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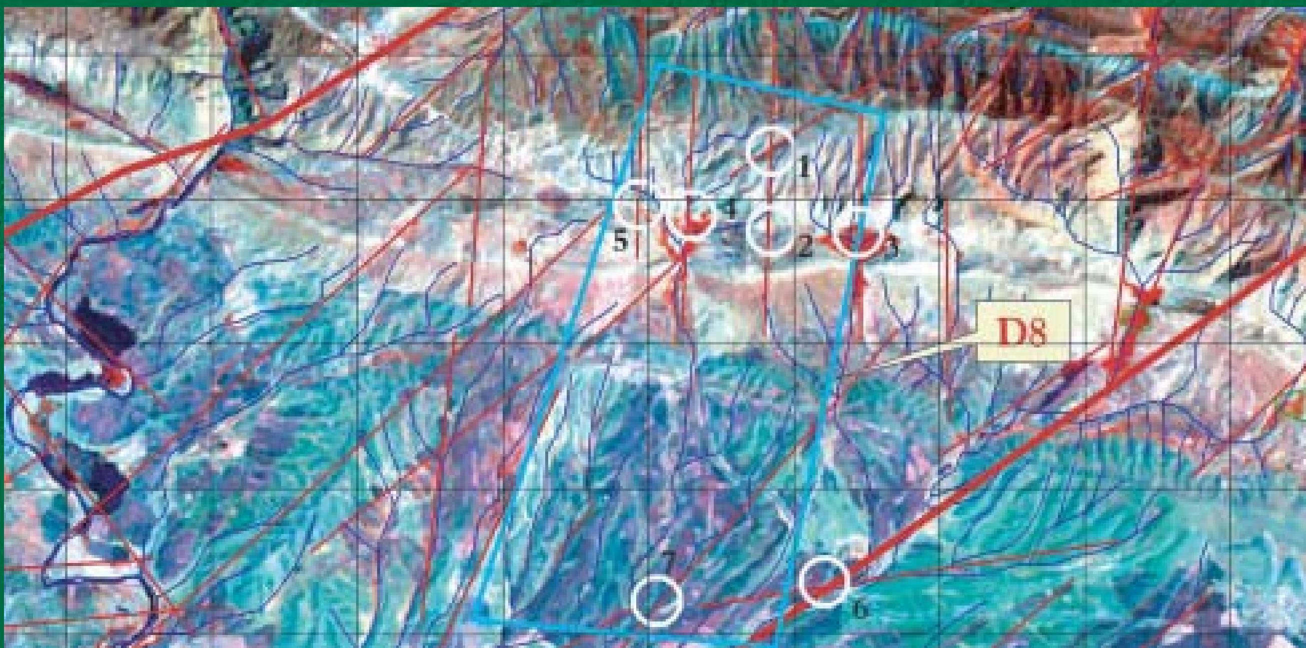
Groundwater search by remote sensing: A methodological approach



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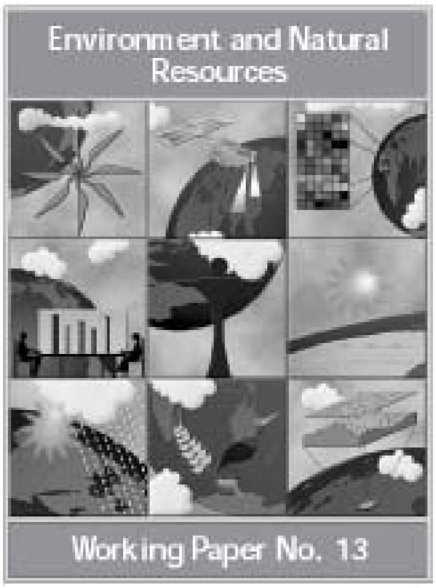

Groundwater search by remote sensing: A methodological approach

by

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ABSTRACT

In the framework of the technical assistance provided to the Groundwater Unit (GWU) of the FAO-implemented IRAQ/SCR/986 "Three-year Agricultural Programme" for the three Iraqi Northern Governorates, a comprehensive remote sensing/GIS methodology was developed to identify potential sites for groundwater exploitation.

The approach used in the study was a development of the traditional standard sequence of drainage, landforms, cover and lineaments analyses, to which several improvements and additions were made, such as:

- all data were in digital format and stored in a geo-database as GIS layers;
- all analyses and interpretations were performed directly from the computer screen;
- on the basis of a previous positive experience, thermal lineaments analysis was performed;
- a comprehensive geo-database was created including all GIS layers which were considered of interest for the study;
- by using the potentiality of GIS software, which allows stacking of georeferenced data for comparison and integration and data query for subsetting the needed information, selected layers of the database were superimposed on the Landsat image kept as background and a logical series of observations was made, leading to a well-substantiated set of interpretation assumptions.

The creation of a GIS database, including the data format and entry, is a time-consuming and laborious exercise, as high accuracy is definitely mandatory. However, once the database is complete, interpretation of features leading to selection of promising sites for groundwater search is carried out easily and quickly. This as a result of data availability of all needed information in a GIS environment.

Thirty test areas, selected by the field team, were investigated and 198 promising sites were identified for further ground survey and subsequent drilling.

Unfortunately, the political situation in the region deteriorated and thus it was impossible for the field team of GWU to check and exploit the results of the study. However, they managed to assess some of the potential sites indicated in the first maps provided and reported an accuracy of about 90 percent.

Keywords: groundwater search, Northern Iraq, remote sensing

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* Environment and Energy Series
* Remote Sensing Centre Series
* Agrometeorology Working Papers

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INTRODUCTION

1.1 Background

In the immediate aftermath of the Gulf War in 1991, the United Nations sent a mission to Iraq which reported the makings of "an imminent catastrophe … if minimum life supporting needs are not rapidly met." The Security Council responded by offering Iraq, in August 1991, an opportunity to sell oil to meet its people's basic needs while the sanctions, imposed in August 1990, remained in place. That offer was not accepted and over the following five years there was widespread suffering with food shortages, an absence of essential medicines and a general deterioration in essential social services.

In 1996 the Government of Iraq and the United Nations Secretariat reached an agreement on a Memorandum of Understanding, setting out the details of implementing Security Council resolution 986 (1995) which had been adopted 13 months earlier. Resolution 986 (1995) set terms of reference for the "Oil-for-Food" programme.

"Oil-for-Food" is a unique programme, established by the Council as a temporary measure to provide for the humanitarian needs of the Iraqi people.The programme is funded exclusively with proceeds from Iraqi oil exports, authorized by the Security Council. Currently 72 percent of Iraqi oil export proceeds goes to fund the humanitarian programme, of which 59 percent is earmarked for the contracting of supplies and equipment by the Government of Iraq for the 15 Central and Southern Governorates and 13 percent for the three Northern Governorates, where the United Nations implements the programme on behalf of the Government of Iraq.
There are nine United Nations agencies and programmes involved in the "Oil-for-Food" programme. These are: FAO, ITU, UNDP, UNESCO, UN-Habitat, UNICEF, UNOPS, WFP, and WHO.

FAO is implementing the IRAQ/SCR 986 Three-Year Agricultural Programme in the three Northern Governorates, for the sustainable rehabilitation of the agricultural sector, including all aspects of agriculture, forestry and fishery. The Water Resources and Irrigation Sub-Sector (WRISS) is the largest of the agriculture-related activities in the three Northern Governorates, with six major fields of activity as follows:

- rehabilitation of existing irrigation infrastructures, ensuring agricultural production on irrigable land;
- construction of new irrigation schemes, extending the irrigated area, and introducing water saving irrigation technologies;
- water harvesting through the construction of run-off collection dams and soil and water conservation measures, increasing soil moisture availability for crop production;
- drilling of deep wells, rehabilitation of shallow wells and maintenance of springs, increasing groundwater resources use for crop production;
- water resources management, ensuring water availability for irrigation purposes in sufficient quantity and quality;

- human resources development, ensuring local professional capacity building and institutional strengthening.

Within the framework of WRISS, a groundwater unit (GWU) was established with the objective of appraising the groundwater availability of the region and identifying sites for groundwater exploitation.

1.2 Objectives of the study

The general objective of the study was to provide the field team of WRISS/GWU with information to facilitate and speed up their ground investigations for groundwater appraisal and exploitation.

In this framework specific objectives were:
- to provide a reliable and uniform topographic coverage of the three Iraqi Northern Governorates;
- to provide, from remote sensing data, detailed information on drainage and watersheds;
- to prepare a comprehensive database in ArcView format including layers from remote sensing data interpretation as well as from traditional data, relevant for groundwater search and hydrological applications;
- to identify for the 30 areas selected by the field team, encompassing a total of 2 044 km^2, specific potential groundwater sites for the necessary ground investigations (field checking and geoelectric surveys) and subsequent drilling, coupled with the information on lithology, geomorphology and, when possible, on expected water quality for every site.

1.3 Study area

The study area covers entirely the three Iraqi Northern Governorates (Dohuk, Erbil and Sulaymaniyah) encompassing 40 627 km^2 (Fig. 1). The main features of the region are reported herein.

Physiography

Northern Iraq can be divided into three main physiographic zones, namely:

1. The northern range of the Zagros Mountains
2. The central range of the Border Folds
3. The southern plains of the Tigris River

The north-northeastern part is characterized by the Iraqi Zagros Mountain range with heights up to 3 600 m above sea level (a.s.l.). This range separates the three Governorates of Northern Iraq from Turkey to the north and from Iran to the northeast. In this area morphology is rather rough, with steep slopes and narrow valleys. Snow coverage is common at high altitudes and vegetation cover is widespread, constituted of both grasses and forests.
A smoother morphology occurs in the central part; the area being characterized by an anticline/syncline system (the Border Folds, *Boccaletti and Dainelli, 1982*) which gives rise to a relief with a general orientation NW-SE. Heights up to 2000 m a.s.l. are reached. Wider valleys occur in this zone, which are strongly influenced by tectonic control. Vegetation is rather sparse, mainly herbaceous.

