Use of Remote Sensing in Ground Water Modeling

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Introduction

Water is vital requirement for the successful raising of the crops. Crops must be supplied with water in the required quantities for their optimum growth, particularly at the critical stages of the crop growth. Irrigation provides crops and plants with water needed for their growth. While the gross irrigation potential is estimated to have been increased from 19.5 million hectare at the time of independence to 95 million hectares by the end of year 1999-2000, further development of substantial order is necessary to meet the requirement of country's estimated 1390 million population by 2025 AD. Production of food grain would need to be raised from present 208 million tonnes to 350 million tonnes by 2025 AD to meet the food grain requirement.

However development of irrigation potential with canals may also have negative environmental impact. Water percolates down into the ground by seepage from the conveyance system and during application of the irrigation water in the fields. This disturbs the pre-existing natural ground water balance, especially at locations where natural drainage is inadequate due to topographic, soil or other reasons. Accumulation of water causes the rise in groundwater. In the absence of sufficient withdrawal, the rise of groundwater table continues. when water table has risen up to the root zone of the crops, it causes waterlogging, rendering the land unsuitable for further agriculture use. Moreover the salts contained in soil & groundwater are transported into the pore spaces of top soil by capillary action and concentration of salts in this manner causes soil salinity.

Waterlogging and salinity are the major land degradation process that restrict the economic and efficient utilization of soil, land and water resources in command areas. Recent revision of as National Water Policy 2002 also places greater emphasis on drainage and reclamation of waterlogged and saline affected lands. According to the policy, drainage system must form an integral part of any irrigation project right from the planning stage. It also sought to intensify research efforts for prevention of waterlogging and soil salinity and reclamation of already waterlogged and saline lands as well as quantifying and reducing negative environmental impacts of water resource projects.

Literature review

Reliable and accurate mapping of areas affected by waterlogging with its location and extent can be extremely useful in chalking out suitable water management strategies to control waterlogging and also to undertake remedial measures to reclaim already waterlogged land. Remote Sensing techniques have shown immense scope for providing a quick inventory of waterlogged area & its monitoring (Sahai et. al. 1982 & Sidhu et. al. 1991). Choubey (1996) stated that a rapid and accurate assessment of the extent of waterlogged areas can be made using remotely sensed data. He determined the waterlogged area in IGNP Stage I from IRS IA LISS II FCC imageries of April 19, 1989 and October 12, 1989. Attempt was also made to correlate the IRS-1A derived waterlogged area with the available water depth and electrical conductivity data to assess the area sensitive to waterlogging.

Sharma (1996) has stated that remote sensing and geographical information system (GIS) can be used separately or in combination with hydrological models. In his study of Arides Mountains, Argentina he has used all the techniques remote sensing, GIS and hydrological modeling successfully. With the aid of these techniques, it is possible to develop better regional model of hydrological processes in a drainage basin.

Arora & Goyal (2002) discussed various causes of waterlogging in IGNP Stage I as high water allowance, excessive seepage from canals, continuous ponding of Ghaggar depressions, lack of use of ground water for irrigation and absence of natural drainage outfall, etc. They concluded that a comprehensive socio-economic survey must be undertaken to visualize negative socio-economic aspects of waterlogging.

Arora & Goyal (2003) highlighted the use of geographical information system (GIS) in development of conceptual groundwater model. Various layers of information such as canal network, recharge zones, subsurface geology and digital terrain model (DTM) of Hanumangarh and Sriganganagar districts were developed in GIS and were then transferred to finite difference grid for developing mathematical groundwater flow model of the area.

Study Area

Indira Gandhi Nahar Pariyojna (IGNP) is one of the largest irrigation and drinking water projects of northwestern Rajasthan. However Hanumangarh and Sriganganagar districts are facing severe waterlogging and salinity conditions since the introduction of the IGNP canal system in that area. Study has been undertaken for this area with the purpose of developing mathematical groundwater model of the area. A greater insight into the reasons of waterlogging and soil salinity in the area and the methodologies to be adopted for its control can be achieved with the help of mathematical model being developed.

