Application of Remote Sensing to Water Resources Management in Arid Regions of China

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KEYWORDS: Remote sensing, Water resources, Arid region

ABSTRACT: China is lack of water resources, especially in its arid regions. So the management of water resources in these areas is very important. Remote sensing technology has its special advantage in this aspect. The paper introduces the application of remote sensing, including GIS, in this field, such as surface water resources and investigation, groundwater exploration, dynamic monitoring of ecology, salinisation, water environment and deserfication, drought monitoring, planing of water diversion project between basins and so on. It shows that remote sensing technology can play important role for West China development, especially in northwest China.

1. Brief introduction of water resources in China

The annual average water resources in China is 2.814 billion m3, ranks forth in the world, but due to its large population, the water resources per capita is only one forth of world's average level, ranks 11oth among the countries all over the world. At present, China is still an agricultural country, the water consumed in agriculture is the most significant one.

Chinese government always pays more attention to water resources utilization and development, this is why it can support 23% population of whole world by 6% of water resources and 7 % of cultivated land all over the world. But in the middle of this century, the population in China would be 1.6 billion, water resources per capital would decrease to 1,700 m3, namely to the level of serious shortage of water resources according to the standard issued by the United Nations. But on the other side, the social-economic development of China would reach the middle level of developed countries in the world. Grain yield will increase 0.14

billion t, while two third of the increase will be produced in the North China where is lack of water. At that time, the level of urbanization will be raised to 50%, water consumed in cities will be increased greatly. So the situation of water shortage will be very serious. The shortage of water resources results from not only water resources itself but also water pollution. Besides, due to the non-uniform distribution of water resources both in space and time, the natural disasters related with water, such as drought, flood and waterlogging occurs frequently. With the development of society and economy, the loss resulting from these disasters becomes lager and larger. So the continuous and steady development of society and economy is closely related to the suspentable utilization of water resources. It is necessary to set up reliable and safest water supply system, to hold back the worsen tendency of water environment and establish effective system for water resources utilization, development and protection.

2. Water resources in arid and semi-arid regions in China

The arid and semi-arid regions in China are mainly located in North China, especially in Northwest China. North China includes the Yellow River Basin, Haihe River Basin, Huaihe River Basin and blind drainage basins, with the total area of 4,200,000 km2, being 43.9% of the total area of whole country. But the annual precipitation is 303 mm, the minimum evaporation from water surface 758 mm and maximum one 2,575 mm. Although its area occupies 43.9% of whole country, but the annual average water resources is only 21.8% of the mean value of whole country, and annual average water resources is only 11.3% of the total amount in China.

From natural conditions, it is true that arid regions are lack of water resources, but it is also related with human-being activities. The effectiveness of water utilization for agriculture is quite low, the phenomenon of wasting water exists, the water consumption for unit industrial products (m^3/ 10,000 yuan) is on the higher side, while the repeated-use coefficient on the lower side, and the water pollution aggravates the shortage of water resources. Because the increase of population and water consumption for economy development, the water for ecological environment is occupied, resulting in a series of ecological problems related to water, such as river withering, lake tail dead, lowering of groundwater table, secondary salinization, invading of sea water along coastal area, quick expansion of deserfication, increase of desert storm and so on.

3. Application of remote sensing (RS), GIS, and GPS to water resources management in arid and semi-arid regions

Water resources is the basis of suspendable development of society and economy in arid and semi-arid regions. It is recognized from the present situation that the key issue is the management. If powerful engineering and non-engineering measures are adopted, the problem in arid and semi-arid regions in China is really possible to be well solved. In fact, RS, GIS and GPS can play important role to water resources management, such as surface water, groundwater, snow and ice investigation, dynamic monitoring of ecology and estimation of water amount necessary for keeping and recovering ecological environment, existing irrigation area investiga tion and irrigation planing, soil moisture and drought monitoring, investigation of soil salinisation, planing, monitoring and effect evaluation of returning cultivated and to forest or grassland, dynamic monitoring of desertification and soil erosion, variation of river course and sedimentation in lakes and reservoirs, site selection of water project and its planning, design, construction and management. What follows is relatively detail introduction is several aspects.