The southwestern part is dominated by the low alluvial plains of the Tigris River and its tributaries. Average altitude is around 400 m a.s.l.

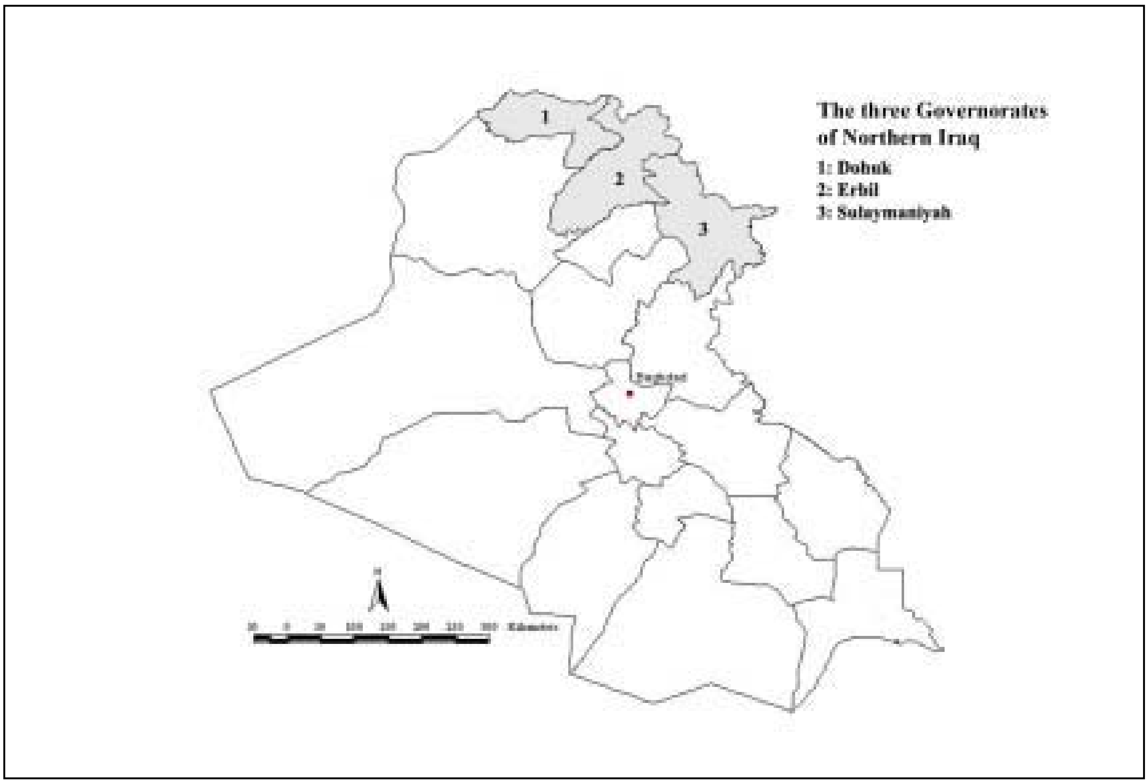

Fig. 1. Study area

Geology and hydrogeology

Northern and north-eastern Iraq geologically are part of the extensive alpine mountain belt of the Near East. The Taurus-Zagros belt developed during the collision of the Afro-Arabian continent with the Eurasian continent (the latter including a number of microplates and island arcs) that culminated in the Miocene–Pliocene.

The Taurus–Zagros belt includes two main zones: the folded zone (Border Folds, see above) and the thrust zone. The thrust zone forms the suture zone of the collided plates and occurs as a narrow strip in the extreme north, just outside the border between Iraq and Turkey, and in the northeast, along the border between Iraq and Iran. The folded zone is much wider (~200 km) and can be subdivided according to the intensity of folding into two main parts: the imbricated folds zone, which consists of a relatively narrow zone of intensely faulted and thrusted large folds near the thrust zone border, and the simply folded zone, which is much wider and consists of smaller and less disrupted folds. The simple folds are further subdivided into two subzones: the high mountain zone, which consists of a series of relatively large mostly asymmetric anticlines separated by narrow synclines, and the foothill zone, which consists of a series of relatively small and narrow anticlines separated by wide synclines (*Ameen,* 1992).

The Taurus-Zagros thrust zone mainly consists of the oldest formations, from Ordovician to Cretaceous, with occurrence of carbonatic and clastic rocks as well as igneous and metamorphics. In the folded zone Triassic to Pliocene units outcrop, mainly sedimentary rocks, with a predominance of limestones and dolomitic limestone. These formations are very significant, because of the intensive karst phenomena and the large volume of potential groundwater storage. Recent Quaternary deposits (alluvium, terrace, colluvium) fill the valleys and follow the main riverbed in the northern and central part, and cover the older Tertiary formations in the plains.

Hydrology

Significant surface water resources occur in the northern part of North Iraq. The major perennial rivers are the Tigris (which runs at or near the southwestern border), the Great Zab, the Small Zab (both in a NNE-SSW orientation) and the Diyala (at the southeastern border of the region). In the northern part of the study area the main tributaries are perennial, however the river runoff reduces towards the south. Ultimately, on the plains, all tributaries (wadis) are ephemeral and dry out regularly by the end of springtime. The main wadis in the south (Erbil area) are Wadi Kurdara and Shiwasor and Wadi Bastora. It is important to note that almost all the major rivers crossing the study area have their origin outside it, namely in Turkey (the Tigris and the Great Zab) or in Iran (the Small Zab and the Diyala), thus their entire watershed covers broad regions outside the study area. Only the Small Zab has a catchment area that extends, for a limited portion, beyond the Northern Iraqi border.

The average discharge of the Great Zab at the Eskikelek gauge station registered over the period 1970-1973 was of 313 m^3/s. Daily river flow varied from 118 m^3/s to 2439 m^3/s. Data from the Altun Kupri station on the Small Zab show an average discharge of 290 m^3/s (period 1970-1972), with a minimum of 82 m^3/s and maximum of 1 265 m^3/s.

Two dams control the Small Zab (Dokan Lake) and the Diyala River (Darbandikhan Dam) in the central part, and their main purpose is to generate hydropower. The construction of the large Bekhma Dam on the Great Zab was not completed. Water from the Dohuk Reservoir and from the numerous impoundments constructed on the smaller rivers is used for traditional irrigation schemes (gravity channels) or for water supply.

Climate

The whole of the study area is characterized by cold and snowy winters and warm dry summers. On the plains, typical semi-arid climatic conditions prevail. Precipitation occurs from October to May, decreasing from the NE to SW. The existing data at Sulaymaniyah meteorological station (in the middle of the territory) show an annual average precipitation of 674 mm for the period 1941-1999. The total annual rainfall registered at this station in 1999 was 338 mm. The mean annual rainfall in the Erbil plain for the period 1941-1970 was 425 mm/year while observed yearly values range between 200 to 700 mm. Rainfall reduction has been observed recently: during the winter and springtime of 1998/99: the observed rainfall was three times lower than average. Comparison of data from all three Governorates for October 1999 to April 2000 shows a reduction of about 50 percent as compared to the mean rainfall for this period of the year.

1.4 Data/software used

The following data and softwares were used in the framework of this study:

Satellite data

Landsat Enhanced Thematic Mapper (ETM) data in digital format were preferred over other satellite data due to the availability of three near- to mid-infrared bands, extremely useful for terrain and lineaments analyses. Furthermore, as Landsat ETM provides eight co-registered spectral channels (one panchromatic with 15 m spatial resolution, six bands ranging from visible to mid-infrared with 30 m spatial resolution, and one thermal band with 60 m spatial resolution), this permitted a large spectrum of band combinations, useful in visual interpretation of different features.

In view of the hydrogeological objectives of the study, Landsat ETM data were selected as acquired in the dry season, to evidentiate features (vegetation, soil moisture) related to the occurrence of water and to avoid overshadowing by too much vegetation.
Six Landsat scenes fully covered the study area, but another four were also available, acquired in different months and/or years.
The Landsat data used in the study are listed in Table 1.

Table 1: Satellite data (Landsat 7) used in the study

Path	Row	Date of acquisition
168	35	28/06/2000 31/08/2000
168	36	28/06/2000 31/08/2000
169	34	03/06/2000
169	35	19/06/2000
170	34	26/06/2000 13/06/2001
170	35	09/05/2000 13/06/2001

Topographic and thematic data

The Operational Navigation Chart (ONC), at scale 1:1 000 000, sheet G 4, edition 10, revised in 1974, available in paper format, was used for a general overview of the area.

Initially the main problem was to locate topographic maps covering the whole area of the study, so as to have a uniform topographic coverage. The field team unfortunately had only topographic maps, at different scales and projections, covering scattered areas. Thus Russian topographic maps, at scale 1:100 000, series J-38 and I-38, in Gauss Kruger projection, were purchased. Maps were provided in raster tiff format by scanning the original sheets.

Lithostratigraphic map, at scale 1:500 000, prepared by Salahaddin University (Erbil) and geological maps, scale 1:100 000 prepared by Gara Bureau (Erbil), Salahaddin University (Erbil) and Sulaimaniyah University (Sulaimaniyah), were provided by the Mapping Unit of the field staff, in paper and raster format. These maps, unfortunately, do not cover the whole study area.

Vector data

Boundaries of the country and of the three Northern Governorates were obtained in ArcView shapefile format from the official FAO GIS database. This data was provided in geographic coordinates (latitude, longitude) and WGS84 datum.

GIS layers in Map Info vector format were provided by the field staff, concerning:
- geology and tectonics for the whole study area at 1:500 000 scale and for seven smaller areas not covering the whole three Governorates at 1:100 000 scale;
- springs and deep wells drilled by FAO all over the study area.