The depth of water table in the command of IGNP Stage I varied between 40m to 50m below ground level (bgl). However soon after the introduction of irrigation, water table started rising. During the period 1952-72, the average annual rate of rise of water table was 0.42 m/year. Waterlogging was first seen in the areas of Badopal & Manektheri in the year 1978. Photo 1 shows the standing water in the fields of Dabli Kalan near Matisawali Head. White patches are also seen indicating the severe conditions of soil salinity. Photo 2 indicates the similar conditions in Luna ki Dhani on the other side of the canal. Loss of trees and agriculture land is clearly visible in the photograph.

Photo 1: Waterlogged and saline waste land near Dabli Kalan.


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Photo 2: Dead trees due to waterlogged area in Luna ki Dhani.

In period 1972-82, substantial rise in water table up to 1.17 m/year was noticed mainly due to return flow of irrigation & filling of depressions through Ghaggar diversion channel. In decade 1982-92, net rise in water table reduced in some of the area to 0.76 m/year due to increase in evaporation from already higher water table areas and larger horizontal spread of water built-up in the soil. In period 1992-94, water level reduced drastically in majority of the area due to scanty rainfall and meager flow in conveyance system. It has resulted in the significant reduction of waterlogged conditions in the area. However in the years 1995-97, water table again started rising at the rate of 0.30 to 0.70 m/year. Since 1998, Rajasthan is facing drought conditions year after year and so till 2002 there has been decline in water table and associated reduction in waterlogged area in the region. The status of waterlogging in IGNP Stage I from the year 90-91 to 2000-01 is given in Table 1 below.

Table 1: Status of waterlogged area in IGNP Stage I

S. No.	***Type of area***	***Area in Hectares***					
		90-91	***92-93***	***94-95***	***96-97***	***98-99***	***00-01***
1	***Waterlogged area (Water table less than 1.0 m)***	8600	13750	10192	17220	19492	12672
2	***Critical area (Water table within 1.0 to 1.5 m)***	17000	22000	18970	24140	27960	13425
3	***Potentially sensitive area (Water table within 1.5 to 6 m)***	198000	202960	198643	297820	298760	225153
	Total	223600	238710	227805	339180	346212	251250

