branch of Cauvery namely the Coleroon bifurcates at the Upper Anicut from the Cauvery is the main flood carrier and it continues to flow in a north-easterly direction to enter the Bay of Bengal south of Porto Novo at the confluence of Vellar in the north.

The Lower Coleroon Anicut (LCA), which is the last point of utilisation of Cauvery water, is located about 110km below the Upper Anicut. More than 50% of the area irrigated in Cauvery Basin in Tamil Nadu comes under Cauvery Delta, the total area is 560,000 ha with four systems of canals; (i) Lower Coleroon Anicut system (49,000ha) (ii) Cauvery System (200,000ha); (iii) Vennar System (190,000) and the (iv) Grand Anicut System (121,000) as shown inFigure2.1

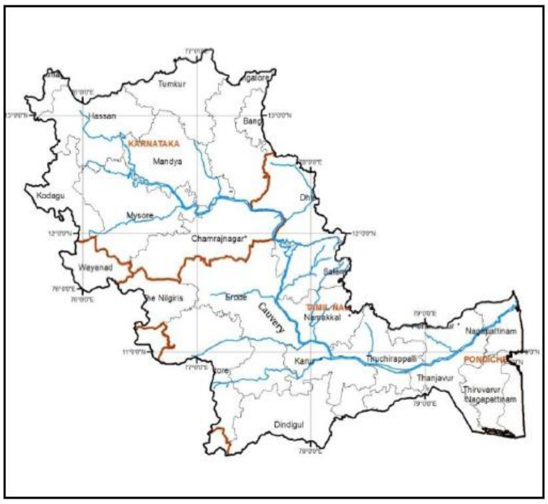

Fig 2.1: Cauvery Basin

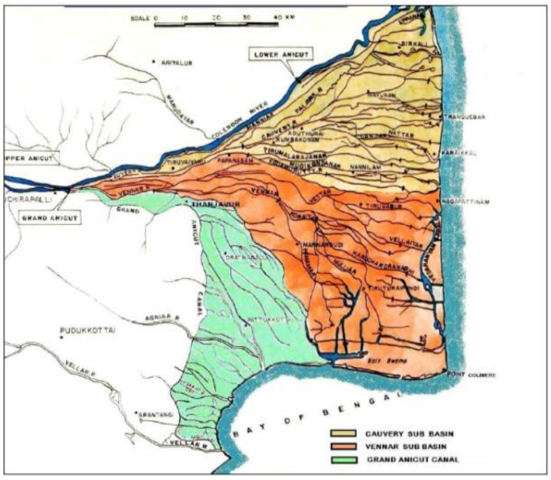

Fig 2.2: Cauvery Delta

2.2 Cauvery Basin Characteristics

The basin location and key topographic and drainage features are shown in Figure 2.3. The major tributaries and their characteristics are listed in Table 2.1.

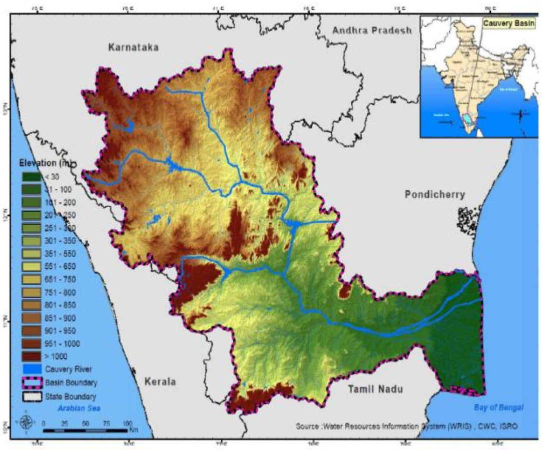

Fig 2.3: Cauvery Basin Elevations

Tributary Name	Catch ment Area (km2)	Origin	Altitude (m)	Length (km)	Sub-Tributaries	State
Arakavathy	4351	Nandidurga	1480	161	Kumaudavathy, Manihalla, Kuttehole, Vrishabhavathy	Karnataka and Tamil Nadu
Harangi	717	Pushpagiri Hills of Western Ghats.	1067	50		Karnataka
Hemavathy	5410	Ballarayana Durga in Western Ghats	1219	245		Karnataka
Kabini	7040	Western Ghats in Kerala	2140	230	Taraka, Hebballa, Nugu, Gundal	Karnataka, Kerala and Tamil Nadu
Lakshmana Thirtha		Western Ghats	1950	131	Ramathirtha	Karnataka
Shimsha	8469	Tumkur District	914	221	Veeravaishnavi, Kanihalla, Chickkhole, Habbahalla, Mullahalla, Kanva	Karnataka
Suvarnavathy	1787	Nasrur Ghat Range		88		