1) Water resources investigation

Discharge in river channel can be accurately controlled by hydrological measurement, while the area of reservoir and lake can be determined by remote sensing. On the basis of that, water storage in lake and reservoir may be determined by means of stage -area-volume curve. This kind of curve can also be worked out on the basis of multi -temple (flood, middle and dry periods) remote sensing images and corresponding simultaneous water levels in the lake or reservoir under investigation. This method is much economic than under-water topographic measurement. Key problem is obtaining enough multi -temple remote sensing images.

Groundwater is the most important reproduced natural resources, especially for livehood, animal husbandry and agriculture in arid regions. Remote sensing can provides the information about geology, hydrogeology geomorgraphy and urban environment analysis. They are helpful for searching groundwater, provides clue for field investigation and improve successful possibility. For finding groundwater, the penetration of radar is helpful to directly find shallow-layer groundwater in the places with ancient river channel and the plain area in front of mountains.

The major description of ice -and-snow water resources is the scale of glacier, extent, thicknes s and properties of snow cover. Remote sensing has the ability for the observation in these aspects. With the advantage of high temporal resolution of meteorological satellites, it is possible to distinguish cloud and snow cover due to the movement of clou d. Moreover remote sensing can play more rule to snow monitoring, such as the determination of the percentage of liquid water in snow pack, so as to more accurately estimate the water equivalent of snow pack and to perform snow-melting runoff forecasting. In the winter of 1997 and spring of 1998, it was known from monitoring by meteorological satellite that the snow cover in the upstream area of the Changjian River is much larger than that in normal years. It was an important basis for predicting heavy flood in 1998.

2) Drought and soil moisture content monitoring, management and warning

Drought is always one of constrained factors for agriculture development, it is also one of natural disasters resulting in most considerable economic loss. Since 1949, the annual average area of farmland affected by drought is about 20,330,000 ha, being 20% of the total area of farmland in the whole country, among which the disaster caused area exceeds 8,220,000 ha. The annual average of reduction of grain due to drought reaches 11,020,000 t. From different considerations, there are agricultural drought, climatic drought and hydrological drought, also with different standard and grades.

Large covering is one of characteristics of drought, the soil moisture content measured in sampling point has certainly the problem of representative, namely, whether the soil moisture content at sampling point can reflect the drought situation over a large area and its spatial distribution. Remote sensing technology has the advantage of macr o, objective, rapid and low cost. With its development, it opens a new way for drought monitoring, especially after the combination with GIS. On the basis of combination together with the conventional measurement of soil moisture content on ground and hydrological modeling, remote sensing becomes more practical and approaches the operational purpose for drought monitoring.

With development of remote sensing sensor, several approaches have been developed. They can directly or indirectly reflect drought regime on the basis of the data obtained from these sensors. The approaches which are relatively practical at present in China are thermal inertia method, crop water shortage index method, deviation from mean normalized difference vegetation index method, water supply vegetation index method and the method of soil moisture measurement by microwave remote sensing. What follow are the brief introduction for these methods.

(1) Thermal inertia method

NOAA (AVHRR) is the usual data source for drought monitoring. In thermal inertia method, after atmospheric correction, the fires step is to calculate ground surface temperature, reflectivity, reflectance through atmosphere on the basis of data from CH1, CH2, CH4 and CH5 (spectrum reflectance from various channels), then calculate thermal inertia value. The second step is to establish the correlation between moisture content and thermal inertia value of soil. It is usually a one -dimensional linear equation with two parameters. The thermal inertia values are different for various types of soil. It is affected directly by the soil pattern and property. The spatial structure of soil has also effect on thermal inertia, but it is quite difficult to actually determine this effect.

The thermal inertia method is suitable for drought monitoring in winter and early spring, namely, under the case of bare soil. In case of land covered with vegetal cover, this method is not so suitable because vegetation may change the thermal conductivity of soil.

(2) Crop water shortage index method.