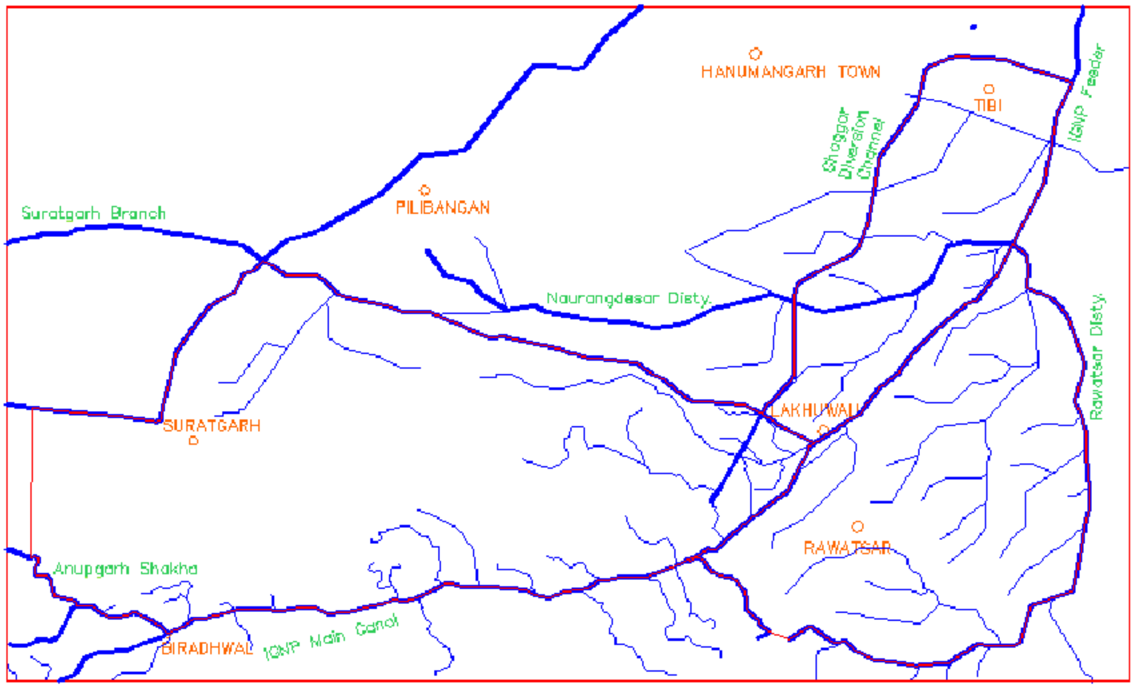

Fig. 1: Study area (Major & minor canal network and towns)

The study area comprising parts of Hanumangarh and Sriganaganagar districts falls between $73^{0}50^{'}$ E to $74^{0}33^{'}$ E longitudes (about 80 kms) & $28^{0}58^{'}$ N to $29^{0}20^{'}$ N latitudes (about 47 kms) in IGNP Stage I phase I. The area, covering about 1772 square kms, lies between IGNP feeder, IGNP main canal, Ghaggar diversion channel, Suratgarh branch and Rawatsar distributory (Fig. 1).

Average annual rainfall in the region is about 240mm with temperature varying from 50^{0} C during May-June to low of 5^{0} C during December-January. The geology of the area is completely concealed under the thick blanket of dunal sand and alluvial deposits of quaternary age. No rock exposure at the ground surface occurs in the area. Sand dunes consist of silt & fine grained sand which are brownish, yellowish or buff in color. The generalized stratigraphic sequence as derived from lithologs of deep boreholes, dug cum bore wells & piezometers of State and Central Ground Water Boards and geological mapping carried out by Geological Survey of India is given below

Quaternary	Recent to Pleistocene	Blown sand, very fine, well sorted and rounded sand silty clays and kankar with frequent lenses of medium to coarse sand
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Paleozoic	Upper Vindhyan	Consolidate ferruginous, fine grained sandstone with shale intercalations.

Groundwater Mathematical Model

Groundwater mathematical model of the study area is being developed in with the following objectives:

1. Estimate the expected future groundwater levels and fluxes for the next 20 years considering that present conditions would prevail. This would also indicate the estimated increase/decrease in waterlogged and saline area in future.
2. Better insight into the reasons of waterlogging & soil salinity with the identification of the area which is further likely to be affected.
3. Methodologies to be adopted for its control and their comparative performance.

In the mathematical model, flow of groundwater is approximated by the partial differential equations, which are simultaneously solved by the computer code to predict future water levels and fluxes. U.S. Geological Survey modular finite-difference ground-water flow model, commonly known as MODFLOW is one of the most popular computer code. It can simulate ground-water flow in a three-dimensional heterogeneous and anisotropic medium.

Mathematical groundwater model can be developed either by using the grid approach or the conceptual modeling approach. Grid approach requires directly creating the finite difference three dimension grid covering the study area and specifying sources/sinks, soil properties, groundwater levels and other model input parameters directly for individual cells. The conceptual model approach involves using the geographical information (GIS) tools to develop a conceptual model of the site being modeled. Computer software GMS can then be used to convert conceptual model to grid model and post process the result of model simulations.

In the present study AutoCAD Land Development Desktop (LDDT) software has been used to develop various GIS layers. IRS IC LISS III dataset was classified in ER Mapper software to utilize remote sensing data as input in the conceptual model. Various GIS layers were imported in GMS software to develop conceptual groundwater model which was then transferred into finite difference grid based model suitable for MODFLOW. Model is currently being validated by utilizing known groundwater levels of years 1991-1995, after which it would be run to predict future response of aquifer to the various stresses.

