Application of remote sensing and GIS techniques for irrigable land investigation

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Abstract The investigation of irrigable land, including effectively and actually irrigated areas, is very important for a reasonable distribution of water resources and for planning agricultural development, especially in arid and semiarid regions. As an experimental area, this investigation by remote sensing and GIS techniques was carried out in Henan Province of China. Landsat-TM images from 1993, 1994, and 1995 were used, together with GIS data and field investigations, to determine the effectively irrigated land and the cultivated area. Data of the NOAA (AVHRR) satellite from March to October 1995 were used together with GIS data and simultaneous field observations at 15 sites for determining actually irrigated land. The established GIS contains all information on topography, irrigation systems, landuse, agriculture, administrative boundaries, river systems, water projects and isolines of precipitation and accumulative temperature. Because reasonable results have been obtained the same investigation will be extended to all provinces of China.

INTRODUCTION

Irrigation is one of the major measures for increasing the production of agriculture. According to the statistics made by Henan Province, after construction of irrigation systems, the crop production increased two to three times in average, and even four to five times in some places. It is, of course, the effect of joint agricultural measures, but irrigation is one of the most important factors. From the fact that in China 80% of the crop is produced on irrigated land, it can be seen that the development of irrigable land is one of the fundamental measures for increasing agricultural production.

Due to the ageing of a part of the water projects such as reservoirs, canals and other irrigation facilities, some originally irrigable areas can not be irrigated now. Besides this, some irrigable cultivated land was used for other purposes. So the statistics on currently irrigated land in our country is not very accurate. The statistics differ from one department to another. This fact is very important for planning the development of irrigable land to ensure the target that the total crop production would be 0.5 billion tons at the end of this century.

Compared to traditional methods, the investigation of irrigable land by remote sensing and GIS techniques has evident advantages as objectivity, time-saving and low costs. A lot of auxiliary information can be obtained at the same time. It can be used to generate new information which is helpful for planners and decision-makers.

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THE RELEVANT SITUATION OF HENAN PROVINCE

This province is located in four large river basins, namely, the Yellow River, the Haihe River, the Huaihe River and the Changjiang River. Affected by atmospheric circulation, geographic and topographic conditions, its precipitation is nonuniformly distributed over the area of 0.167 million km^2, within one year and between years. The normal growth of crop is more or less affected by water supply in different times and places. During 100 years from 1887 to 1986, the southern part suffered by drought 25 times, the eastern and southwestern parts 36 times, the western and northwestern parts 43 times. So, appropriate irrigation is the key to a plenteous harvest.

The Henan Province is located in the transient region between the second terrace and the third terrace. There are mountains, hills, basins and plains. Mountains and hills, occupying 26.6% of the total area, concentrate in the west, south and northwest. The centre and east are plains, occupying 55.7% of the total area. The elevation of most plains is between 40 and 100 m a.s.l., increasing to 100 or 200 m a.s.l. in transient areas from the plains to the hills. Most of the irrigable land is located in the plains and in parts of the hills, so our investigations are focused on the regions with an elevation less than 400 m a.s.l. Channel irrigation is valid only for regions with an elevation below 200 m a.s.l., pumping irrigation below 300 m a.s.l. and well irrigation below 400 m a.s.l.

The main crops in this province are wheat, rice, peanut, tobacco, cotton, corn, sweet potato, vegetable and fruit. The growing situation is the most important indirect criterion to judge whether the crops are irrigated or not. It is also affected by the phenologic zone where the crops are located. So, a comparison should be done only for the same crop in the same phenologic zone. For convenience, the whole province is divided into three phenologic zones according to the isoline for accumulative temperature.

At present, the major irrigation modes in this province are canal and well irrigation. Drip and sprinkler irrigation are only developed in a few places. This variety of irrigation modes brings more difficulties to the investigation on irrigated land.