The definition of crop water shortage index is as follows:

$$CWSI=1-E_a/E_p \qquad (1)$$

where E_a is actual evapotranspiration, while E_p evapotranspiration capacity. The smaller the value of Ea, the higher the value of CWSI, indicating less water supply ability, namely land is arid. Because evapotranspiration has close relation with soil moisture content, namely water supply ability, so CWSI also has close relation with soil moisture content. Both CWSI and soil moisture content indicate the degree of soil drought. The analysis for experiment shows (Tian Guoliang, 1992) that the relation between them is better to be expressed by the following logarithmic equation:

$$CWSI=A+B*Ln\ W \qquad (2)$$

where W is soil moisture content expressed in percentage. The correlation coefficient between

CWSI and the soil moisture content in the soil profile from ground surface to the depth of 50 cm is higher than those for other soil layers. The norm of drought according to CWSI is: heavy drought when CWSI>0.913, middle drought when CWSI is from 0.912 to 0.765, slight drought when CWSI is from 0.764 to 0.617, normal when CWSI is from 0.616 to 0.322, humid when CWSI<0.321.

The infrared temperature T_e can be obtained from NOAA meteorological satellite. It has simple linear relation with daily evapotranspiration. Besides, infrared temperature can be used to calculate daily average temperature and then E_p. So CWSI can be calculated from infrared temperature from NOAA meteorological satellite and level of drought can be classified.

(3) Deviation from mean normalized vegetation index method

Normalized difference vegetation index (NDVI) is expressed as :

$$NDVI=(CH2-CH1)/(CH2+CH1) \quad (3)$$

where CH1 and CH2 are spectrum reflectances from first and second channels of NOAA (AVHRR) separately. The vegetation index calculated from remote sensing data can reflect the growth situation of plants, while the normalized one can reduce, to a certain degree, the error from sun elevation, atmosphere and observation for the place not beneath the satellite.

Water supply may affect growth regime, so normalized vegetation index can reflect indirectly drought situation, although there is a lag in time. On the basis of calculated NDVI from NOAA (AVHRR) for many years, the average value of NDVI for each place and each time can be obtained. This average value may indicate the mean situation of water supply from soil. The longer the time series is, the better the representative of these mean values is. The deviation or relative deviation of concurrent NDVI from mean value shows the degree of drought or humidity. The level of drought for different regions can be determined in this way.

This method is simple and easy to be used, also quite objective, but it is necessary to notice what period is the data accumulation term in long time series, namely, normal period, dry period or humid period.

(4) Water supply vegetation index method

When crops are suffered from drought, their leaf apertures are partly closed in order to reduce the loss of water. It makes the increase of temperature of leaf surface. The more severe the drought is, the higher the temperature of leaf surface is. At the same time, the growth of crops is affected by drought, resulting in the decrease of leaf area index (LAI). Besides, leaf will also be wither under high air temperature. All of these may result in reduction of NDVI..

Water supply vegetation index (WSVI) is defined as follows:

$$WSVI=NDVI/T_s \quad (4)$$

where T_s is the brightness temperature of the forth channel of NOAA (AVHRR). The smaller this index is, the more severe the drought is.

(5) Microwave remote sensing

The dielectric characteristics of object is the principle factor deciding microwave emissivity. The dielectric constant of water is 80, while dry soil is 3. The difference is very significant. It means that the dielectric constant is very sensitive to soil moisture content. It makes the change of soil emissivity from 0.95 when soil is dry to 0.6 or less when soil is humid, namely the variation of 30% on natural emissivity of soil. The main objective parameter affecting microwave emissivity is the volumetric moisture content in soil layer from ground surface to the depth of 5 cm. This is just the theoretical basis for measuring soil moisture content by microwave remote sensing. The soil property, surface roughness and characteristics of vegetal cover must be also considered. The backscattering coefficient has good relation with dielectric constant, but it is also related with statistic characteristics of surface roughness. For a given soil moisture content, surface roughness has certain effect on the relation between backscattering coefficient and incoming angle. Passive microwave remote sensing has the shortage of low spatial resolution and more affecting factors. Combining use of mutual relation on some common physical factors, such as surface roughness and incoming angle, of active and passive microwave remote sensing, the accuracy of soil moisture content measurement by microwave remote sensing can be heightened. In case of bare land, the accuracy of determination of soil moisture content in surface layer (0-5 cm) by microwave remote sensing is quite high.

