REMOTE SENSING MONITORING OF THE DYNAMIC CHANGES OF VEGETATION COVERAGE AND ITS TYPES BEFORE AND AFTER THE EMERGENT WATER TRANSPORTATION TO THE LOWER REACHES OF THE TARIM RIVER

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ABSTRACT:

Two factors of the vegetation coverage and its types sensible to the ecological changes before and after the Emergent Water Transportation Project are investigated based on three periods of the multi-source and multi-type remote sensing (RS) images such as TM image, ETM image and ASTER image collected from the summer of 1999, 2002 and 2004, respectively, together with the basic geographic data and the special data in the target research. The framework of system classification, conversion model building, remote sensing extraction and interpretation are opted to be used as well as field investigation and databases warehouse building technology, the theory of the integrative spatial and attribute data and seamless integration of multi-source data. The gathered data are reclassified, stored and managed in the respective databases for further repetitive extraction and verified analyses. The vegetation coverage and its types, on the ground of geographic information system (GIS) technology and the groundwater levels during the real-time monitoring, are calculated through the mathematic statistic method, and analyzed in a qualitative and quantitative way. The potential vegetation coverage is categorized into four classes: poor, lower, moderate and satisfactory, respectively, and then extracted and examined. The vegetation types are interpreted and separated into four classes: waste grassland，farm land, forest land, reed field. The research indicates that: (1) The moderate and satisfactory coverage of vegetation evidently go up in area by 1.68 $x10^3$ hm^2, 9.09 $x10^3$ hm^2 respectively. The poor, lower vegetation coverage areas constantly fall into decline by 7.83 $x10^3$ hm^2, and 9.99 $x10^3$ hm^2 on the average from 1999 to 2004 respectively, and some turn for worse is prevented and stopped in some area. (2) The farm land increases from $1.48x10^4$ hm^2 in area in 1999 to $1.51x10^4$ hm^2 in area in 2002, and then to $1.72x10^4$ hm^2 in area in 2004 with a yearly increasing ratio of 3.52%. (3) To be concluded, the emergent water supply plays a decisive and significant role in promoting the ecological environment in the research region. But there is a long way to rejuvenate the whole Green Corridor and turn the extremely fragile ecological environment in the lower reaches of the Tarim River as a whole on a large scale.

1. INTRODUCTION

Ecological environment is essential for human beings to thrive on the Earth. With the increasing advance of science and technology and the dramatically growing world population, the beings have been changing the earth environment on a large scale at an unprecedented speed, which have resulted in a series of serious ecological problems threatening our beings' lives and production, such as soil and water loss, grassland degeneration, land desertification, etc. Thus the studies, monitoring and investigations on ecological environment in a given area have become one major concern of the hot topics in the research fields all over the world. The Tarim River Basin with extremely fragile ecological environment constantly keeps itself in the foreground by virtue of dangerous ecological problems during the development of the local basin economy. Many Chinese and foreign researchers concentrate on the ecological problems in this region from different perspectives, significant, scientific and advising though, most studies are conducted through physically interpreting the remote sensing images and the changes in the corresponding areas instead of the integrative management of the massive monitoring data and their integrated analysis, which are essential and inevitable for the long-term regional ecological monitoring.

The research, based on the advanced technologies of 3S, data warehouse and background information, attempts to focus on two factors of the vegetation coverage and its types sensible to the ecological changes before and after the Emergent Water Transportation Project, which was started by the Tarim River Basin Management Bureau in May 2000. It is a trying initiative to settle the contradiction between the water resource utilization and eco-geological environmental protection in the lower reaches of the Tarim River by the local government through discharging irrigating water to the down-stream from the Daxihaizi Reservoir and the Bositeng Lake. The down-stream has received six times of water from the upper stream and middle stream of the River by July 2004.