Remote Sensing Data

Pre and post monsoon images of IRS IC LISS III were used to generate waterlogged area and landuse/landcover maps of the study area. Fig. 2 shows the false color composite consisting of bands 1 to 3 of post monsoon season as visualized in ER Mapper software. Image has been visually enhanced by transforming the input limits to 99% histogram (0.5% from the lower and 0.5% from the higher end). IGNP canal can be clearly seen in the lower part of the imagery spanning from north east to south west. Ghaggar river bed is also visible in the upper part of the imagery.

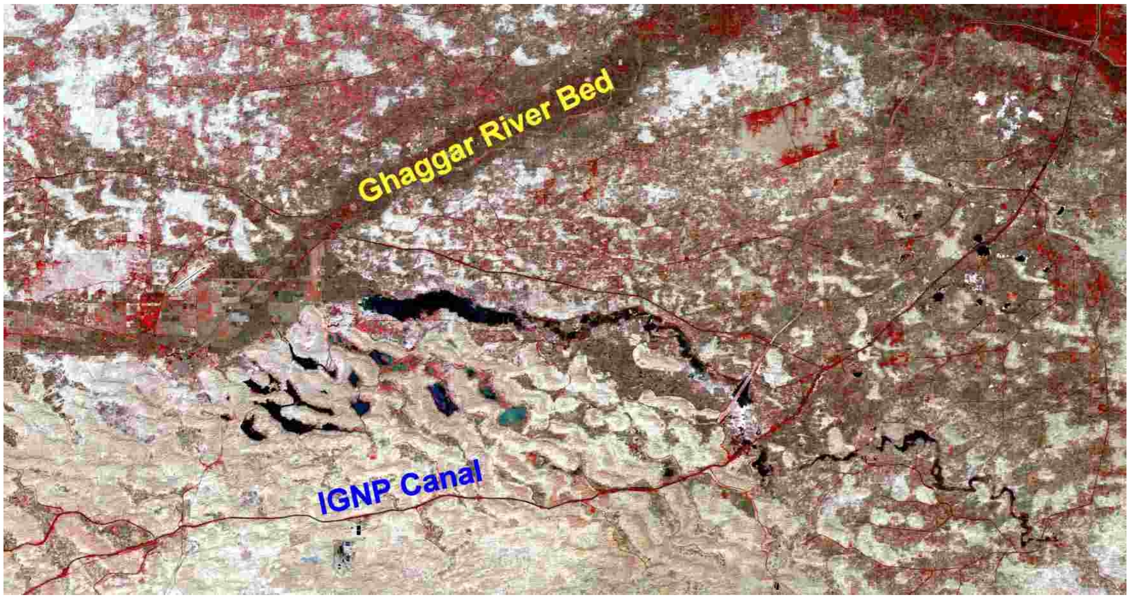

Fig. 2: Visually enhanced FCC LISS III image of study area

Bands 3 and 4 were used to derive the waterlogged and sensitive to waterlogged area as shown in Fig. 3. In the backdrop, RGB composite of bands 3, 4 and 2 of the study area to be modeled is seen. Groundwater data of 100 piezometers in the area was collected from Command Area Development, IGNP, Bikaner and was used to validate the waterlogged area, interpreted by remote sensing imagery. It was found that the area estimated by remote sensing was fairly comparable with the waterlogged map of the CAD, IGNP.