Table data

MS Excel worksheets containing data on springs, deep and shallow wells for only five areas in the three Governorates (Aqra, Arbat & Kourmal, Chamchamal, Sumail and Zakho) were provided by the field team.

Softwares

The following softwares were used:
ENVI 3.5 (and later on 3.6) was used for georeferentiation and general image processing. The same software was used by the field team;
ERDAS 8.4 for visual analysis and interpretation;
ArcView 3.2 for GIS data acquisition, analysis and presentation. A freeware extension, named "Rose Tool" was used for creating rosette diagrams from lineaments data;
Terranova ShArc 3.0 for vector data editing.

CHAPTER 2

METHODOLOGY

The methodology used in this study follows the standard sequence of drainage, landforms, cover and lineaments analyses and the integration of their results for geological and hydrogeological assessment. This approach was used successfully for many years with both aerial photographs and satellite images for the above tasks. However, in this study several improvements and additions were made, namely:

1. all data were in digital format and stored in a geo-database as GIS layers;
2. all analyses and interpretations were performed directly from the computer screen;
3. on the basis of a previous positive experience, thermal lineaments analysis was performed (see 2.6);
4. a comprehensive geo-database was created including all GIS layers which were considered of interest for the study (see 2.7); for instance tabular data on wells and springs with their location, discharge and other pertinent information, vector data on geology; drainage and lineaments and raster data on satellite images;
5. by using the potentiality of GIS software, which allows stacking of georeferenced data for comparison and integration and data query for subsetting the needed information, selected layers of the database were superimposed on the Landsat image kept as background and a logical series of observations was made, leading to a well-substantiated set of interpretation assumptions.

The creation of a GIS database, including the data format and entry, is a time-consuming and laborious exercise, as high accuracy is definitely mandatory. The time required for its preparation is also related to the area under consideration. However, once the database is complete, interpretation of features leading to selection of promising sites for groundwater search is carried out easily and quickly. This as a result of data availability of all needed information in a GIS environment.

2.1 Topographic maps georeferentiation

Topographic coverage of the three Northern Governorates area is given by a series of 62 maps at 1:100 000 scale. (Fig. 2). These maps were provided as raster files (tiff format) scanned from the original paper version. They are of Russian origin with the following projection parameters:

- Projection: Gauss-Kruger
- Ellipsoid: Krassowski
- Datum: Pulkovo 1942
- Zone 8 (42°-48° East)
- Units: meters

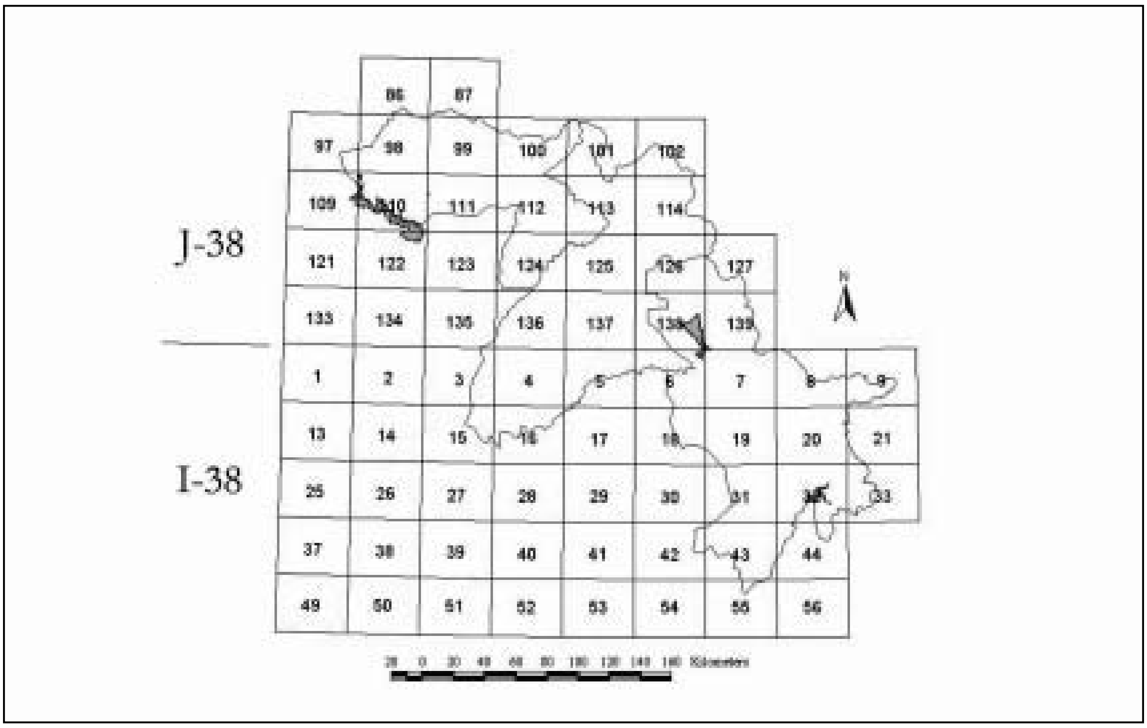

Fig. 2. Topographic maps index

In order to georeference these data in the projection used in the project (i.e. UTM – WGS 84), a coordinate conversion was carried out on the corners of the 62 maps. The conversion was performed using a module of ENVI 3.6 software (***Map Coordinate Converter***), in which each single couple of coordinates east and north were recalculated from one system to another. In this case, from Gauss Kruger – Pulkovo 42 to UTM – WGS 84. A table, listing the four corners coordinates (x and y, in meters) for each map was, thus, created. Two adjacent maps have the two coordinate couples in common, which guarantees a perfect matching at least at the corners.

The table of coordinates mentioned above was also used to create a GIS layer representing the topographic maps index of the topographic coverage (Fig. 2). This layer was created with the GIS software TN-Sharc, with a command that generates regular grids, represented by lines and polygons, according to a specified distance on the x and y axes. In this case, the distance was given by the difference between the coordinates of map corners. The topographic maps index GIS layer has been then converted in *shapefile* format in order to be integrated in ArcView with the other layers of the database.
The topographic maps index layer was essential each time it was necessary to know which topographic map covered a given area, such as in the georeferencing of Landsat images, in the digitizing of the stream network and in the interpretation of geologic features.

A problem to be solved before starting the georeferentiation procedure was represented by the fact that the original raster files of topographic maps included both the map area and the accessory elements, such as title, legends, etc. Thus, a further step was to subset the map area with a cutting tool of a generic raster image manipulation software, in order to generate the files ready to be georeferenced.

The georeferencing procedure was carried out using ***ENVI Registration Module***, with the Ground Control Point (GCP) method. For each map file, the four corner coordinates have been entered as GCPs and a first order polynomial transformation was used to re-calculate the coordinates of each pixel in the raster layer. The Root Mean Square error (RMS) always resulted less than the pixel value.

After resampling (the cubic convolution method was used in order to obtain a smooth appearance of the map), a new raster file (geotiff format), with a resolution of ten metres, was generated for each topographic map file, carrying the correct UTM –WGS 84 coordinates.
An evaluation of the quality of georeferentiation was carried out by loading in ArcView both the topographic maps index layer and the georeferenced maps and checking for mismatching. Slight differences were found especially on the sides of the maps (around 20 m), probably related to deformations present in the original paper maps or errors occurring during the scanning procedure. These differences were judged insignificant for the further process of georeferentiation of Landsat imagery.

Georeferenced topographic maps were used for: 1*)* Landsat images geocoding, 2*)* stream network acquisition (in support to satellite images) and 3*)* morphology interpretation in the phase of location of sites suitable for groundwater search. They were immediately sent to the field team, as they constituted the essential baseline information for any field work.
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2.2 Satellite data georeferentiation

Ten Landsat 7 ETM scenes were available for the study; their characteristics are reported in paragraph 1.4. Satellite data were made available by the distributor in a raw format, with system correction but without georeferentiation. This means that they were not oriented to any given coordinate system, thus they cannot be integrated with other geocoded GIS layers.
The first operation to be carried out on satellite images is then to geocode them, using already geocoded data as a reference. Normally, the most common data used for this task are topographic maps.

Operatively, each Landsat scene was firstly imported in ENVI 3.5 in order to be managed by the software. Three different files were generated for each scene: one containing the panchromatic band, another the six multispectral bands and the third the thermal band, making a total of 30 image files. The procedure of georeferentiation (or geocoding) was then applied first to the ten multispectral images, which were the first to be used in the study. In a second phase, the thermal and panchromatic image files were georeferenced, using as a reference, the multispectral files.

Since the process of georeferentiation was carried out as an image-to-image registration (i.e. a single image registered on another single image), and not with manually entered coordinates taken from hardcopy maps, a problem arose, as each Landsat scene covers an area far greater than the one covered by a single topographic map. Consequently, topographic maps had to be combined together in mosaics to cover the area of each Landsat scene. The following procedure was used to select the maps to mosaic: using ArcView, the topographic maps index layer previously produced (see para. 2.1) was overlaid on the Landsat scenes index layer (Fig. 3), which is a vector shapefile created from the coordinates of the four corners of each of the six Landsat scenes (taken from the header file) representing with polygons the areas covered by the scenes. A spatial query was applied to retrieve all the topographic maps intersecting a given Landsat scene. By means of the ENVI tool ***Mosaicking***, six topographic mosaics were then generated, which were used as reference in the georeferentiation process.