Source: http://www.indiawaterportal.org/node/91

Table 2.1: Major Tributaries of Cauvery

The average annual surface water potential of the basin has been estimated1 to be 21.4 km3. It has been further estimated that 19.0 km3 is utilizable. Present surface water use in the basin is 18.0 km3. The principal soil types found in the basin are red soils, black soils, laterite, alluvial soils, forest soils and mixed soils. The major soil type is red soils. Major land uses are the agriculture and forest. The cultivable area in the basin is about 5.8 Million ha, which is 3% of the total cultivable area of the country. The land under cultivation is 48%. with about 24% of the cultivable area is under irrigation. The major crops grown in the basin are paddy, sugarcane, ragi, jowar and cash crops of coffee, pepper, banana, betel vine, gingili, onion, cotton, black gram. The hydropower potential of the basin has been assessed as 1359 MW at 60% load factor.

2.3 The Hydrometric Network.

The hydrometric network in the basin includes 159 rain gauges and 24 meteorological stations maintained by IMD falling in the states of Karnataka, part of Kerala and Tamilnadu. CWC observe stream flow (GD), sediment (GS) and water quality (WQ) at 12 stations in Karnataka, 1 in Kerala and 17 in Tamil Nadu as shown in Figure. Six stream flow stations are in the delta area, concentrated around a small area that is a part of Pondicherry.

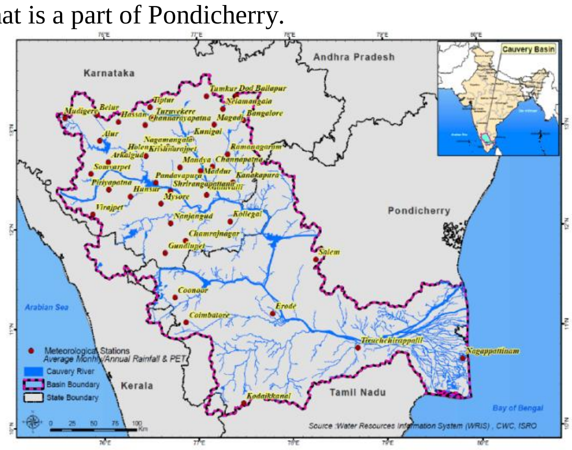

Fig 2.4: IMD Hydro-meteorological Sites

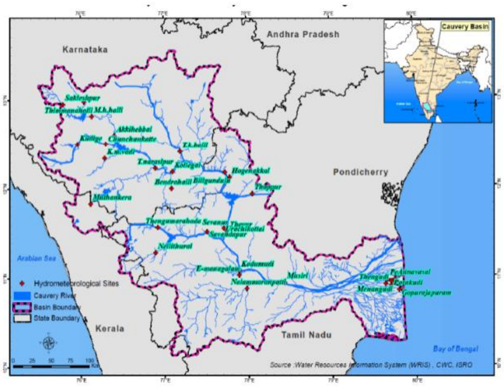

Fig 2.5: River Gauges

2.4 Precipitation in the Cauvery Basin

The analysis presented here is based on the IMD gridded 0.5o×0.5o data that covers the 35 year period 1971 to 2005.

Annual Precipitation

Figure 2.6 presents isohyets of mean annual precipitation over the Cauvery Basin. Precipitation varies considerably across the basin. The western side of the catchment mainly experiences the south-west monsoon from June to September and the eastern side experiences north-east monsoon from October to December. The rainfall during the rest of the year is insignificant. The total rainfall in the basin across the year can be segregated into parts; about 50% is received during the south-west monsoon, about 33% in the northeast monsoon, roughly 10% in the pre monsoons and the rest in the winter months. Annual precipitation varies from about 700-900 mm in the interior to 1200 and above in the eastern and western edges of the basin.