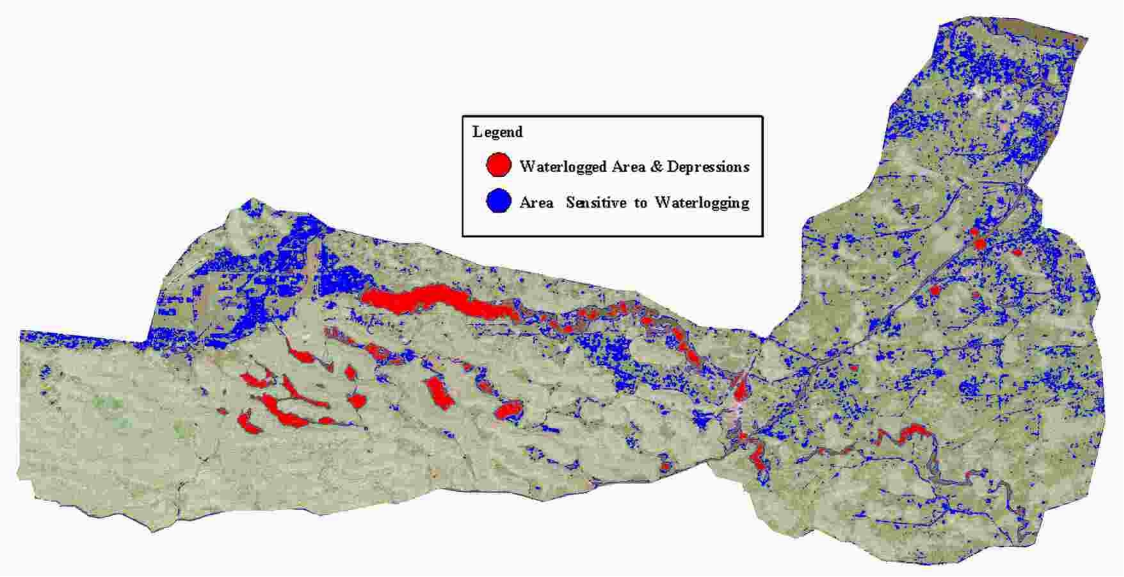

Fig. 3: Waterlogged & sensitive to waterlogging area in study area

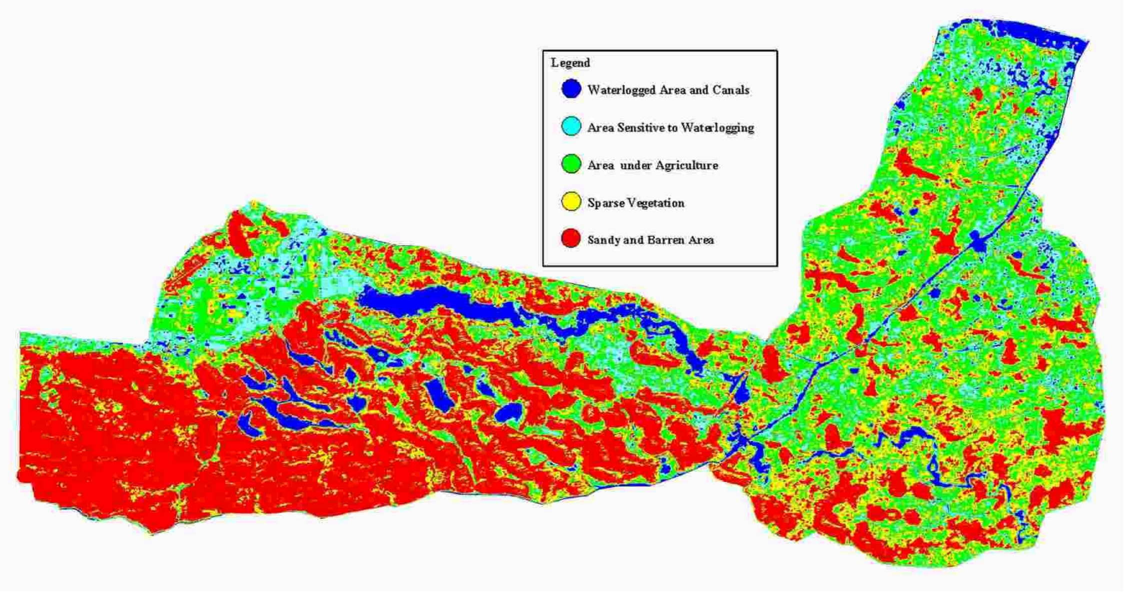

Fig. 4: Landuse/landcover classifications as useful for groundwater modeling

Landuse/landcover maps were also developed on the basis of unsupervised classification, which were then improved on the basis of ground truth. Various collateral data with respect to landuse and waterlogged areas and other information were collected from various IGNP departments, research farms and farmers. Fig. 4 shows the landuse/landcover map of the area. Though it would be possible to choose more number of classes, only limited number of classes which were useful for groundwater modeling purpose were chosen. Table 2 gives the statistics of the various landuse/landcover classes.

Table 2: Landuse/lancover classification

S. No.	Classification	Percentage area
1.	Waterlogged	5.9%
2.	Sensitive to waterlogging	10.5%
3.	Agriculture	22.9%
4.	Sparse vegetation	22.6%
5.	Sandy & Barren	38.1%
	Total	100.00%

Elevation data of more than 800 points were used to develop the digital terrain model (DTM) of the area. Depressions, low lying and elevated areas are highlighted due to magnification of the Z axis by about 6000 times. Fig. 5 shows the 3D view of the study area as developed in ER Mapper software.