APPLICATION OF REMOTE SENSING AND GIS TECHNIQUES IN THE INVESTIGATION

Principles of the investigation

The definition of effectively irrigated land is: land with levelled ground, conveyance irrigation system and water supply in normal years. The first two conditions can be found from statistics. 1994 was a normal year for water supply. Combined with the Landsat-TM images of 1993 and 1995, the water supply condition can be analysed through the growing situation of the crops. So, the judgement of the growth situation of crops is the most important factor for the determination of both, actually irrigated land during the investigation period and effectively irrigable land. For each year, the actually irrigated area is lower than the effectively irrigable land, while for a period of several years, the assembly of the former should approach the latter.

Irrigation has an important effect on the growth of crops. Although it does not matter whether crops are irrigated or not, the chlorophyll content of the leafs and stems of crops increases with their growth. But its increasing rate is different depending on water supply. With the increase of chlorophyll, the reflectivity of crops in the near infrared wavelengths around 0.85μ (IR 0.85) increases, while for red wavelengths around 0.65μ (R 0.65), the absorption increases, but the reflectivity decreases. Therefore, the vegetation index reflecting the growth situation of crops usually adopts the following forms: (IR 0.85)/(R 0.65), (IR 0.85) - (R 0.65), or (IR 0.85 - R 0.65)/(IR 0.85 + R 0.65). The higher the vegetation index, the better is the growth situation, and *vice versa*. The growth of crops depends on many factors, but irrigation is the most important. The example given by the Menjing County of Henan Province shows that in the same village in 1995, the wheat production is 11 250 kg ha^{-1} for irrigated fields, while it is 1500 kg ha^{-1} for fields without irrigation. A standard Landsat-TM color-composit (using band 4, 3, 2), shows bright red areas which are crops with sufficient water supply and regular veins caused by the canal system. For well irrigated areas, regular veins are not so obvious, so the groundwater condition is first analysed by hydrogeological maps, to judge the water supply conditions of areas without large irrigation systems.

There is a delay between irrigation and the growth situation. The growth rate is determined by time series analysis. So, a few Landsat-TM images are insufficient and the NOAA (AVHRR) data with low resolution in space and high resolution in time are used as an auxiliary measure. Through comparison, the difference between IR 0.85 and R 0.65 is adopted as the vegetation index.

For calibration, 15 field sites were arranged covering different topographic, phenologic and agricultural regions and irrigation modes. Four test sites are located in an area without irrigation. The area of the observation site is 1 km^2, corresponding to the spatial resolution of the NOAA satellite. The observation was made once a decade, including items as soil moisture content at the layer 20 cm below ground surface, type of crop, growth stage, the situation compared with normal years, irrigation within the decade and the accumulative or average values of precipitation, evaporation and air temperature.

A GIS stores and manages all data including the classified vegetation index derived from NOAA (AVHRR) data and other information such as landuse, rivers, reservoirs, lakes and so on, derived from Landsat-TM data. This is the key tool for determining the actually irrigated area. In this study the GIS is set up on workstations, supported by the ARC/INFO software. It contains administrative boundaries, river systems, landuse, communication, elevation-lines, isolines of accumulative temperature, large-sized irrigation network, isolines of precipitation of each decade, reservoirs and lakes. This information is stored in layers. The ranks of classified vegetation indices treated by the ERDAS software are stored in time series for each grid.

Classification of the vegetation index

If we have historical vegetation index data for different crops in different phenologic zones, especially data for irrigated and nonirrigated crops, the classification becomes quite easy. Unfortunately, up to now, this kind of data is not available. So we first tried to find the difference between data from irrigated and nonirrigated field sites. As expected, the vegetation indices at the four described test sites are always lower than those from other irrigated sites. It is not sufficient to determine the threshold, it can only be used as a reference. A comparison of the growth situation of crops was done for the same crop in the same phenologic zone as mentioned before.