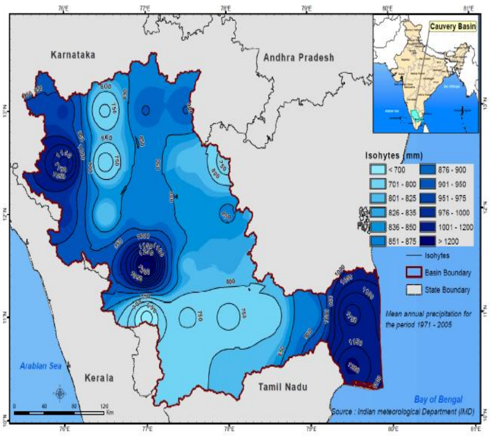

Fig2.6: Mean Annual Precipitation

III. GROUNDWATER

3.1 GENERAL

The total area of Cauvery basin is 81,155 sq.km. Out of this an area of 34,273 sq.km falls in Karnataka, 43,856 sq.km in Tamil Nadu, 2878 sq.km in Kerala and 148 sq.km in UT of Pondicherry. The Cauvery basin runs from west to east for some 800km and its north-south dimensions ranges from 65 to 280km. The mean annual rainfall in the basin ranges from 575 mm at Singallur, Tamil Nadu to 3350 mm in Markara area, Karnataka . The Cauvery River is dammed by the Mettur Dam and the Grand Anicut barrage. The mean annual flow is 20.5 billion cubic meter per year.

Geologically a major part of Cauvery basin is covered with hard crystalline rocks comprising granites, conglomerate and meta-sediments. The semi-consolidated formations comprising sandstones, shale of Gondwanas and Quaternary alluvium occur in delta part of the basin. Geological map of the Basin is given in Figure. In the Cauvery delta, rock formations of Precambrian crystalline to Quaternary sediments exist. In the Quaternary alluvial sediments there are both shallow (unconfined) and deep aquifers (semi-confined). A UNDP project in 1972 estimated the presence of 500 million cubic metres of ground water in delta including the part to the north of the Coleroon River .

The western and central part of the basin is occupied with hard rock aquifer whose yield potential through tube wells of 100 m depth ranges from 1 to 5 lps. The coastal delta area is underlain with Tertiary sandstones and an alluvial aquifer system. The yield potential of Miocene sandstone aquifers extending to a depth of 80 to 150 m range from 25 to 40 l/s.

3.2 Irrigation Efficiency:

The overall project efficiency is taken as product of (i) on form field application efficiency, (ii) field channels efficiency and (iii) canal conveyance efficiency. Field application efficiency can be enhanced by good water management, and adequate on form development in the form of land shaping and grading and construction of field water courses and drains. Field canal efficiency can be enhanced by lining the field channels (from block outlet or canal outlet to the field inlets) or by piped supply. Canal conveyance efficiency can be improved by canal lining, weed eradication, reduction of wastages from escape and improved gate control.

3.3 Recommended Institutional arrangements for the Irrigation Department

It is recommended to install such systems within the command area of large irrigation schemes (based on the extent) to obtain real-time weather data such as, rainfall intensity, wind speed, air temperature. Such systems provide data based on short time intervals. Under these circumstances, performance assessment of the irrigation schemes is recommended in the Irrigation Department (as one of the key stakeholders). The author of this thesis recommends to implement the following strategies.

- Introduce a performance assessment program for the irrigation schemes, with a minimum number of indicators as used in this study..
- Select and train staff for image processing, GIS techniques, and data processing related to performance evaluations i.e. to implement the proposed program.
- Cooperate with farmer organizations to achieve the objectives of the performance assessment program. In order to implement a performance evaluation program as above, a central monitoring unit for each irrigation scheme should be established

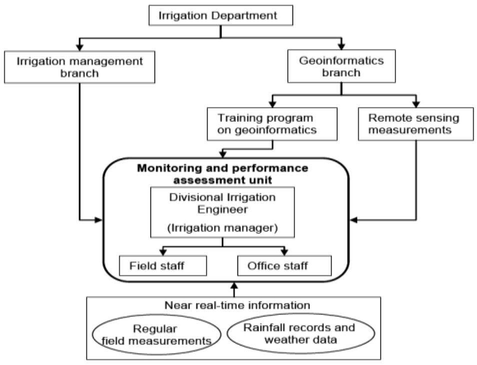

Figure 3.3 Organizational setup to implement a performance assessment program in the Irrigation Department

IV. SATELLITE REMOTE SENSING APPROACH TO DETERMINE CROP PARAMETERS

4.1 GENERAL

In the performance assessment of irrigated crops, satellite remote sensing techniques can be applied to quantify spatial-temporal variations of water use in two broad areas.