Three periods of the multi-source and multi-type remote sensing images such as TM image, ETM image and ASTER

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image are collected from the summer of 1999, 2002 and 2004 respectively, together with the basic geographic background data and the special data needed in the target research. Firstly, these remote sensing images are processed in the framework of system classification, conversion model building, remote sensing interpretation, and then verified, confirmed and maintained based on the geographic positioning system (GPS) through field investigation; Secondly, four special separate databases such as remote sensing image database, special database, basic geographic database and attribute data are built and completed on the basis of the data warehouse technology, the theory of the integrative spatial and attribute data and seamless integration of multi-source data. The gathered data are reclassified, stored and managed in the respective databases for further repetitive extraction and verified analyses. Finally, the vegetation coverage and its types, on the basis of geographic information system (GIS) technology and the groundwater levels during the real-time monitoring, are calculated through the mathematic statistic method, and analyzed in a qualitative and quantitative way. The potential vegetation coverage is categorized into four classes: poor, lower, moderate and satisfactory, respectively, and then extracted and examined. The vegetation types are interpreted and categorized into four classes: waste grassland, irrigated land, forest land, reed field. The study aims at providing macro guidelines to water resource distribution and basin economy sustainable development in the target research zone.

2. BACKGROUND OF THE RESEARCH ZONE

The research zone, 428 kilometers long in total, lies between Kala and Taitema Lake stretching from 39°25′13″ N to 41°02′36″ N; from 86°32′14″ E to 88°57′12″ E. It is dry and windy here all the year round. Difference in temperature spans great between night and day time. It seldom receives rainfall with the annual precipitation under 50 mm on average, but its annual evaporation capacity averagely amounts up to 2 500 – 3 000 mm, which is characterized with a typical warm temperate zone, arid desert climate. Since 1970s with more and more human beings' exertions on the environment and the disordered development of the water resources in the middle and upper stream sections of the Tarim River, the flux to the lower stream section has become less and less and consequently lead to the draught-up of the channel 360 km beyond the Daxihaizi Reservoir and the same destiny of the Taitema Lake, plus sharp shrinking of the Green Corridor between the Tkalimakan and Kumtag deserts.

Severely damaged ecological environment warns us of the urgent problem of the water resource utilization and eco-geological environmental protection in the arid western area of China, which directly hinders the completion of our Western Development Strategy. Hence the central government once has sent delegates and work teams to make comprehensive investigation of the Tarim River Basin. The local Tarim River Basin Management Bureau started an emergency water system, the Emergent Water Transportation Project in May 2000. It is a trying initiative to settle the collision between the water resource utilization and eco-geological environmental protection in the lower reaches of the Tarim River by discharging irrigating water to the down-stream from the Daxihaizi Reservoir and the Bositeng Lake, and the lower stream section has received six times of water till July 2004. Great changes have taken place in the emergency water accepted areas. The total discharged waters and their details are shown in Table 1 as the followings:

Time range	Quantity (10^8 m^3)	Distance (km)	Position of water head
2000.05.14-2000.07.12	0.99	102	Kaerdayi
2000.11.03-2001.02.05	2.26	216	Alagan
2001.04.01-2001.11.18	3.82	360	Kurgan
2002.07.20-2002.11.10	3.31	360	Taitema Lake
2003.03.01-2003.11.03	6.23	501	Taitema Lake
2004.04.22-2004.06.25	1.02	360	Taitema Lake

Table 1 Discharge quantity and its distance of Daxihaizi Reservoir

3. STUDY METHODS

3.1 Data collection and pretreatment

3.1.1 Data resources

The major data resources are supplied by the local Tarim River Basin Administration Bureau, including three periods of remote sensing images before and after the emergency water suppliers, which are made a comparative analysis with the basic geospatial data in the target area. The data are classified into three types: remote sensing data, basic geospatial data and attribute data.

The remote sensing data include TM images collected on 19 September 1999 before the first emergency water supply; ETM^+ images on 24 August 2002 after the fourth water supply; the ASTER images on 28 August 2004 after the sixth water supply. Moreover, the SPOT images of Kaerdayi area on 20 August 2003 are added for contrast as well as the Quick Bird images of Taitema Lake on 30 August 2003. The basic geospatial data cover variety of image information concerning the target area such as reference points, residential areas, location names, traffic, water systems and vegetation, etc. They are scaled at 1:100000. The attribute data are the statistic attributes corresponding to the images.