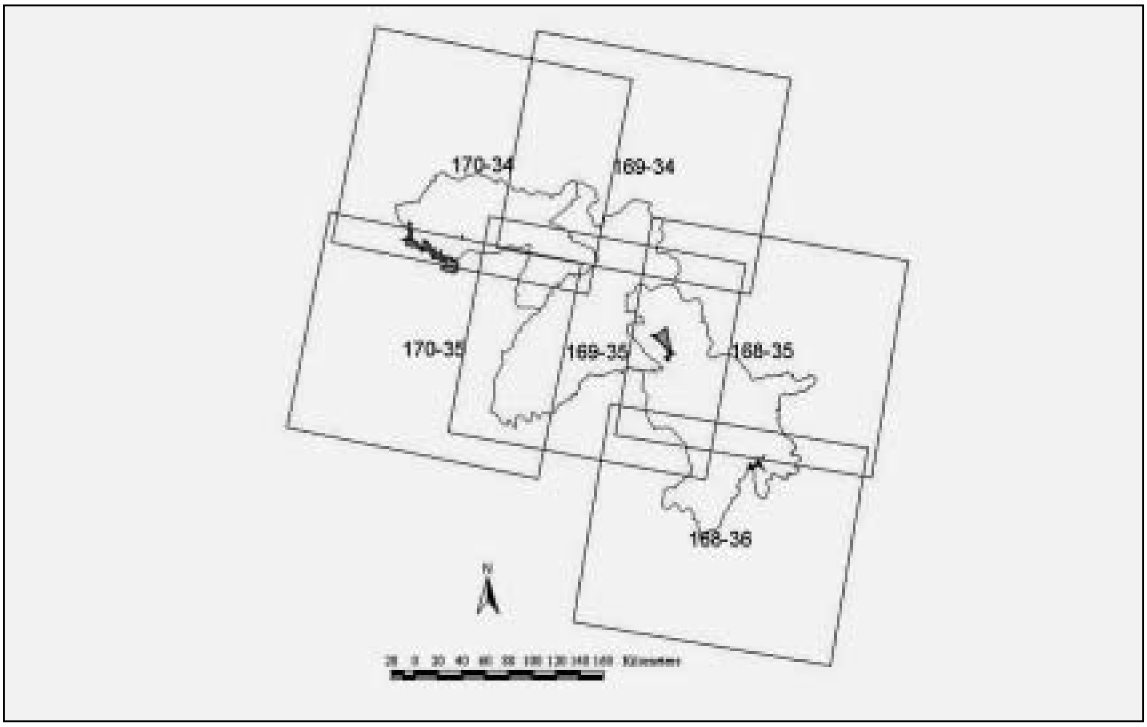

Fig. 3. Landsat scenes index

The procedure of image-to-image registration uses Ground Control Points (GCP) recognizable both on the satellite image and on the topographic maps in order to attribute ground coordinates (in a given coordinate system) to the first one. GCPs are located on the reference image, usually on features such as cross roads, river confluences, corners of fields. In the specific case, several limitations were found in the choice of GCPs: first of all the large time span existing between the topographic maps editing, dated between 1972 and 1982, and the Landsat imagery (2000-2001). Urban areas and roads had undergone a significant development in the last few years, making such features on the topographic maps almost always unrecognizable on the satellite image. However, as a whole the region still maintain a natural environment. Secondly, a certain amount of approximation was detected in the drawing of some topographic maps elements, especially roads and tracks, but also rivers, although the main differences were detected on alluvial plains where river courses could have changed over the last 20 years.

For the above reasons, the choice of GCPs to be used fell in the majority of cases on river confluences in valleys cut in hard rocks or on roads crossing, that is only where a good match between topographic map and Landsat image features was evident.
Moreover, the total number of GCPs identified for each scene was consequently low compared with the recommended minimum values of 10-20. A mean value of 10 GCPs was used for each Landsat scene, trying to choose the points homogeneously over the image. The RMS errors were always kept less than the pixel unit (0,4 to 0,6).

The parameters of the coordinate system used for geocoding the Landsat scenes are:

- Projection: UTM
- Ellipsoid: International 1909
- Datum: WGS84
- Zone 38 (42°-48° East)
- Units: meters

For every scene, a second order polynomial transformation was applied which provided better results than the first order, while keeping distortions low enough. For the resampling step, the cubic convolution method was used, in order to obtain a highly readable image. This resampling technique modifies the pixel value permanently, thus it cannot be used when the real radiance values of pixels must be calculated. Since the use of Landsat data in this study was foreseen only for visual analysis, cubic convolution was considered the most appropriate method.

As a result of georeferentiation, 30 new resampled images were generated, namely: ten geocoded multispectral scenes (six bands, 30 m spatial resolution), ten geocoded panchromatic scenes (one band, 15 m spatial resolution) and ten thermal scenes (one band, 60 m spatial resolution).

These images were converted also into other formats other than the ENVI format, such as ERDAS **.img** and **geotiff**, in order to be managed in ArcView and ERDAS Imagine.
Once georeferenced, Landsat scenes are ready for any further elaboration and interpretation, and any GIS layer created in ArcView starting from these images automatically gets the georeferentiation from them.

2.3 Drainage analysis/watershed identification

Significance of drainage pattern

The drainage system, which develops in an area, is strictly dependent on the slope, the nature and attitude of bedrock and on the regional and local fracture pattern. Drainage, which is easily visible on remote sensing imagery, therefore reflects to varying degrees the lithology and structure of a given area and can be of great value for groundwater resources evaluation.
Drainage is studied according to its pattern type and its texture (or density of dissection) (Way, 1973). Whilst the first parameter is associated to the nature and structure of the substratum, the second is related to rock/soil permeability (and, thus, also to rock type). Actually, the less a rock is permeable, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. This gives origin to a well-developed and fine drainage system. On the other hand, in karst regions, where the underground circulation of water is much more developed than the surficial one, drainage is less developed or missing altogether.

Six basic types of drainage patterns were identified, namely: 1) dendritic, 2) trellis, 3) parallel, 4) radial, 5) anular and 6) rectangular. Their features and occurrence are as follows (Way, 1973):

1. In the dendritic pattern, a tree-like branching of tributaries join the mainstream at acute angles. Usually this pattern occurs in homogeneous rocks such as soft sedimentary or volcanic tuffs.

2. Trellis is a modification of dendritic, with parallel tributaries converging at right angles. It is indicative of bedrock structure rather than material of bedrock. It can be associated to tilted or interbedded sedimentary rocks, where the main channels follow the strike of beds.
3. In the parallel pattern, major tributaries are parallel to major streams and join them at approximately the same angle. It can occur in homogeneous, gentle and uniformly sloping surfaces whose main streams may indicate a fault or fracture zone. Common in pediment zones.
4. The radial pattern is a circular network of approximately parallel channels flowing away from a central high point. It usually occurs in volcanoes or domelike structures characterized by resistant bedrock.
5. Anular pattern is a concentric network of channels flowing down and around a central high point. This pattern is usually controlled by layered, jointed and fractured bedrock, in granitic or sedimentary domes.
6. The rectangular is a modification of the dendritic pattern, with tributaries joining mainstream at right angles, forming rectangular shapes. It is controlled by bedrock jointing, foliation and fracturing, indicative of slate, schist, gneiss and resistant sandstone.

Further modifications of the six basic schemes give origin to more than 20 other patterns that cover almost all the possible existing cases.

In addition to the pattern characterization, drainage can also be described in terms of texture or density of dissection. On this basis, three types can be identified: 1) fine, which is indicative of high levels of runoff, suggesting impervious bedrock and/or fine textured soils scarcely permeable; 2) medium, which can be related to a medium runoff and mixed lithology, and 3) coarse, which indicates little runoff and consequently resistant, permeable bedrock and coarse, permeable soil materials.

Digitalization of the drainage network and of the watersheds boundaries

The GIS layers of the drainage network, lakes and watershed boundaries for the whole study area were digitized at the computer screen by analysing the Landsat images and the rasterized topographic maps. The digitalization of the drainage network was the most time-consuming since almost 60 000 stream segments were acquired. Nine catchments cover the three Governorates of Northern Iraq and four artificial reservoirs occur in this area.
The digitizing procedure for the above-mentioned GIS layers was carried out using both ArcView GIS and Terranova SHarc. The first software provided the environment for data entry, while the second was used for the construction of the topology of the GIS layers that were created.

Concerning watershed divides, the three Governorates of Northern Iraq are crossed or bounded by four main rivers: the Nahr Dijlah (the Tigris), the Nahr Az Zab Al Kabir (the Great Zab), the Nahr Az Zab As Saghir (the Small Zab) and the Nahr Diyala. Of those, only the Small Zab has a watershed which is almost completely contained inside the administrative boundaries of the three Governorates. The other three main rivers cross the study area originating from other countries such as Iran and Turkey. Thus, their basins are far greater than the area under analysis and the data available (remote sensing and topographic maps) were not sufficient to delineate the watershed boundaries for these rivers.

For these reasons, only the Small Zab watershed was completely mapped, as it has only a small portion outside Iraq. Consequently, only the Small Zab watershed is suitable for further hydrologic studies, since it is the only one for which data are already available.

The watershed boundaries were digitized as GIS layer, using both the Landsat images (mainly False Colour Composite 453) and the topographic maps as references. The acquisition of this GIS layer was carried out at a scale of 1:50 000. Further corrections and improvements of the preliminary version were carried out during the digitizing of the drainage network (Fig. 4).