- Classification of land cover (e.g. water bodies, bare soils, and vegetation) and agricultural land use (irrigated and non irrigated areas).
- Estimating variations of important crop parameters such as evapotranspiration, root zone soil moisture and plant growth.

Land use, classification using satellite data becomes useful in situations where detailed digitized ground maps are not available, and especially when they are not updated regularly through overland surveys. The situation in the two n irrigation schemes which forms the study area of this thesis is just that, and spectral properties of satellite images of sufficient resolution are used to demarcate the areas under paddy cultivation.

Estimating crop parameters with satellite spectral data has the advantage that accessing such information being easy, fast and economical. However it faces a difficulty because algorithms used to interpret such data require *too much input data* which beats the purpose of applying remote sensing. For the particular case involved in this study, namely, determining the requirement of evaporative depletion of water at different stages of crop growth and the seasonal grain yield of paddy in irrigation schemes , a simplified algorithm called SEBAL (Surface Energy Balance Algorithm for Land) was used (Bastiaanssen, 1995). It overcomes such constraints by using the concept of evaporative fraction (i.e. latent heat, as a fraction of net available energy per given area) and the surface energy balance (Ahmad, 2002) which require a minimum amount of climatic data as inputs, generally available from the Meteorology Department

4.2 Satellite measurements

MODIS measurements have been used as the remote sensing inputs in the study. Out of 36 MODIS spectral bands of different spatial resolutions, 4 have been used for the SEBAL model. The spatial resolution of both visible (band 1) and near infrared (band 2) bands is 250 m at satellite nadir and for both thermal bands (band 31 and 32) spatial resolution is 1000 m. However, the ultimate results are confined to the 1000 m resolution. Therefore the images of band 1 and band 2, which were pre-processed into the standard spatial resolution of 1000 m, are used for image analyses.

4.3 Water in dry zone areas and irrigation for paddy

There are two types of irrigation schemes in the country, namely reservoir schemes and diversion weir schemes. In case of significant areas, additional reservoirs are constructed within the irrigation system for water storage. In a river basin, most of the irrigation schemes located one downstream of the other in the form of cascade, reusing drainage water from the schemes upstream. Water delivery for paddy cultivation is adjusted to meet the demand of each crop growth stage and excess water is discharged through the drainage canals.

4.4 Major aspects related to irrigated agriculture

Irrigated agriculture can be described as a set of *inter-related processes* by which individual water users (or user organizations) and water institutions use water together with other input resources to grow crops in relation to their goals (Bos, 2001). The management activities, that control the level of inputs and the processes, determine crop yield. Performance assessment of irrigated agriculture can be related to the processes, level of outputs (e.g. crop production), and the efficiency of the outputs over inputs (e.g. grain yield in terms of cultivated area). Also, the degree of achieving ultimate goals using the optimum amount of resources determines how effectively the input resources have been utilized to produce the desired outputs i.e. *effectiveness of the process*.

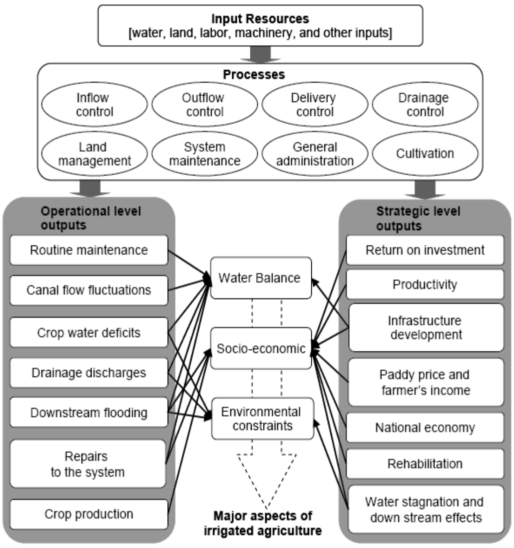

Figure 4.4 Identification of major aspects of irrigated agriculture through analyzing its inputs,processes, and outputs.