3.1.2 Data pretreatment

There are two images in the collected data, which are firstly pretreated through histogram equalization and then extended through piecewise linear, and finally composed through false color so that they can be repeatedly identified and compared with ease and convenience. It is proved that the spectral characteristics of TM/ETM^+ images tell us that Band 5 (1.55-1.75μm) are mainly sensitive about soil moisture and plant water contain; that Band 4 (0.76-0.90μm) are correlated to growth and the number of the plants; that Band 3 are used to tell the difference in the absorptivity of plant chlorophyll whose changes reflect the contents of xanthophyl and lutein in autumn. Of the three bands of 5, 4 and 3 the spectrograms of vegetation and soil have great divergence. Hence the TM/ETM^+ data in 1999 and 2002 are treated within Band 5, 4 and 3 through false color composition for further comparison. Since the characteristics of Band 4, 3 and 2 generally correspond to those of Band 5, 4 and 3, the ASTER data in 2004 are processed by the limits of Band 4, 3 and 2 through false color composition.

After that these compositions are processed through another series of procedures such as geometric rectification and registration, image inlay, image enhancement and image cutting, etc. They are in the end zoomed down to the scale of 1:100 000 and stored as remote sensing images with latitude and longitude coordinate system in the GeoTIFF format.

3.2 System classification

The classification system, direct signifiers of the ecological environmental changes of a given area, is the key to realize the remote sensing monitoring of these dynamic changes. The ecological analysis in this research as well as the field investigation review that the nature of the target research zone is poor. The natural features are so rare that the majority of the vast area is desert only with few withering populus euphratica growing on either side of the channel, and scarce trees and shrubs scattering on the waste grassland. On the basis that vegetation is the immediate director of the water supply on the ground, the research aims at studying two ecological factors of vegetation coverage and its types and monitoring the vegetation in different periods.

Based on relevant environmental administrative regulations such as Implementation Scheme for National Land Classification and Technical Specifications for Grass Resources Investigation, together with other existing studies and field investigations, etc., vegetation coverage is categorized into poor, lower, moderate and satisfactory of four kinds, while vegetation types are grouped into farmland, forestland, waste grassland and reed field which are showed in Table 1 The assessment index of classification system. The dynamic changes in both factors are conducted qualitatively and quantitatively.

Assessment Index	Classifications Index			
Vegetation coverage	poor	lower	moderate	satisfactory
Vegetation type	farmland	forestland	waste grassland	reed field

Tabel 2 The assessment index of classification system

3.3 Remote sensing information extraction

The current extracting technology of remote sensing information relies mainly on visual interpretation, additionally on automatic extraction. Then the precision of the extracted information diverges a great deal by virtual of various factors such as the experience of the interpreter, how much he know about the research target and the typical of the sample area, etc., beside the characteristic defects of the remote sensing images themselves, for example, the same object may have different spectra and reversely the different objects may have the same spectrum. Then it is rational and necessary to build a quantitative model of information extraction in the long-term ecological environmental monitoring. Now that the natural features on the remote sensing images are considerably complicated, a variety of algorithms such as maximum likelihood classifier method, spectral angle match method and artificial neural network method, etc. are accessible though they have different focuses. None is perfect to accomplish to draw the various ground features one step at a time. Which method is acceptable for the given research depends on the comprehensive consideration of the images properties, field environment, the requirements, etc.

The paper uses two algorithms of vegetation coverage transformation model and density slicing to extract the required vegetation coverage information, the method of dividing layers of classification to the vegetation type information, which is then processed through precision verification and rectification based on the GPS technology. These data with the consistent classes meeting the study objectives are tailored into land coverage graph and land type graph at the scale of 1:100 000 in 1999, 2000 and 2004 respectively, which are regarded as the basic monitoring data of the research zone.

