# 3 METEOROLOGY AND HYDROLOGY

## 3.1 GENERAL

In the groundwater balance study, it is important and essential to consider surface water which may recharge to aquifer in the ground. The following factors are considered and measured as illustrated in Figure 3.1.

- Precipitation such as rainfall, snowfall, etc.
- Evaporation
- Seepage to underground regarded as recharge to aquifer

However in reality, there are some restrictions that make the study difficult. In the case of this study, for example absolute small amount of rainfall, freezing temperature in winter are those restrictions. Therefore the recharge to the aquifer is estimated by a different approach as described in chapter 6.

## 3.2 METEOROLOGICAL CONDITION

### 3.2.1 Meteorological Observation Station and Available Data

There exist two (2) meteorological stations; one under operation, the other abandoned in the Study Area as listed below:

| Station | Year of Establishment | Altitude (m) | Observation Item |
|---|---|---|---|
| Altai City (Airport) | 1954 | 2,180.7 | Temperature, precipitation, humidit pressure, wind, evaporation |
| Khan Tayshiryn (Mountain) | 1978 | 2,890.0 | Temperature, precipitation, humidit pressure, wind |

The location of these meteorological stations is indicated in Figure 3.2.
In Altai City station, the meteorological observation has been conducted for over 40 years since 1954, and valuable data were accumulated. Temperature, precipitation, humidity, air pressure, and wind have been observed at this station. Khan Tayshiryn station was in operation for 11 years from 1978.
Monthly precipitation records, monthly average, maximum and minimum temperature

records after 1954 were collected for Altai City station, and after 1978 were collected for Khan Tayshiryn station.

The data on monthly humidity, evaporation, and average wind velocity and direction for 1987 and 1988 i.e. for only two (2) years were also collected at Altai City station.

The parameters and periods of meteorological data collected for each station are illustrated in Figure 3.3.

### 3.2.2 Meteorological Characteristics

Altai basin is characterized by a rainy season from June to August, of which precipitation shares about 66% of the annual precipitation. Average annual precipitation of Altai and Khan Tayshiryn stations are calculated to be 181.6mm and 200.4mm, respectively. Monthly mean temperature in the basin varies from a minimum of -18.6°C in January to a maximum of 14°C in July at Altai City station and from a minimum of -19°C in February to a maximum of 8.6°C in July at Khan Tayshiryn station. Annual average temperature is calculated to be -1.7°C at Altai City station and -5°C at Khan Tayshiryn station. Humidity is high in winter, but low in rainy season of summer because of the low capacity of saturated vapor at low temperature. Annual average humidity is calculated to be 53.9% and 58.7% at Altai City and Khan Tayshiryn stations, respectively. Climates for Altai City and Khan Tayshiryn are illustrated in Figure 3.4.

The details of each meteorological parameter are discussed below.

#### (1) Precipitation

Based on the collected precipitation data, average monthly precipitation is calculated for each station as tabulated below.

| Station | Average Monthly Precipitation (mm) | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | (mm) |
| Altai | 1.1 | 2.1 | 5.8 | 10.5 | 13.2 | 29.2 | 48.2 | 41.8 | 17.1 | 7.3 | 3.1 | 2.2 | 181.6 |
| Khan Tayshiryn | 1.1 | 2.3 | 7.3 | 10.8 | 13.8 | 31.5 | 39.1 | 55.4 | 22.4 | 11.1 | 4.0 | 1.6 | 200.4 |

Note : Altai City ; data from 1955 to Aug. 1996; Khan Tayshiryn data from 1978 to 1989

The annual average precipitation varies from about 100mm to 280mm at Altai City station and from 110mm to 295mm at Khan Tayshiryn station.

As tabulated below, about 64% of precipitation in average concentrates during rainy season from June to August.

| Station | Annual Precipitation (mm) | Precipitation in Rainy Season (mm) | Percent to Annual Precipitation |
|---|---|---|---|
| Altai City | 181.6 | 119.2 | 66% |
| Khan Tayshiryn | 200.4 | 126.0 | 63% |
| Average | | | 64% |

Probability analysis was made for the precipitation of annual and rainy season at Altai City and Khan Tayshiryn stations. The results of probability analysis by using Gumbel's distribution method are summarized in Table 3.1. Figure 3.5 presents the fitting of probability of annual precipitation at Altai City station by Gumbel's distribution and checking the fit by Thomas Plotting Position formula.

Daily rainfall was also observed in 1997 and 1998 by JICA Study Team. The result is summarized as the monthly total in the table below.

Monthly Rainfall in mm

| | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | - | - | - | - | - | - | 83.7 | 1.2 | 11.6 | - | - | - |
| 1998 | - | - | - | - | 15.9 | 10.6 | 113.7 | 13.1 | 7.1 | - | - | - |

## (2) Temperature

Monthly mean, maximum and minimum temperature records were collected. Monthly average and annual maximum and minimum temperatures are tabulated as follows.

| Station | Average Monthly Temperature (°C) | | | | | | | | | | | | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | (°C) |
| Altai City | -18.6 | -16.2 | -9.1 | -0.6 | 6.9 | 12.7 | 14.0 | 12.7 | 6.3 | -1.9 | -10.3 | -16.0 | -1.7 |
| Khan Tayshiryn | -18.6 | -19.0 | -13.4 | -5.8 | 3.1 | 7.7 | 8.6 | 7.2 | 2.3 | -4.5 | -11.9 | -16.2 | -5.0 |

Note: Altai City data from 1954 to Aug. 1996; Khan Tayshiryn data from 1978 to 1986

The absolute maximum temperature is as high as 29.7°C in Altai City, while that for Khan Tayshiryn in mountainous area reaches only about 22.5°C. In Altai City, the absolute minimum reaches -40.8°C though it is located at lower elevation. It may be caused by its site condition, suggesting that temperature may be different from place to place depending on site condition such as topography, etc.