The soil moisture content measured on ground is the major basis for calibrating the parameters in drought monitoring model by remote sensing. After measurement, transmission and processing, soil moisture contents are input the GIS-based information management system. Two-directional inquiry can be realized, namely, to inquire soil moisture content from the location of sampling point and to inquire location from soil moisture content. Combining with multi-intermediary measures, warning will be issued by sound, color and light when soil moisture content decrease to a certain degree. Besides the depletion of soil moisture content can be predicted by hydrological model. With these information, and also the distribution of crops and water demand during corresponding growth period, decision for drought against measures can be made, namely, from where and when to divert how much water to mitigate the drought situation.

3) Dynamic monitoring of desertification and effect evaluation after harness

Desertification is related to natural conditions, especially the vibration of climate and water resources, also related to excessive human-being activities. Desertification reduces farmland area, vegetation cover and grassland area, is also one of sources of desert storm and atmospheric pollution. At present, the desertification area in China already reaches 2622000 km2, being 27.7% of the total territory area.

Due to the difference of climate and water resources conditions, there are three types of desertification, i.e. desertification of sandy grassland, activation of fixed dune and invading of moving dune.

Facing the serious situation that desertification is still developing, the emphasis of harness will be laid in four regions. Different measures would be adopted according to the characteristics of each region.

(1) Increase of vegetal coverage is the key measure for the region surrounding Beijing and Tianjing.
(2) Returning farmland to forest or grassland is the key measure for the region where agricultural area and pastoral area are mixed.
(3) Returning farmland to grassland and limiting animals' number according to the situation of grassland is the key measure for the region of grassland.
(4) Construction of green ecological defense for cities and highways to prevent the invading of desert and mitigate the attack of desert storm for oasis.

Remote sensing is the best tool for monitoring desertification and vegetation covering area, situation, grade and spatial distribution. Most of remote sensing images can be used for desertification monitoring. Because the key place of harness is laid on the sandy grassland which is being degenerated, part of water resources will be distributed to harness such kind of grassland not for deserted grassland. The grassland should be classified into five grades according to their covering percentage. So monitoring by the satellites with higher resolution is necessary for some local areas.

4) Dynamic monitoring of ecology and estimation of water demand for ecology

It is a serious problem that water demand for ecology was not considered in water resources distribution. That means the development of society and economy occupies the water for ecological prevention, leading to the serious deterioration of ecological environment. The situation in downstream basin of the Talimou River and Heihe River is the most typical example.

One of advantages of remote sensing is that it can trace the history. So it is a powerful tool for dynamic monitoring. For example, remote sensing can be used for determining the variation of ecology before and after three times of urgent water diversion to downstream basin of the Talimou River. Besides, the ecology in the Heihe River Basin should be recovered to its level of 1980's. At present, the only way to know the ecological situation in 1980's is remote sensing images during that time period. The variation of area, density, biologic mass and spatial distribution of vegetation its self is not so significant in a short time period and mainly concentrates along both sides of the river course. So the images with higher resolution are necessary. ETM^+, CBERS and TM may be selected to investigate and monitor a large area, and SPOT is necessary for some key areas.

For estimation of ecology water demand, it is important to combine remote sensing with conventional data, such as temperature, precipitation, runoff and topography. The basic idea is as follows.

(1) Ecological background (first class) is made first according to topographic and climatic (temperature and precipitation) conditions.
(2) Ecological background is overlaid on land use classification from remote sensing to reflect the effect of non-climatic factors, such as runoff and human-being activities. The resulting in secondary sub-area involves controllable and non-controllable areas.

(3) On the basis of detailed classification of land use, third-class area is produced, ecological water demand can be estimated through quantitative calculation for each kind of unit area, i.e. third-class area.

For detail, ecological background is produced through superposition of !:100,000 DEM and isohytal map of annual average precipitation of the whole country. After separation of mountainous area, plain is divided into three regions, i.e. plain desert, plain grassland and desertificating grassland, forest and grassland-forest regions. 200 mm of precipitation is the boundary between desert and desertificating grassland. Secondary sub-area is made through superposition of land use on the ecological background. The area with artificial effect is first separated, then the area with non-regional vegetation is separated. The rest part is the area with regional vegetation. In this way, the irrigated and non-irrigated agricultural area are separated from ecological background with four first-class regions. What are added in secondary sub-area are natural runoff and non-irrigated agricultural areas. Comparing secondary sub-area with isohytals of annual average runoff, the area affected by natural runoff and human being activities is separated. Superposition, analysis and comparison between detailed land use and secondary sub-area, the controllable and non-controllable ecological water demand can be estimated.