3.3.1 Vegetation coverage extraction

There are several drawing methods of vegetation coverage information with their own advantages and disadvantages. Through the study of the remaining experience model method, vegetation index method and mix-pixel analytical method, etc., the model of normalized difference vegetation index (*NDVI*) is opted to obtain the relevant information for it collects all the merits of the method such as the environment vegetation index (*EVI*), difference vegetation index (*DVI*) and double difference vegetation index (*DDVI*) etc. This index is sensitive to the vegetation monitoring. It is one significant and indirect index of the growth and number of vegetation in some area, which has linear correlation with the vegetation coverage density. *NDVI* can be calculated through the formula (1) as the following:

$$NDVI = (NIR - RED) / (NIR + RED) \qquad (1)$$

in which *NIR* and *RED* represent the reflectivity of vegetation on the near-infrared band and on the red band respectively. The vegetation index is transformed into vegetation coverage model through another formula:

$$f_{NDVI} = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \qquad (2)$$

in which f_{NDVI} stands for vegetation coverage, $NDVI_{\min}$ and $NDVI_{\max,}$ the minimum and maximum normalized difference vegetation index respectively.

Images of *NDVI* are fist transformed into vegetation coverage according to the formula (1), and then the latter, based on vegetation coverage classification system, is sliced into five classes of water substance less than 0.1 (< 0.1), between 0.1～0.3, 0.3～0.6, 0.6～1.0. Finally this process is accomplished.

3.3.2 Vegetation type extraction

Natural features of vegetation types on the vegetation index images have little difference in the spectral characteristics. It is considerably difficult to identify now that some different objects have the same spectrum and reversely one single object may have different spectra. The method of dividing layers of classification can be applied to achieve the results by simpler combination which are difficult to be completed through complicated method. Hence it is applied to complete the vegetation type extraction for natural features are relatively simplex with lower influence of human beings' living and production in the target research zone.

First, the experience threshold is pre-set to distinguish vegetation from non-vegetation on the ground that two natural features on the NDVI images are distinctively divergent. Then, the vegetation images of trees, bushes, stretches of farmland and grasses are drown in terms of their apparent difference on the NDVI channel, among which the ground object quadrates are segregated by the spectral angle match method. At last, non-vegetation images including waters and bare grounds are extracted according to their corresponding spectral characteristics. The minimum method is used to supervise the classification and complete the information extraction in this procedure.

3.4 Database building

To build corresponding databases is essential to store all the collected data for the dynamic ecological environmental monitoring over the long period of time. Generally they are saved and managed and applied and disseminated in the unit of standard map format. This normal method consequently results in the Coverage format in the database. The special database is continually to keep and provide the monitoring results, and mainly used on the analysis of geographical statistics and spatial overlay. The vector data features datasets and classes in this data warehouse are built on the data types and collected time and saved as the same format as the basis data. The attribute data are created in the independent feature class and in slow responses and difficult regional maintenance and analysis. When multi-users share their data at a time it comes into jam or collision with each other, which cannot meet the demands for data query with ease and convenience. The research adopts the current prevailing data warehouse and SDE technology as well as the theory of the integrative spatial and attribute data, seamless integration of multi-source data to build four separate databases namely basis database, special database, RS database and attribute database within the program. As far as the RS database, it is built in terms of image types, scales and zones with horizontal continuity and vertical connection. Lossless compression (LZ77 algorithm) is used to set up the storied pyramid spatial index with its own latitude and longitude coordinate system, which is stored in the raster catalog. The basis database is mainly to index and display the background information, and to assist query and retrieval, in which the data are organized on the basis of layered and frame map structure, and the vector data feature datasets are formed on their types and scales. The basis data are saved as frames or view pictures

kept to the corresponding warehouse directly through the relevant computer program. Additionally, for the system safety, all users are accessible to the database available only through the passwords entitled by the administrator. The procedures of database building are illustrated in Figure 1 Flow chart of database building as the following:

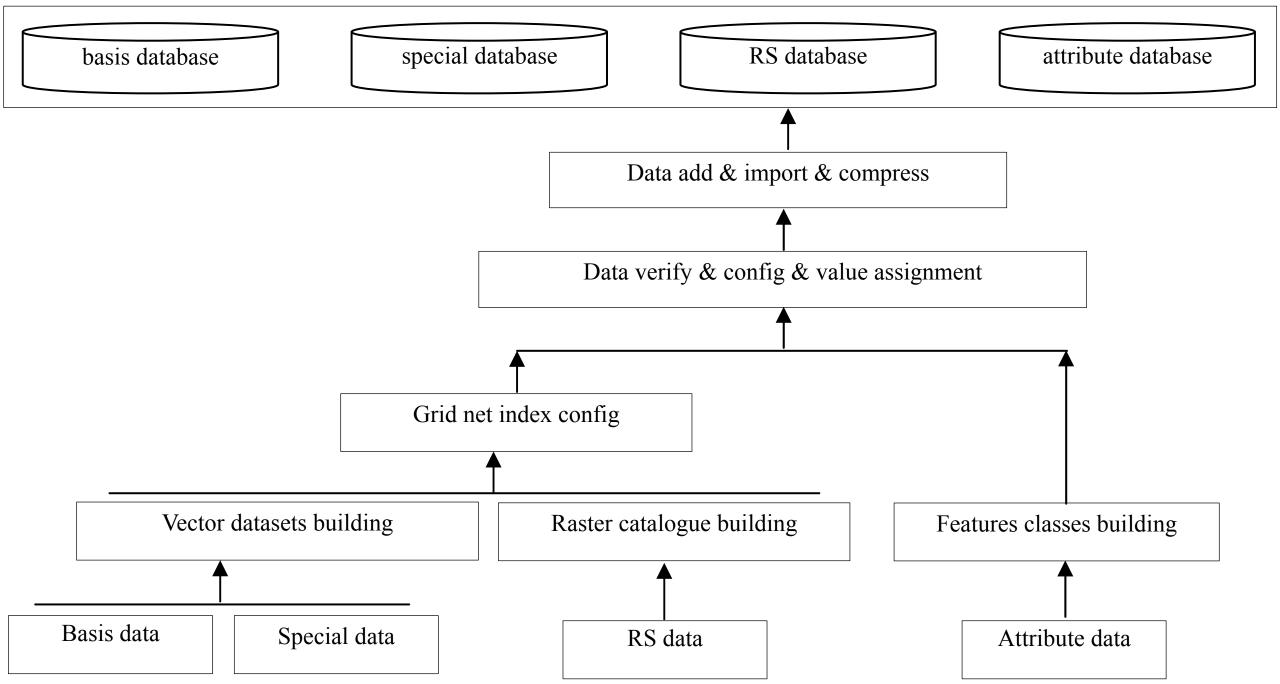

Figure1 Flow chart of database building

4. DISCUSSION AND ANALYSIS

4.1 Vegetation coverage change

Varity of vegetation coverage are interacting with each other practically. The dynamic changes that we have obtained are only one static phase of the continuity in the history. They are in essence a considerable complicated interaction between natural forces and human activities. Based on the statistical and overlay analysis of the three periods of RS data, the vegetation coverage map and area change are demonstrated in Figure 2 and Table 2 respectively which prove that:

(1) There are few and slight changes in the vegetation coverage happening on either bank of the channel between 1999 and 2002. Generally, the areas of the poor and lower vegetation coverage tend to become less and less in the target area while

the moderate and satisfactory coverage become more and more. To be more specific, the poor and lower coverage averagely decrease in size by 458.83 hm^2 and 906.19 hm^2 respectively, but the moderate and satisfactory coverage averagely increase in size by 1184.54 hm^2 and 180.49 hm^2.

(2) The vegetation coverage stretches along the two sides of the channel from the middle stream to the lower one between 2002 and 2004. Some parts of the riverbed used to be dry in the research zone now begins to keep some water and form small pools. Even there appear small river forks or water outlets. The relatively large area of the plant community comes into being around the eastern outlet of Kaerdayi, which is much more distinctive than before the emergent irrigating water supply in 1999. During this time, the poor and lower vegetation coverage continues on declining, with average decrease by 323.88 hm^2 and 9082.91 hm^2 respectively. In turn, the moderate and satisfactory coverage still goes up by 497.46 hm^2 and 8909.32 hm^2 respectively on average.