V. METHODOLOGY

5.1 Geographical information systems

5.1.1 DEFINITION OF GIS

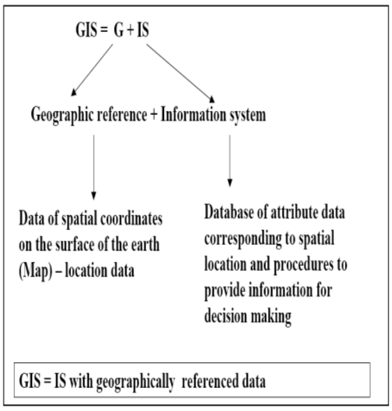

Fig 5.1.1 Working principle of GIS

A GIS is basically a computerized information system like any other database, but with an important difference: all information in GIS must be linked to a geographic (spatial) reference (latitude/longitude, or other spatial coordinates).

5.2 REMOTE SENSING

The science (and art) of acquiring information about an object, without entering in contact with it, by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

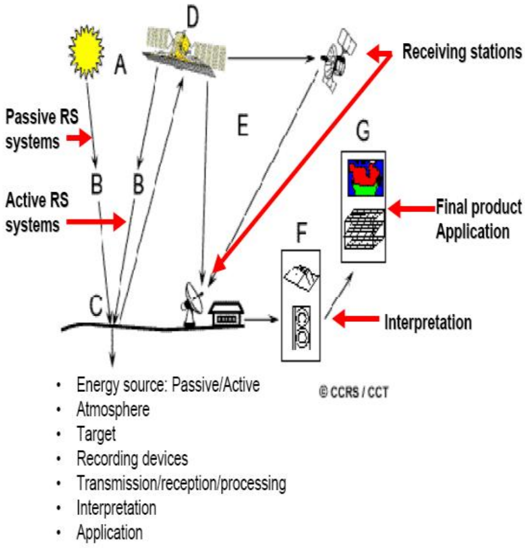

Fig 5.2 Working principle of remote sensing

The traditional method of presenting geographical information in two dimensions is in the form of maps. Maps are graphic representations of the earth's surface on a plane paper They shape the way we visualize, assess and analyze spatial information. A map consists of points, lines and area elements that are positioned with reference to a common coordinate system (usually latitude and longitude).. They are drawn to specified scales and projection. Map scales can vary and depend on the purpose for which the maps are created. Projection is a mathematical transformation used to represent the real 3-dimensional spherical surface of the earth in 2-dimensions on a plane sheet of paper. The map legend links the non-spatial attributes (name, symbols, colours, thematic data) to the spatial data. The map itself serves to store and present data to the user. Such, analogue maps (on paper) are cumbersome to produce and use, particularly when there are a large number of them to be used for analysis. Computer based GIS facilitates both creation of maps and using them for various complex analyses. It allows working with geographic data in a digital format to aid decision making in resources management.

A GIS produces maps and reads maps. Its major advantage is that it permits identifying spatial relationships between specific different map features. It can create maps in different scales, projections and colours. But it is not just a map making tool. It is primarily an analytical tool that provides new ways of looking at, linking and analyzing data by projecting tabular data into maps and integrating data from different, diverse sources. This it does by allowing creation of a set of maps, each with a different theme (soils, rainfall, temperature, relief, water sources, etc.).

VI. CONCLUSION

The issues raised in this report urgently need to be thoroughly investigated by combining satellite remote sensing and GIS techniques with hydrologic modeling, supported by selective and intensive data collection campaigns. Hydrologic modeling is an important tool for understanding the transfer process of salt and water from surface to groundwater and the causes of rising groundwater. Combining information obtained through satellite remote sensing with ground data in a GIS format has proved to be efficient in identifying major crops and their condition and determining area and yield of wheat, the major crop in the Cauvery command in the rabi season.

In addition, for diagnosing problems associated with performance of a wheat-based irrigation system, these techniques are cost-effective. The satellite inventory was completed for about US$0.03/ha. In the Cauvery Irrigation System, the practice of allocating and distributing the canal water supplies under the warabandi principle leads to the current high productivity of water. The long term sustainability of agricultural productivity seems threatened, however. In some areas, saline water tables are rising, and soils are becoming sodic, while in areas that have fresh groundwater, water tables are falling. There is an urgent need for the irrigation agency to thoroughly examine water management problems on the farm, regionally, and system wide. By combining satellite remote sensing and GIS techniques with hydrologic modeling, appropriate ways can be found to modify the present water allocation and distribution practices to sustain productivity and maintain the health of the Cauvery system.

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