5) Investigation for returning cultivated land to forest or grassland

Returning cultivated land to forest or grassland is an important decision made by the central government for protecting ecological environment in West China. Remote sensing is the best measure for large-area investigation, including the area of cultivated land which has been returned, tas well as the area in which trees or grass has been planted.

Because the area returned to forest or grassland is not so large and not connected together, besides it is not easy to distinguish grass and wheat seedling, at present the test by means EOS (MODIS) is carried out for such kind of investigation. It has 36 bands, with the spatial resolution from 500 m to 250 m, and revisit period being two or three days. Due to its higher temporal resolution, it is possible to distinguish grass and wheat seedling from short difference in growing period. Besides, MODIS provides effective information to calculate biological mass, so it is also possible to distinguish them from this aspect. The purpose of this kind investigation is to judge if the cultivated land has been returned and if grass has been planted. As for the area, MODIS is not accurate enough, but it is possible to be quantitatively determined by ETM^+ or CBERS.

Water consumed by trees and grass, especially grass is much less than crops. For arid regions, it is unnecessary to excessively emphasize self-supporting in grain. The best way is to develop agriculture, forestry and animal husbandry separately in their suitable places. The macro decision must be made and limited by water resources.

6) Irrigation area investigation and development planning

In order to contend water, irrigation area is blindly developed in some places. The irrigation area from statistics way is smaller than the actual one. It results in water shortage in downstream basin. In order to realize comprehensive management of water resources for the whole basin, the irrigation area is an important and basic information.

The definition of irritable area is as follows: land with leveled ground, conveyance irrigation system and water supply in normal years. At present the major irrigation modes are channel and well irrigation. Drip and sprinkler irrigation are only developed in the area near cities. Grain production increases 4 to 5 times after the construction of irrigation system. From above description, it can be know that land, major channel, land use and water body can be distinguished through TM or ETM+, Crop growth situation can be learnt from meteorology satellites. On the basis of remote sensing, the irrigation area can be determined and a GIS-based irrigation information system can be established. According to the test performed in the Henan Province in China, the accuracy may reach 97%.

In arid regions, it is not suitable to overly develop irrigation area. If there is enough water resources the irrigation planning can be done on the basis of GIS-based database including water body, precipitation, soil, groundwater table, temperature, topography, runoff, water quality of groundwater. After weighting different factors separately, the place suitable for developing irrigation can be optimally selected.

6) Monitoring of salinisation

Salinisation is a typical phenomenon of ecological environment in arid and semi-arid regions. It has direct interpretation identification in remote sensing images for bare land. The bare land includes the farmland after harvest or just after seeding, the farmland with poor plant due to salinisation. The most obvious interpretation identification for saline-alkali soil is the spot with light white color. The boundaries of spots are naturally curved. The shape of spot is belted, netted, annular, arched, divergent or mottled. In the infrared images during rainy season, the light color sources from the surface of saltern above the salinized soil layer, without or with less salt efflorescence. The surface soil becomes solid grey-white crust because the soil is lake of organic matter, impervious and poor aerated. It is different from the soil without salinisation or the salinized soil after flushing by rainfall, with relatively higher reflectivity. In dry season, the light color of salinized soil is caused by the salt crust or salt efflorescence formed due to salt movement to surface. With the increase of salinity, the reflectivity also increases gradually in the region of wavelength from visible band to near-infrared band, presenting a characteristic curve with near-yellow hue, because the white salt efflorescence has the yellow soil as its background.

Among the interpretation identifications of salined soil, hue is the most important one, but the shape identification in remote sensing image is also important. Such as the white spot on the both sides of ancient river channels are belted, those in river beach on low highland of sprindle, those around depressions are annular, those on slope are of stretch and those in the boundary of bursting fan are belted.

Secondary salinisation area resulting from improper irrigation in Northwest China already reaches 2 million ha, being one third in the whole country.