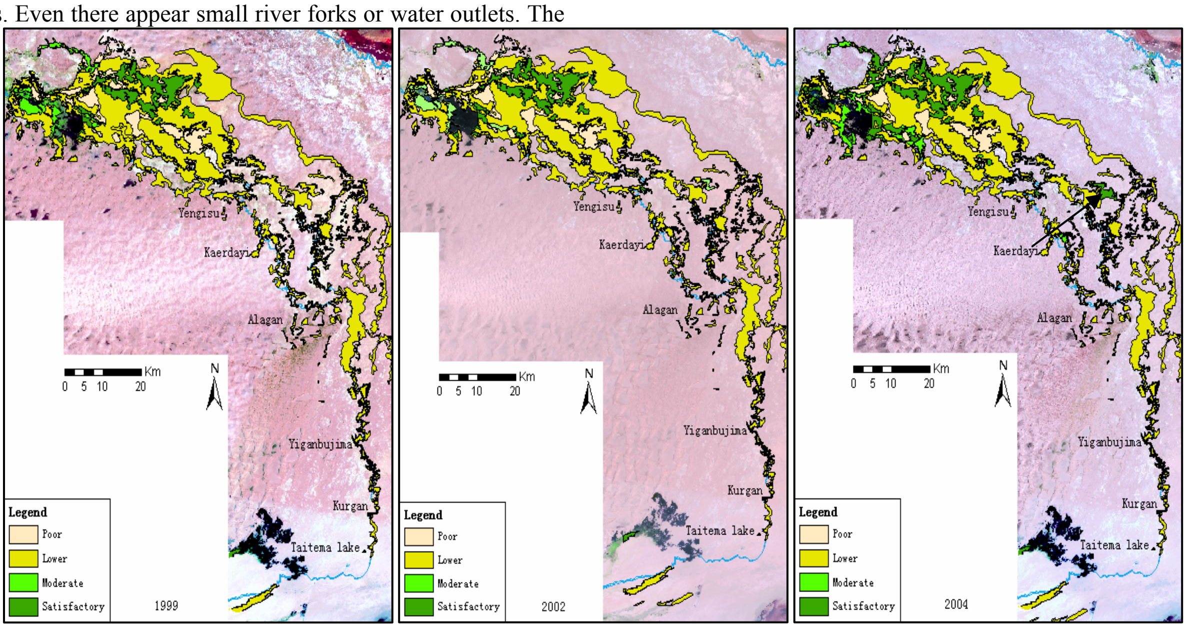

Figure 2 Overlay map between vegetation coverage and images in 1999, 2002 and 2004 in the study area

Vegetation coverage	Area (hm^2) 1999	2002	2004	Area change (hm^2) (1999–2004)	Annual change rate (%)
poor	16228.20	15769.37	15445.49	-782.71	-0.96
lower	136810.95	135904.76	126821.85	-9989.10	-1.46
moderate	7447.16	8631.70	9129.16	1682.00	4.52
satisfactory	17146.80	17327.29	26236.61	9089.81	10.60

Table 2 Area change of the vegetation coverage types in the study area

4.2 Vegetation type change

The natural environment in the research zone is bad and weak with few types of vegetation. The study, based on three periods of RS data statistics and overlay analysis, reviews the vegetation type map and their areas demonstrated in Figure 3 and Table 3 as the following which disclose that:

(1) Except that the waste grassland declines in size in the research zone during 1999 and 2002, the farmland, forest land and reed field increase one year and after another averagely by 255.31 hm^2, 225.92 hm^2 and 82.56 hm^2 respectively, especially downward areas of Alagan, in which the withered and dying populus euphratica forest begin growing greener and better than before the emergency water supply at the end of 2004. This change indicates that the emergency water supply is the decisive factor to improve the ecological environment in the research zone which is confirmed true by the field survey.