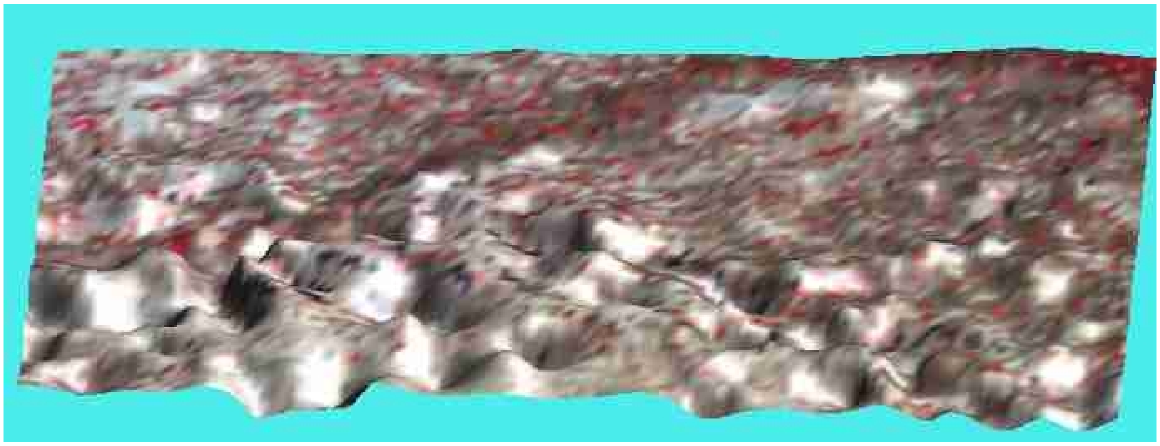

Fig. 5: 3D IRS imagery with Z magnification showing depressions & low lying area.

Conclusions

Following conclusions can be drawn on the basis of present study:

1. A rapid and accurate assessment of the waterlogged area can be made by the use of remotely sensed data. Low lying lands which were not indicated by the water table observations as waterlogged could be identified on the IRS imagery.
2. Groundwater modeling requires limited landuse/landcover classification, which can be done with the help of remote sensing data using unsupervised classification which is then refined on the basis of ground truth.
3. IGNP Stage I command area faces severe problem of waterlogging resulting from over irrigation, seepage losses through canal and distributory system and Ghaggar depressions.
4. The integrated use of GIS and remote sensing techniques can be successfully used to develop conceptual groundwater model, which can then be converted into mathematical finite difference groundwater flow model of the area.

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