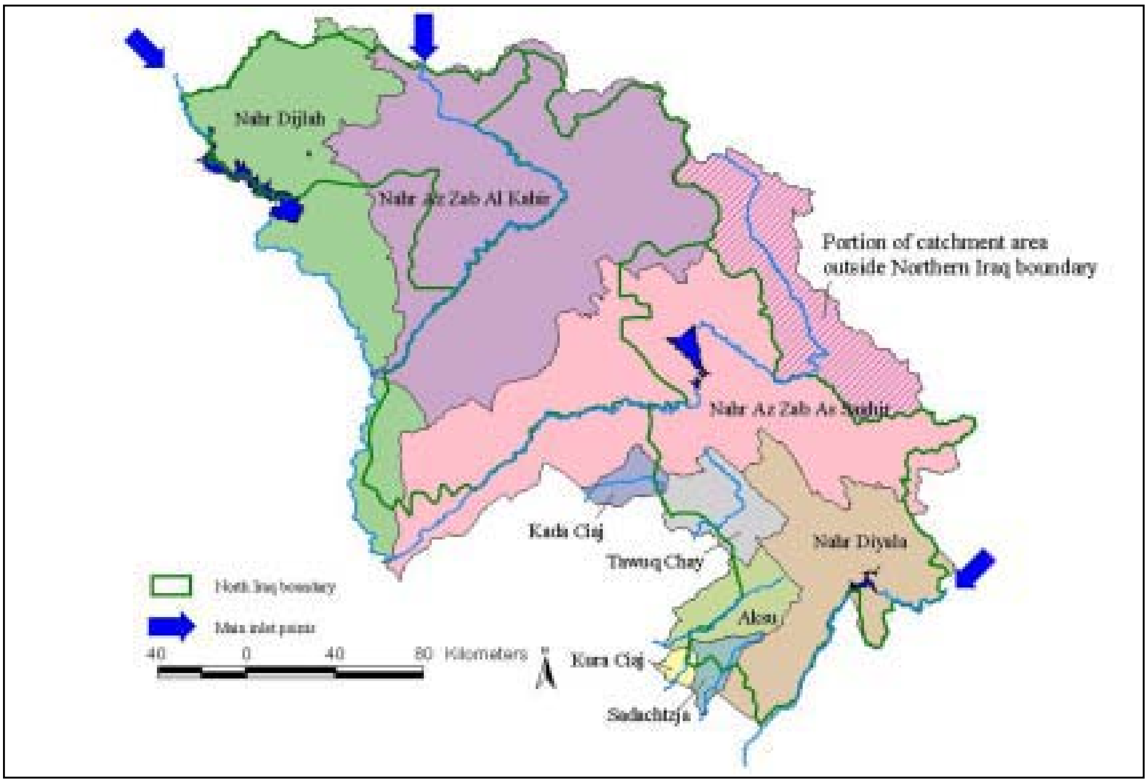

Fig. 4. Watersheds occurring in the study area

For the mapping of the drainage network, separate shapefiles were produced for each main catchment area. This was mainly due to the fact that priorities on certain areas had to be respected. Starting from the main stream in the catchment, classified as first order channel, the tributaries up to the ninth order were digitized. Later on, the shapefiles related to each basin were merged in a single drainage network GIS layer.

The digitalization of the drainage network was carried out by analysing as background reference the Landsat images at the visualization scale of 1:50 000. Band 5 was preferred among the other spectral channels, due to the fact that, as an infrared band, contrast of light and shadow is enhanced. False Colour Composites were also used, especially to detect drainage by means of riparian vegetation in low areas. FCC 453 or 456 were chosen.

In order to optimise the digitizing procedure, Landsat whole scenes were also subset, to obtain smaller and easy to load and manage images. Subsets were usually tailored on groups of topographic maps according to the watershed under consideration. Contrast stretching techniques (linear and piecewise linear) were applied to these images to enhance the readability, giving good results. High pass filters (edge enhance) were tried, too, but without appreciable improvement of image characteristics.

In all those cases where drainage was not clearly detectable from Landsat images, essentially in areas with almost flat morphology or on darker slopes, topographic maps were used as a reference to complement the information provided by the satellite images (Fig. 5).

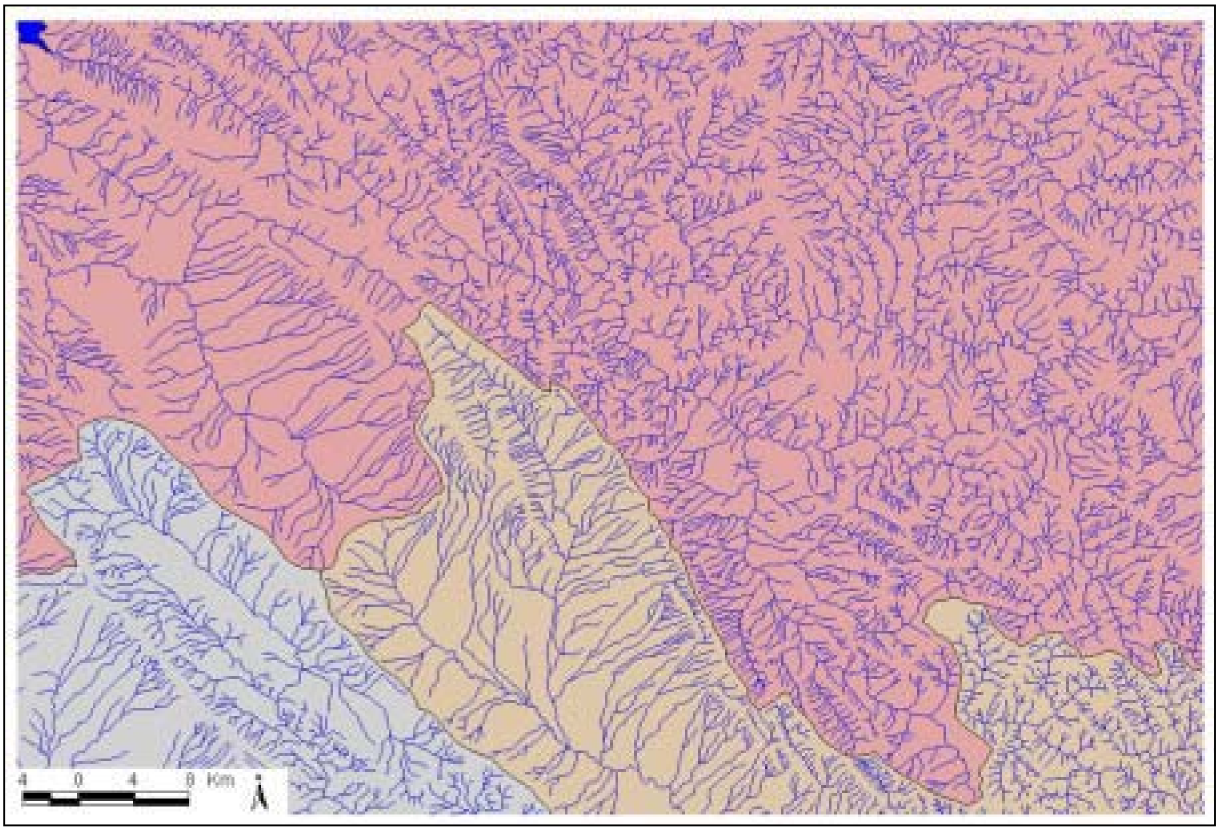

Fig. 5. Example of drainage network

The digitizing of the coastline of lakes was performed by using the Landsat band 5 to take advantage of the absence of reflectance of water in the infrared wavelengths. Topographic maps were utilized only as reference to observe the high variability of coastline in time (from the 1970s to present). A certain variability was also observed between Landsat images of June 2000 and August 2001. Lake coastlines were thus acquired only from one date, namely June 2000.

Drainage analysis

The three physiographic regions (see para 1.3) occurring in the study area largely influence the drainage network.

In the Iraqi Zagros Mountain Range a generally dendritic pattern is usually observed. Locally, a control of stream segments by fractures and faults is clearly recognizable and the pattern can change to angulate. This is a variation of dendritic in which linear features have modified the original shape. Furthermore, in this area a frequent orientation of valleys in the alpine direction (NW-SE) can be detected.

The Border Folds zone, characterized by an anticline/syncline system with a variable trend (from alpine in the centre-southeast to E-W in the northwest), greatly influences the drainage pattern. In general terms, this area is characterized by a trellis-like drainage, where the mainstream typically runs along syncline axes in topographic lows or inside an eroded anticline. Tributaries coming down from the slopes of fold flanks are short, frequently ephemeral and at right angles in respect to the mainstream. Frequent cases of antecedence were observed, where rivers cross an anticline in deep gorges. Locally, examples of captures also occur, which greatly contributed to making the stream network rather complicated (a contorted pattern can possibly be identified). In the Border Folds zone, plains of different size, located among the folded terrain, also occur. In those flat areas, the drainage pattern tends to be dendritic, with a predisposition to parallel. A strong control by linear features is also observed. Areas with absence of drainage have been observed as a rather common feature in this portion of the study area. Geological maps have confirmed the calcareous nature of bedrock in those zones, where, due to karst phenomena, underground water circulation is much more developed than surface runoff.

As we move towards the southern borders of the three Governorates, flat alluvial areas become predominant. Here the drainage pattern is definitely dendritic and parallel, although some pinnate examples with long tributaries are still present in connection to folded areas. Tectonic control of river channels is noticeable, especially concerning the main tributaries of the Tigris, of the Small Zab and of the Diyala which have parts of their course clearly oriented along NE-SW (anti-alpine) fractures.

2.4 Landforms analysis

Landforms analysis was performed on the screen from Landsat 453 FCCs and band 5 images only for areas around each of the 30 test sites, as it was known since the onset, that detailed study for identification of groundwater promising sites would have to be carried out only for selected test sites and not for the whole area. It was thus unnecessary to have a comprehensive landforms GIS layer in the database,

Detailed landforms analysis was therefore performed for areas around and including each test site, noting all terrain features of interest, such as anticlines, synclines, monoclines, erosion forms, dip and tickness of beds, etc., that is all features that were possibly influencing groundwater storage and transmission. Figure 6 shows the typical landforms occurring in the Border Folds physiographic region.