(2) During the period of the year 2002 and 2004, the water supplies continually increase from the upper- and mid-stream of the Tarim River and nourish the plants growing on the both sides of the bank, and then the vegetation types tend to be much more various than before. The plants are thriving and the vegetation coverage betters off apparently, as well. With the increase in the irrigation water supply, the inhabitant living in the target research area regenerate wasteland blindly and excessively year by year, therefore part of wasteland, forest land and reed field are gradually transformed into farmland, which leads to a sharp increase in the farm land (with 2078.47 hm^2 on average). Both waste land continually decreasing and the farmland reversely increasing happens at the expense of vegetation destruction. If such tendency is not intervened and prevented, the land desertification will grow worse and then causes the local ecological environment to become from bad to worse.

Vegetation type	Area (hm^2) 1999	2002	2004	Area change (hm^2) (1999–2004)	Annual change rate (%)

farmland	14820.62	15075.93	17154.40	2333.79	3.15
waste grassland	109478.79	108428.77	105026.69	-4452.10	-0.81
forestland	36737.23	36963.15	36984.41	247.18	0.13
reed field	1504.63	1587.19	3004.12	1499.49	19.93

Table 3 Acreages change between vegetation types from 1999 to 2004

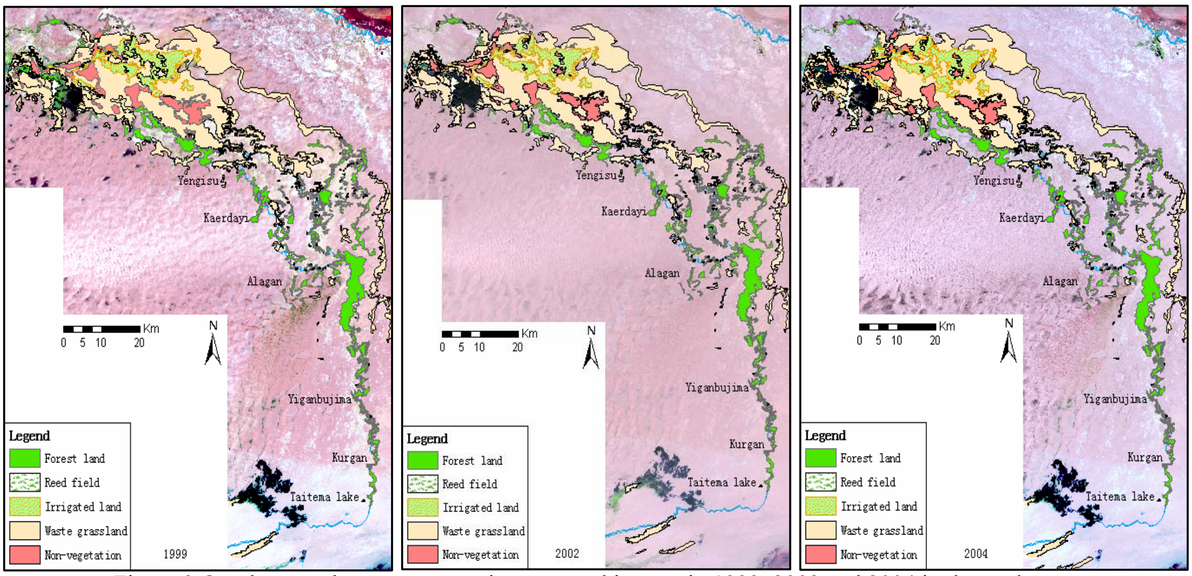

Figure 3 Overlay map between vegetation type and images in 1999, 2002 and 2004 in the study area