The procedure of classification is as follows: Only a few of the vegetation indices are negative, so the minimum value is taken as 0, all other values are shifted accordingly. The interval between the minimum and the maximum value is divided by 10 resulting in 10 classes. The rank number for each grid is taken as the attribute and this is transferred into the GIS. The same work was done for all time periods and the rank numbers for each grid are arranged as time series. The short time interval (NOAA daily orbit) is not useful for analysis, so evaluations are made in intervals of 10 days at least and 20 days at most, depending upon whether we can receive the NOAA data with no clouds. It is found through analysis that although the classification standards for multiple time periods are not the same, the difference between two successive time periods can be used as the reference of growth rate. If the ranks of one grid are high in all time periods or the increasing rates are quite high, we may judge that this grid has been irrigated as one criterion. A final conclusion will be made in the GIS. At the same time a distribution map of the vegetation indices for each time period can be drawn.

Irrigation information in the GIS

Apart from the information obtained by remote sensing, the other information stored in the GIS was digitized. The established GIS can also be used for planning and managing irrigation systems of entire provinces or counties after the investigation of actually irrigated and effectively irrigable lands.

The judgement of irrigated areas using a GIS was carried out in the following way: The attributes of relevant layers are superimposed for analysis. Grid cells following a series of criteria are selected. The layers topography, landuse, crop kind, phenologic zone and rank of vegetation index are superimposed to obtain a first result. After this the layers river system, reservoirs, irrigation network, isoline of precipitation and the consideration of water supply conditions will be superimposed. on the first result for further analysis.

Landuse is the most direct and obvious criterion. Only cultivated land can be an irrigated area, forested areas are not considered. Rice has to be irrigated. Besides this, elevation is an important criterion. The elevation of most irrigated land is less than 400 m a.s.l. The few irrigation projects constructed in mountainous areas can be treated in a second analysis. According to the analysis of data from field sites, the rank of the vegetation index is often >7 for sites with enough rainfall or irrigation. For all time periods the mean value of 7 is taken as the threshold for the growth situation. During the spring season of 1995 the rainfall amount for whole province was on the lower side. So, in general, all spring crops were irrigated if possible. But we cannot fully exclude the possibility that some nonirrigated crops grew quite well due to enough rainfall. On the contrary, some areas with high vegetation index and small reservoirs in high mountains are excluded due to their elevation. Besides this, the vegetation index of some irrigated areas may be lower due to other reasons. Therefore, this first result following the above discussed criterion should be considered again and a second analysis is necessary.

The second analysis is mainly performed on water supply conditions, so the layers of rivers and channel systems, lakes and reservoirs are superimposed on the first result. Areas without any possibility of irrigation should be excluded. For areas with a possibility of irrigation, analysis should be done on three aspects. One is precipitation. A comparison was done for each decade. If precipitation is always higher than the water demand, the area should be excluded from irrigated areas. The second is the elevation, even if it is above 400 m a.s.l. an area with a possibility of irrigation should be included in irrigated areas. The third is for areas with an elevation below 400 m a.s.l. and irrigation possibility, but with a low vegetation index due to other reasons. In this case field investigation is necessary.

The same procedure was performed for each time period. The assembly of irrigated areas for all time periods is the irrigated area during the period of investigation.

RESULTS OF THE INVESTIGATION

The investigation performed by remote sensing and GIS techniques and other data sources, resulted in an area for cultivated land in the Henan Province of 77 191.96 km^2. The effectively irrigable area was 42 779.12 km^2, the actually irrigated area in 1995 was 34 873.31 km^2. These areas are obtained on a county basis.

Through appraisal, the average accuracy of the investigation reaches 97.5%.

CONCLUSION

Through practical investigations of irrigated land by remote sensing and GIS techniques for Henan Province of China, it can be seen that remote sensing and GIS techniques are applicable to this kind of investigation. The result is very good. It gives us the confidence to continue this research and extend the investigation to the whole of China.