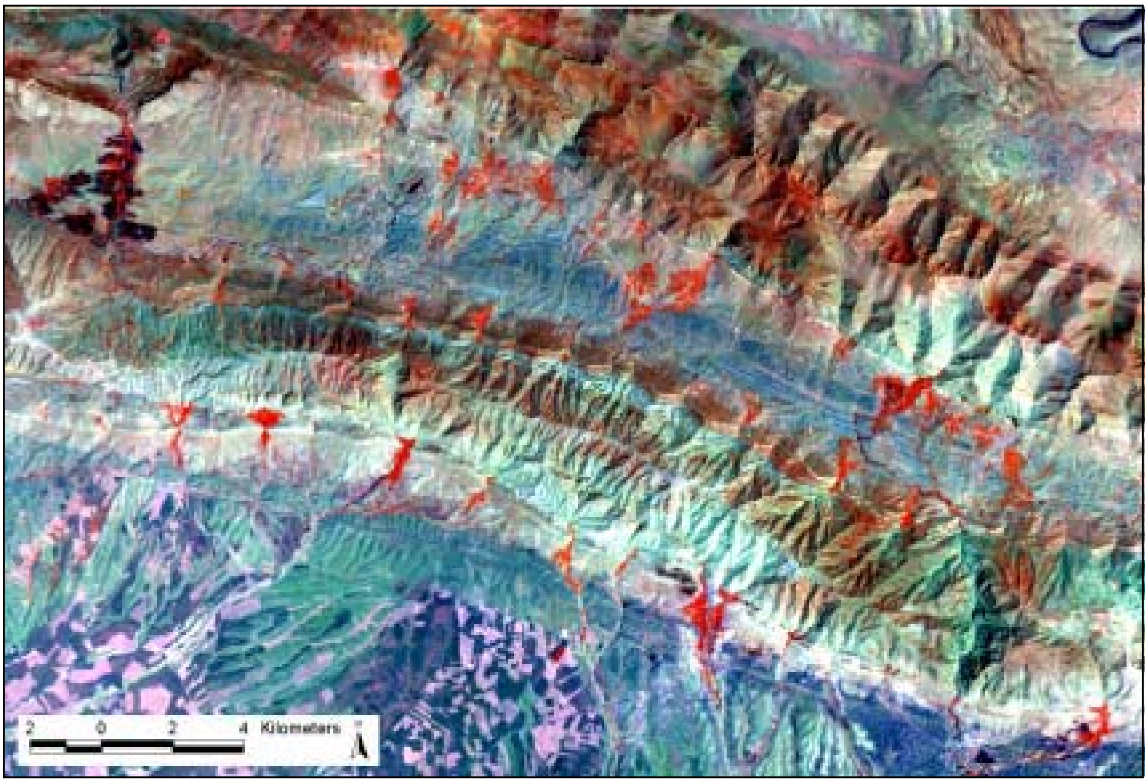

Fig. 6. Typical anticline and syncline sequence of the Border Folds region

Alluvial fans and pediments were, however, mapped for the whole study area and the relevant GIS layer was entered into the database, in view of locating potential sites for shallow wells drilling.

2.5 Cover analysis

Cover analysis was performed directly on the screen and consequently a GIS layer related to cover features was not included in the database.

For hydrogeological studies the occurrence and types of natural vegetation and their spatial distribution may provide useful information. However, very little natural vegetation is present in the region, all hills and mountains of the study area being mainly covered by sparse grasses, dry in the period of Landsat data acquisition (June-August).

Thus, attention was focused on patches, sometimes large, of green grasses, indicating the possible occurrence of springs. In several cases this assumption proved correct, either through ancillary data (spring layer) or by the particular location of the grass patches, for instance located along the contact between pervious and impervious rocks or on lineaments.
Furthermore, areas of green grasses indicated increased soil moisture or the occurrence of water, providing further inputs in the selection of promising sites for groundwater search.

2.6 Lineaments analysis

With limited exceptions, geological formations, ranging from Trias to Miocene, outcropping in the study area, are essentially composed of limestone, dolomitic limestone, dolomite, marls, marly limestone and sandstone. Towards the borders of Iran and Turkey, igneous, metamorphic and sedimentary rocks outcrop, however no test site was selected by the field team in this area.

Thus, the lithologies occurring in the region can be considered as "hard rocks" from a hydrogeological point of view.

In this kind of rock, the amount of groundwater available is entirely dependent on the storage and rate of infiltration in the faults and fractures. This, in turn, depends on whether the fracture is open or tight. It can be said quite simply that a tight fracture contains no water while an open one may produce a considerable yield of groundwater. In most cases this can be related to tension or shear phenomena in the ruptural deformation of the rocks (Larsson, 1977).

Tensional faults, that is those parallel to the direction of the tectonic stress or orthogonal to the direction of crustal extension, may be believed open and somewhat wider than compressive/shear faults, which are orthogonal or inclined with respect to the direction of tectonic stress and consequently tend to be tighter. Thus, it should be much easier to recognize tensional faults in a satellite scene than shear faults and this should be reflected in the lineaments frequency histogram.

It is well known that fracture traces and lineaments are important in rocks where secondary permeability and porosity dominate and where intergranular characteristics combine with secondary openings influencing weathering and groundwater movement. Latthman and Parizek (1964) established the important relationship between the occurrence of groundwater and fracture traces for carbonate aquifers and, in particular, that fracture traces are underlain by zones of localized weathering and increased permeability and porosity. Fracture traces and lineaments are likely to be areas of secondary permeability and porosity development in carbonate rocks. The fracture zones form an interlaced network of high transmissivity and serve as local groundwater conduits from massive rocks in interfracture areas. Thus, as fracturing greatly increases the solution of limestone and dolomite, creating preferential avenues for groundwater movement, there is not a real need, in theory, to discriminate among lineaments; the basis for the selection, in a carbonate area, of a suitable place for groundwater development, including the necessary field investigations, is the occurrence of a well-defined lineament along which topographic lows should be selected, according to accessibility and local water needs.The importance of a comprehensive lineament analysis in a groundwater search is thus evident.

The digitalization of lineaments was carried out through visual analysis at the screen of Landsat band 5 and of enhanced images. Special elaborations, such as filters (high pass, edge detect and directional) were applied to scenes to extract more information. Ronchi Gratings were also used as an aid to lineaments identification.

As for drainage, lineaments were firstly digitized for each separate watershed and then merged together. Moreover, the linear features were classified as **regional** and **local**, based on their relevance (Fig. 7). Regional lineaments represent fractures or faults crossing a large part of the study area, affecting a deeper portion of the bedrock, and thus can play an important role in groundwater storage and transmission. Local lineaments cross a limited area but may be of interest when they represent a tensional fracture or in karst areas.

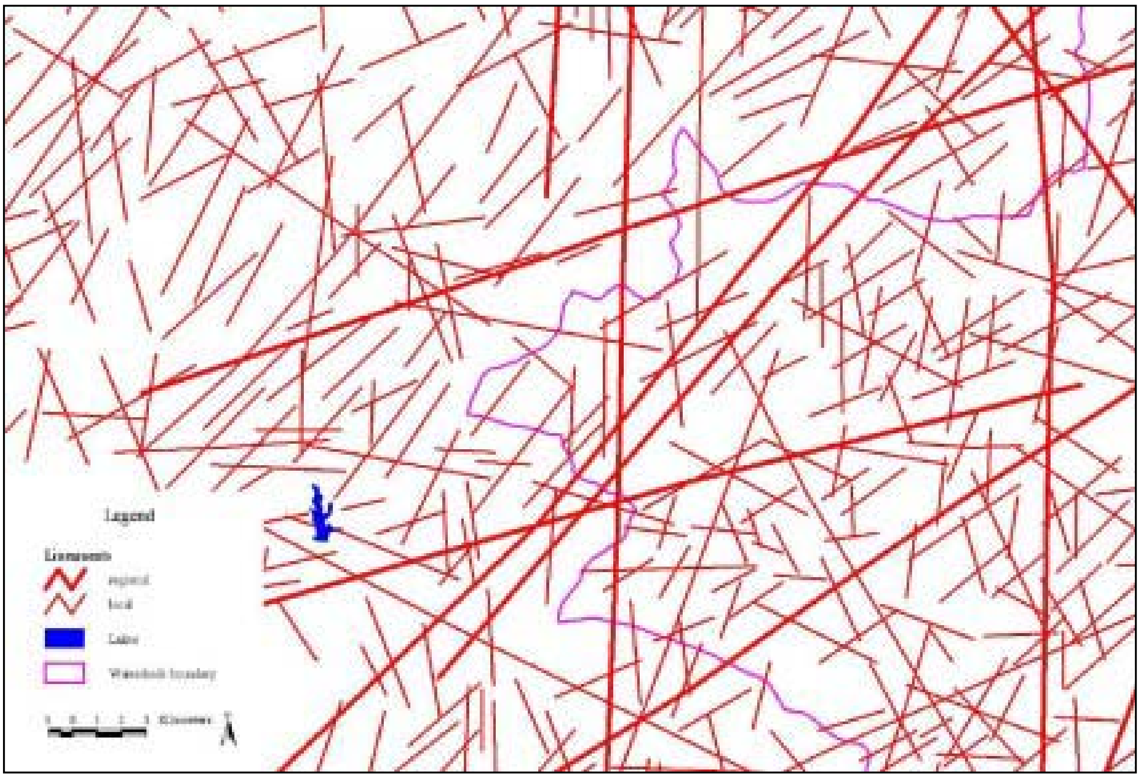

Fig. 7. Regional and local lineaments

Following the positive experience gained in the Syrian Arab Republic (Travaglia and Ammar, 1998) and as the Landsat scenes were all acquired during the dry season, the mapping of thermal lineaments was performed. The rationale for this is that good amounts of water percolating into fractures should affect, by capillarity, the moisture content of the soil above, making it cooler than the surroundings. Therefore, through simple digital enhancements of Landsat band 6 (60 m spatial resolution, resampled at 28.5 m for correlation with the other bands) it was possible to map linear thermal anomalies corresponding to areas slightly cooler than the surroundings. A critical review of the results allowed for the removal of creeks, rivers and irrigation canals with