8. Water environment monitoring

Water pollution results in part of water resources which is already very limited can not be used, like snow plus frost-one disaster after another. So the monitoring for water environment is also very important

At present, remote sensing is very effective for monitoring blue green alga due to eutrophication in lakes and reservoirs and red tide along the coastal area. With the sampling on water surface, the water quality classification into five grades can be roughly done. In general it is carried out by the multi-band composition of ETM+ digital images. Which bands would be used are decided according to the major pollutants in the water body under investigation. The quantitative determination of various chemical elements by means of high spectrum is a forward research subject in the world. According to our experiment performed in the Guanting Reservoir, turbidity and conductivity have better spectrum characteristics. The fundamental approach is the first or second derivative of spectral characteristic curve.

9. Planning, construction and management of water project

Apart from the consideration of hydrological factors and economic evaluation, the site selection of reservoir and key water control project must consider the topography and the geological evaluation which can be done by remote sensing and GIS. The planning of water diversion project can be performed on the digital platform. Remote sensing is the major source of data and information into GIS-based database, the spatial analysis and on-line virtual reality technology can play their important role on this basis. It is being carried out for the west line and middle line of “water diversion from south to north project”, including route selection, geological investigation, simulation of water transportation, selection of dam and tunnel sites, estimation of cubic meter of earth and stone, as well as the distribution of water after diversion. After the completion of east and middle line of “water diversion from south to north project”, the arid and semi-arid regions can share more water from the yellow River. The west line can divert 15 billion m3 water every year and improve greatly the situation in these regions. These project are the relatively thorough solution of water shortage in most of arid and semi-arid regions in China.

10. Real-time monitoring and management system of water resources

Due to the importance of water resources and extensity and complexity of its information, it is very necessary to establish a special system for real-time monitoring and information management to provide basis for decision-making on a integrating information platform.

The data and information sources from remote sensing and conventional measures. There are real-time data and historical data. Information is managed by GIS and can be used together through network.

System consists of four sub-systems, i.e. data acquisition, data transmission, data processing and decision-making support system (DSS).it can automatically acquires real-time data of hydrological data including rainfall, discharge and water elevation in river channel, lakes and reservoir, groundwater table, soil moisture content and so on, as well as water quality of surface water and groundwater. Data is transmitted by communication satellite, microwave, extra-short wave, short-wave radio or computer network to the sub-center or center of information management.

In spatial database, there are real time data and historical data. The spatial data includes basic geographic data, such as water body, topography, land use, land cover, administrative boundary, communication, plant distribution and son forth, social-economic data, water resources data concerning utilization and development, such as water supply and demand. Besides, there are banks of maps and remote sensing images.

Data processing includes the processing for remote sensing images and other data, also the update of database. In the respect of DDS, there are bank of models and expert knowledge, it can provides comprehensive and synthetic basis for decision making. The functions of the system are as follows .

1) inquiry

Information inquiry can be carried out in two directions, namely to inquire attribute from location on map and to inquire location from attribute or condition, rule and term.

2) Statistics

The statistics can be done both in time and space or according to the condition, rule and term..

3) Prediction and warning

Combining with special models, what is made are water resources prediction, storm-flood forecasting, low flow prediction, soil moisture content forecasting, snow-melt runoff forecasting and prediction of water supply and demand.

4) WebGIS

WebGIS is adopted for this kind of system in order to realize operation and transfer in distance and in multi terminals including the figures in sector format.

5) Planning

The planning includes water resources utilization and development, irrigation development, water project, agriculture distribution, returning farmland to forest or grass and so on.

6) Consultation

Consultation is often held for finding a solution concerning water resources management. This system can no doubt provides information, alternatives and corresponding consequence for decision making.

7) Virtual simulation and audio-visual and three-dimensional display

8) Synthetic regional analysis

At present, there are two basins and two provinces are taken as the experimental area for establishment of water resources information management system, The Heihe River Basin and the Liaoning Province belong to the area with shortage of natural water resources, while the Tai Lake Basin and the Jiangsu Province the area with shortage of water resources due to pollution.

Conclusion

1) Through long-term practice in China, it can be seen that remote sensing can play an important role to water resources management in arid and semi-arid regions.
2) It is very helpful to apply remote sensing technology together with GIS , GPS and conventional measures.
3) High resolution and high spectrum are necessary for solving some issues concerning water resources management in some key places of arid or semi-arid regions.
4) Further study is necessary, especially on ecology water demand and quantitative determination of chemical elements in water body by remote sensing.