4.3 Effects of emergency water supplies

As far as the dry western area of China is concerned, the emergency water supply is expected to be the immediate factor directly affecting the local ecological environment, which will contribute to the healthy growth of vegetation, and to the prevention or even reversion of land desertification. The continuing water resources will stimulate the ecological environment to develop on a sound track and not the vice versa. There are two water supplies in the research zone, the natural rainfall and the emergency water. The target area expands vast desert and it therefore has the dry desert climate with rather low precipitation but with considerable high annual evaporation. The observation data supplied by the local monitoring station prove that the recent annual precipitation has been the same level of 17.4 to 42.0 mm on average. For the extremely dry and hot area, the effects of such little rainfall on the local environmental system can be ignored. Theoretically, the ecological environment change has little relation to the natural rainfall, and it is dominantly brought up by the emergency water supplies. During May 2000 through July 2004 when Kaidu River receives abundant natural water with high flow year, Tarim River Basin Administration Bureau supplies six times of emergency water from the release sluice of Daxihaizi Reservoir with the total quantity 1.76×10^9 m^3 and 927.59 km long from Bositeng Lake to Taitema Lake (Ref. Table 1).

Groundwater levels are found improved great on the monitoring cross section between Akedun and Kuergan, most of which over the stretch of 2 km round the Daxihaizi Reservoir and the Taitema Lake were more than 8 m deep before the emergency water suppliers. The groundwater less than 4 m deep used to averagely cover 5 km^2 but now increase to 20 km^2 in size on average after the emergency water; the groundwater range of 4-6 m deep goes up from about 129 km^2 to 261 km^2 or so; 6-8 m deep from about 183 km^2 to 330 km^2 or so. The changing area is constantly promoted with the times of emergency water suppliers. The vegetation in turn expands in which the plants along the river bank relatively grow well and few changes take place on a little far away from the bank. Since the emergency water suppliers in the research are only given through the Tarim River, their effects on the plants and groundwater levels centre on the river and expand towards the trips of the river sides, which is the cause for the plants on the either side of the river rejuvenate and thrive first with abundant water nourishing. The vegetation coverage is improved and the responding strips rise with the number of water suppliers. The vegetation with poor coverage spreads far away from the river channel for the emergency water is just a linear pioneer project which cannot extend its effects further from the river bank.

After the implementation of the emergency water supplier project, the water discharged from the mid- and upper-streams of the Tarim River constantly increases, which is enable the branches and lakes and other water areas go up year by year, and part of river channel used to be dry begins to keep water and forms small pools. Thus the groundwater levels obviously go up along two strips of the river sides and the grasses, trees, bushes and other plants are nourished to grow well. Consequently the vegetation on the two sides of the river is promoted great and the corresponding ecological environment improved gradually. In one word, the implementation of the Emergency Water Supplier Project is expected to be the decisive factor to better off these changes in the target research zone.

5. CONCLUSIONS

(1) The study, focusing on two factors of the vegetation coverage and its types sensitive to the ecological environment in terms of classification system building, RS data interpretations, field investigation and other methods, reviews the spatial changing tendency of the local ecological environment after the emergency water suppliers, that is, the plants in the research target grow better, and vegetation coverage constantly increases year by year, and some obvious ecological turns for worse are prevented and even stopped and gradually become better in the lower reaches of the Tarim River. The research certifies that the ecological emergency water supply project is a successful trying to some extent. But it is just a temporary initiative, which merely stimulates the plants growing on both sides of the River and the intensity of its effects is not strong enough to extend to those a little far away from the river bank. The ecological environment is not optimistic in the lower reaches of the River as a whole.

(2) Farmland in the research zone goes up in size constantly and rapidly during 1999 through 2004, which is at the expenses of decrease in waste land, reed field and destruction of the forests and water area. If such tendency goes further the land desertification will increasingly grow worse and lead to the local ecological environment unbalanced more. Therefore the integrated macro-adjustment system is expected to set up and carried out and the forests are legally not entitled to be cut disorderly and excessively, and the wasteland is not to be randomly regenerated to the farmland.

(3) The method used in this study is creative with the combination of 3S, warehouse and other information technology. The normalized difference vegetation index (NDVI) is mainly used to calculate the vegetation index. Both factors of vegetation coverage and its types are integrated to one analysis of the ecological environmental monitoring data in a qualitative and quantitative way. This method is highly advantageous with a short period, macro accuracy and top automation. The monitoring data are practical and dynamic and corresponding results accordingly are advisable for the reality. It is a prevailing tendency and means in dynamically monitoring the ecological environment in a given area.

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