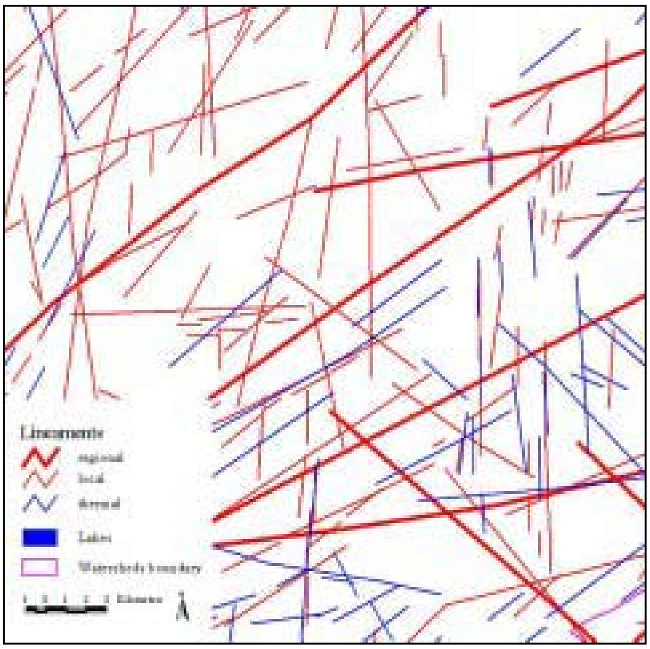

Fig. 8. Thermal and other lineaments

flowing water. The remaining thermal lineaments often coincided with lineaments mapped previously. When this happened, the occurrence of a thermal anomaly provided further reasons to select the lineament for field investigations (Fig. 8).

As a result of the lineament analysis, three GIS layers were included in the database, namely **regional, local** and **thermal lineaments**.

In hard rock hydrogeology, the most important lineaments are those indicating tensional fractures, although in karst terrain all fractures may favour weathering and solution of the carbonate rocks. In this case the most promising lineaments are those having the same direction of the slope.

Rosette diagrams, performed through "Rose Tool", indicated, for almost the whole region, a clear N35E trend. Only in the northern part of the region, in the vicinity of the town of Atrush, there is a clear shift to an almost N-S trend (Fig. 9).

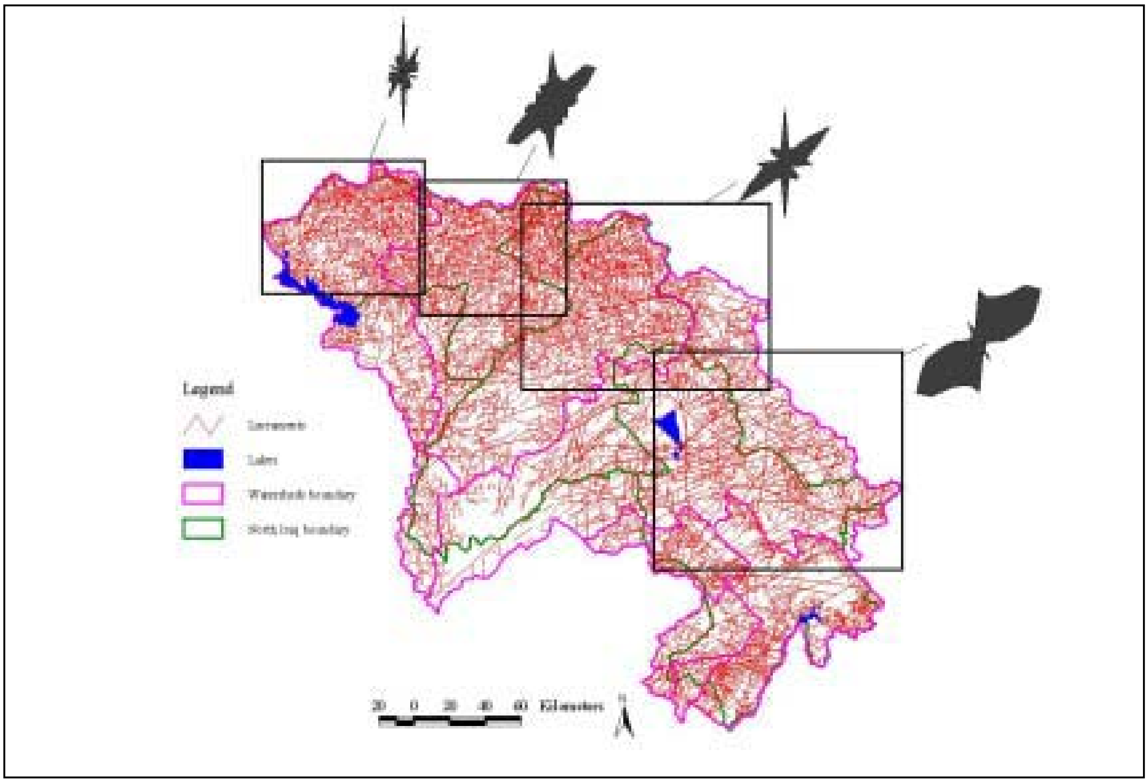

Fig. 9. Rosette diagrams

As a suite of textbook-like anticlines and synclines occur in the region, easily recognized in the Landsat scenes, the identification of the tensional trend is immediate. Actually, tensional fractures are parallel to the direction of the tectonic stress, that is orthogonal to the axis of the folds. A quick verification of the above provides a N35E tensional trend, confirming the rosette diagram results.

In the northern part of the region, the folds have an almost E-W axis, due to some rotation of the tectonic stress. There the tensional trend is N-S, but regional lineaments with the N35E direction should also be regarded as tensional. In that area tensional fractures are probably related to two different episodes of tectonic stress or result from the combination of two simultaneous stresses.

2.7 Database preparation

For the purpose of this study, a geographical database (or geo-database) was created, made up of several information layers in raster (Landsat images, topographic maps) and in vector format. The creation and management of all the data was carried out using ENVI 3.6, ERDAS IMAGINE 8.4, ArcView 3.2 and TNSharc 3.0. All layers in the database were projected into the UTM-WGS84 system in order to be overlaid without problems.
The information layers that constitute the geo-database belong to three different categories: 1) reference data, 2) derived data and 3) external data.

Reference data are all that information used as background and reference for the creation of new layers on the basis of visual analysis. Examples are the Landsat images and the topographic maps. It must be stressed that, regarding the former, the geo-database does not include only the ten Landsat scenes, with panchromatic, multispectral and thermal bands, but also numerous subset images created for various purposes, in order to keep image dimensions low for a better management. In particular, 17 subsets were created (including multispectral and thermal bands), covering the whole study area, to digitalize both the drainage network and the lineaments, while another six sub-scenes (including panchromatic, multispectral and thermal bands) were clipped for examining in detail the thirty priority areas.
With regards to the topographic maps, 62 georeferenced maps were entered into the database, plus a series of six topographic mosaics produced by joining groups of maps for the purpose of georeferencing the Landsat scenes.

Derived data constitute all the newly created information on the basis of reference and other data, mainly by means of visual interpretation, but also through different elaborations. If all the temporary layers are excluded, a total of almost 60 new GIS layers were created.
Most of these layers were digitized on the computer screen from visual interpretation of Landsat images and topographic maps at 1:50 000 scale, namely the drainage network, the lakes, the watershed boundaries, the lineaments (both normal and thermal), the pediments and alluvial fans. For these GIS layers an unique shapefile covering the whole study area was produced plus separate files for each watershed in order to fulfil the project needs. Other layers, such as the topographic maps and Landsat scenes indexes, were created on the basis of coordinates taken from the images headers and other tables.

External data was provided both by FAO geo-database and by the FAO Field Team in Iraq. From the first source, the officially recognized borders of the three Governorates of Northern Iraq were supplied in vector shapefile format. This information layer was used as a reference for determining the borders of the study area: in fact, whenever the watershed boundaries of the main rivers extended far outside the three Governorate areas, they were traced coincident with the administrative boundaries. The only problem related with this layer is that its original scale of acquisition is smaller than 1:50 000. This is fairly clear from the high approximation of the boundary in respect to morphologic features such as mountain crests or rivers. Since this problem could not be solved (no other source of administrative boundaries at a greater scale was available), the GIS layer was left as it was.

Data from the FAO Field Team was provided in vector and tabular format. Among the vector information layers, all in MapInfo format, which were firstly converted into shapefile, only those pertaining to geology, tectonics and springs/wells were used in the database. Six information layers concerning lithostratigraphy of discontinuous areas in Northern Iraq were received. These six coverages, acquired from data at 1:100 000 scale, cover only a limited part of the whole study area. Other six layers concerning tectonics (faults, fractures and folds) for the same areas have been coupled to the lithostratigraphy to have a general geological framework of these zones. Moreover, a layer on lithostratigraphy of the whole three Governorates was available, taken from a 1:250 000 source, thus less accurate than the previous. Finally, two more coverages with information on springs and deep wells drilled by FAO for the whole study area were provided.

Tabular data, in Excel format, were the source of other information on wells and springs, but in this case for limited areas. Five zones (Aqra, Arbat/Kourmal, Chamchamal, Sumail and Zakho) were covered. For each of the above zones, tables showing information on small rivers and wadi, deep wells, shallow wells and springs were made available. Each table had a couple of fields containing the X and Y UTM-WGS84 coordinates and a great number of other data. Among them, the discharge for springs and wells was particularly important for the purpose of our study. Thanks to the coordinate fields, these Excel tables were converted to a point GIS layer and integrated with the other coverages in our possession.

The purpose of this data (geology, springs and wells) was to provide a reference in the interpretation for the investigation of promising sites for groundwater in the 30 priority areas. Lithostratigraphy and tectonics, placed on top of Landsat images were used to obtain an interpretation key of satellite data to locate those geologic formations most suitable for groundwater storing (e.g. limestones with karst phenomena). Springs and wells, compared with lineaments, both normal and thermal, could give precious indications on which fractures allow the higher circulation of water. Unfortunately, a part of the provided data could not be used properly, mainly due to a lack of accuracy. Stratigraphic data acquired from 1:250 000 scale source was too approximate for our working scale (1:50 000) and when superimposed to Landsat images, this evident inaccuracy made this layer almost useless. Geological data from 1:100 000 scale source showed a better precision, although for limited areas. For this reason, these layers were used only for a small number of the priority areas. Regarding springs and wells, three different kind of problems were encountered. One problem was lack of information: the data provided did not cover in detail the whole study area. Another was about springs discharge values, which in some cases appeared to be too high to be credible (around 38 000 l/s). The last was the positioning of wells and springs. A considerable number of points showed coordinates far outside the study area, possibly due to typing or some other data entry mistakes, or GPS reading errors. This uncertainty on data reliability greatly influenced the utility of these GIS layers in the investigation. Their necessary limited usage was always subject to critical evaluation.

The availability of other data sets could have helped in the investigation carried out for the location of promising sites for groundwater, however, they were not immediately available. A digital elevation model (DEM) could have provided useful information on morphology and surface water routes. Coupled with meteorological data (also lacking), it could have been used for water balance estimations. A DEM with a ground resolution compatible with the study scale (30 m) could have been generated from height information taken from topographic maps. Another missing useful GIS layer was an updated road network. This could have given information on where to plan ground investigations for the validation of remote sensing-based interpretation. An updated road network could have been acquired by Landsat images, using the panchromatic band. Finally, a land cover GIS layer could have shown those areas where water is needed (e.g. arable land). Landsat images can easily provide a valid background for land cover classification. Time constraints did not allow for their preparation.

2.8 Interpretation

The field team of WRISS/GWU selected 30 test areas (Fig. 10) according to local requirements and subdivided them into three classes of first, second and third priority (ten test areas for each class), thus interpretation was performed according to this order of priority.

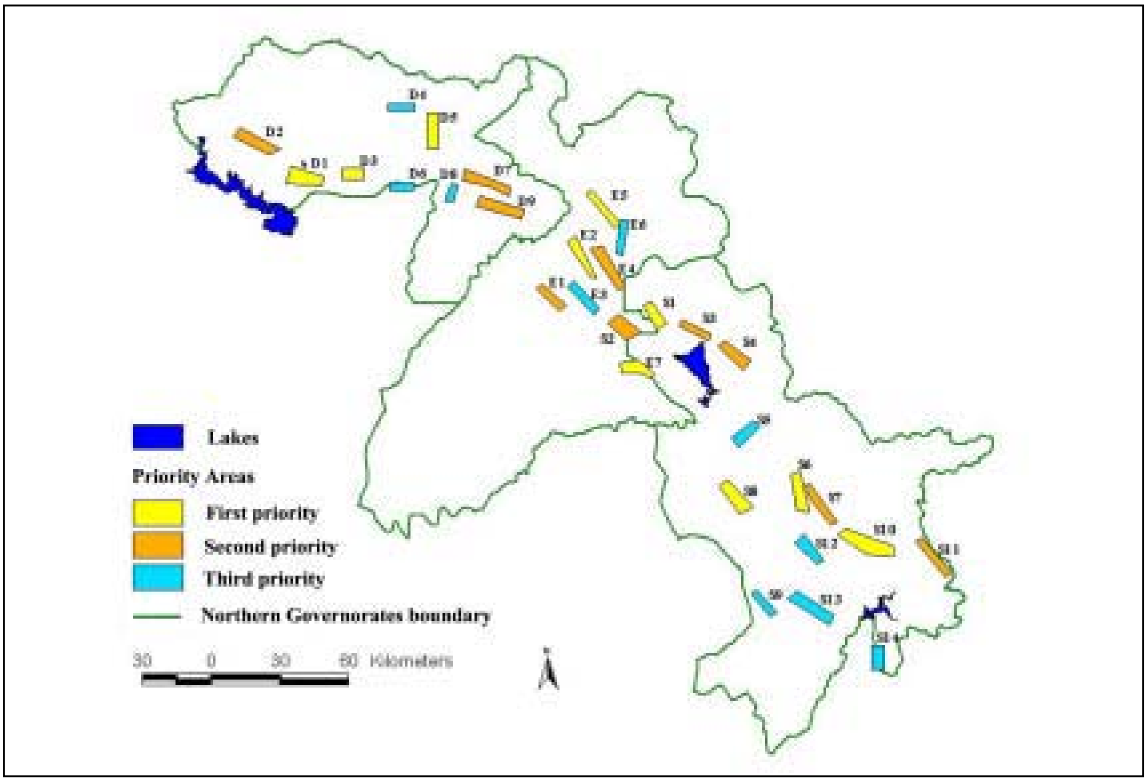

Fig. 10. Location of test sites

Taking advantage of the large spectrum of information available in the database, the following procedure was used to identify the best sites for further field investigation.The Landsat FCC 453 subscene encompassing the test area to be investigated was firstly displayed at 1:100 000 scale to have an overview of the area from a geological point of view.

Landforms, dip and tickness of beds, erosion features, limits of formations were carefully noted and lithologies were inferred (the authors are both geologists). Only then the geological layer was overlaid. Often the formation limits of the geological map did not match the same kind of boundaries clearly visible on the satellite image, however this layer was used to extract information on the lithologies occurring in the different formations and complement/confirm the geological interpretation assumptions already made.The overlaying of the drainage layer on the Landsat FCC, kept as background, with its types and density of dissection, then provided precious information on the bedrock and its permeability, karst areas, erosion features and soil permeability in the plains. During this part of the interpretation exercise, the Landsat image was often displayed at 1:50 000 scale to observe some features in detail. Band 5 was also used to evaluate terrain morphology. On the Landsat FCC, from this point onward at 1:50 000 scale, the green patches of grasses were noted, indicating either springs or humid zones. At this point the regional and local lineament layers were overlaid. Tensional lineaments, preferably regional, were considered first and then their crossing with other lineaments. The overlaying of the thermal lineament layer provided further important inputs for the selection of a site. Actually, if a thermal lineament coincided with a regional or local lineament, then there were good reasons to infer the occurrence of water into that fracture.

Layers of springs and wells were then overlaid. Although not fully trustworthy, as indicated in the previous paragraph, these layers provided further inputs in the site selection process. Actually, the occurrence of wells producing above average or of springs with considerable discharge located on a lineament, provided further positive proof for the selection of an adequate site on that fracture. Similarly, the presence of springs at the boundary between pervious and impervious rocks, the former having a recharge area at higher elevation, suggested potential drilling sites for confined aquifer. Once selected on the basis of the above considerations, the site was indicated on the map for ground assessment by the field team.

2.9 Field checking

By applying the interpretation procedure indicated in the previous paragraph to the 30 test areas selected by the field team of WRISS/GWU, 198 promising sites for groundwater assessment were identified.

During the interpretation exercise many more potential sites were also identified thanks to the availability, through the database, of a complete range of information. However, only 198 sites for further field investigation were reported on the 30 maps provided to the field team, and that for three reasons, namely:

1. they were classed as the best sites to field check;
2. the field check will take months to be completed, thus it was unnecessary to provide second choice sites to inspect;
3. it was always possible to consult the database to locate other sites if the field team so requested.

In some cases, sites in the close vicinity, but outside the test area indicated, were selected, as they were ranked as much more promising than other sites inside.

All maps (see Chapter 3) were prepared at scale 1:50 000, geo-referenced to UTM WGS84, with a Landsat FCC 453 as background and drainage and lineaments layers overlaid.

The following field procedure was

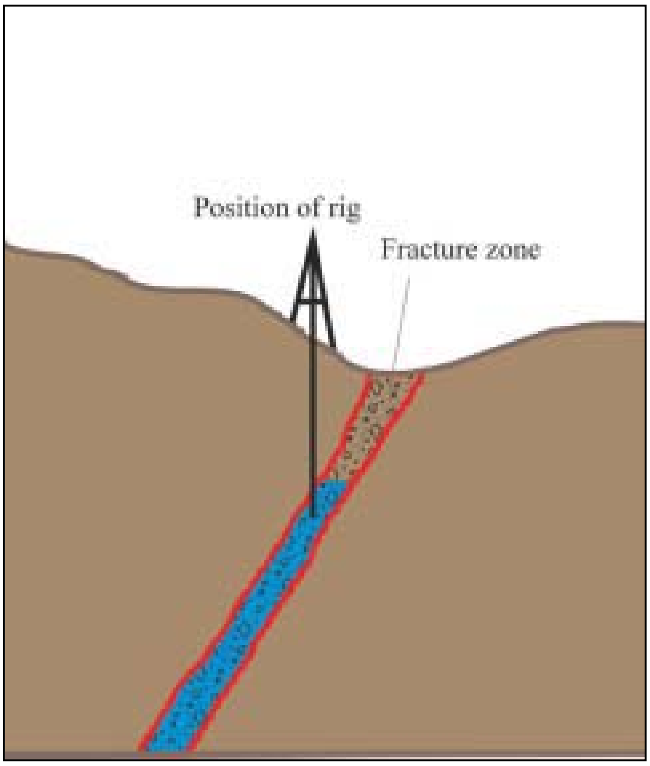

Fig. 11. Correct positioning of rig

suggested to the field teams:
- identification on the ground of a site indicated on the map through GPS;
- identification of lineament or crossing of lineaments on the ground through its/their terrain features;
- selection of a topographic low along the tensional lineament and in the vicinity of the site indicated;
- carring out of a geoelectric survey orthogonal to the lineament (best if tensional) trace to ascertain wideness and dip of the fracture zone and occurrence and depth of groundwater. Vertical electric sounding according to the Schlumberger method (four electrodes laid out using the Schlumberger configuration) was the recommended procedure;
- according to the results of the geo-resistivity survey, if positive, placing of the well rig in the appropriate site.

Figure 11 indicates a possible scenario.