The data for recent years

The data of daily temperature, which are the maximum and the minimum air and ground temperature, were collected. This data together with water level records of the wells is expected to give a detailed account for hydrogeological conditions of the study area as described in chapter 6. The monthly average of the data was tabulated below.

Average Maximum and Minimum of Daily Temperature (Degree C)

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAX Air | 1997 | - | - | - | - | - | 19.9 | 20.9 | 20.5 | 12.9 | 8.5 | -4.6 | -6.3 |
| | 1998 | -11.9 | -3.9 | -1.8 | 9.1 | 14.3 | 21.2 | 19.8 | 20.3 | 18.9* | - | - | - |
| MIN Air | 1997 | - | - | - | - | - | 6.8 | 8.4 | 7.0 | 0.3 | -6.0 | -16.2 | -20.1 |
| | 1998 | -25.4 | -18.4 | -17.0 | -2.4 | 1.1 | 7.1 | 9.3 | 8.0 | 5.6* | - | - | - |
| MAX ground | 1997 | - | - | - | - | - | 39.9 | 38.6 | 37.6 | 29.1 | 22.2 | 1.7 | -3.7 |
| | 1998 | -6.1 | 4.3 | 12.8 | 21.5 | 34.6 | 40.5 | 36.8 | 41.5 | 37.5* | - | - | - |
| MIN ground | 1997 | - | - | - | - | - | 3.7 | 5.8 | 3.6 | -3.9 | -11.0 | -21.0 | -24.6 |
| | 1998 | -27.2 | -22.3 | -18.4 | -7.0 | -2.1 | 4.2 | 6.6 | 5.1 | 2.2* | - | - | - |

*; Average of the first half of September 1998

## (3) Humidity

Monthly mean humidity records were collected and the following table shows their average for each meteorological station. These average data were calculated by Meteorological Institute based on the observed records from 1954 to 1990 for Altai station and 1978 to 1983 for Khan Tayshiryn station.

| Station | Average Monthly Humidity (%) | | | | | | | | | | | | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | (%) |
| Altai City | 65 | 61 | 53 | 45 | 42 | 47 | 57 | 52 | 52 | 51 | 58 | 64 | 54 |
| Khan Tayshiryn | 66 | 62 | 64 | 56 | 52 | 57 | 62 | 57 | 58 | 42 | 66 | 62 | 59 |

Note: Altai City data from 1954 to 1990; Khan Tayshiryn data from 1978 to 1983

Humidity reaches its minimum of 42% in May and increases to the maximum of 65% in January at Altai City station. Those in mountainous area of Khan Tayshryn are 66% for the maximum in January and November 42% for the minimum in October.

### (4) Wind

Monthly mean wind velocity records were collected and the following table shows their average for each meteorological station. Average data for wind velocity were collected at Altai and Khan Tayshiryn stations. These average data were calculated by Meteorological Institute based on the observed records from 1954 to 1990 for Altai City station and 1978 to 1983 for Khan Tayshiryn station.

| | Average Monthly Wind Velocity (m/sec) | | | | | | | | | | | | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | |
| Altai City | 2.8 | 3.1 | 3.5 | 4.5 | 4.5 | 3.8 | 3.3 | 3.2 | 3.3 | 3.6 | 3.6 | 2.9 | 3.5 |
| Khan Tayshiryn | 4.3 | 5.0 | 5.2 | 6.3 | 5.6 | 3.8 | 3.7 | 4.4 | 3.9 | 5.1 | 5.6 | 4.9 | 4.8 |

Note: Altai City data from 1954 to 1990; Khan Tayshiryn data from 1978 to 1983

The data shows that spring is the most windy season of an year. People suffer from strong sand storm in this season.

### (5) Evaporation

Evaporation records were collected and the following table shows the monthly average for Altai City meteorological station.

| | Average Monthly Evaporation (mm) | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | (mm) |
| Altai City | - | - | - | 57.6 | 100.1 | 125 | 129 | 113 | 91 | 50.5 | - | - | 665.8 |

Note: Altai City data of 1987 and 1988

This average data was calculated by Meteorological Institute based on the observed records of 1987 and 1988.

The observed daily evaporation is equivalent to 1.8 mm/day in average ( if the evaporation during the winter season is assumed to be zero). Evaporation from November to March is not indicated on collected data because of the freezing temperature. The maximum evaporation period occurs in July.

JICA Study Team also measured the evaporation from July 1 1997 to October 31, 1998.

Monthly Evaporation in mm

| Station | | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Altai City | 1997 | - | - | - | - | - | - | 238.7 | 179.2 | 136.2 | - | - | - |
| | 1998 | - | - | - | - | 182.2 | 217.0 | 166.5 | 146.5 | 136.1 | 68.1 | - | - |

Evaporation from November to April is not indicated on collected data because of under freezing temperature. (See the section of Temperature)
The daily average evaporation calculated from the given data is 1.7mm ( if the evaporation during the winter season is assumed to be zero )

## 3.3 HYDROLOGICAL CONDITION

### 3.3.1 Hydrological Station and Available Data

The following hydrological stations are available in Zavhan River system. The river water level and discharge are observed at these stations. The locations of the above hydrological stations are presented in Figure 3.6.

| Station | River System | Year of Establishment | Catchment Area (km²) | Observation Item |
|---|---|---|---|---|
| Guulin | Zavhan River | 1971 | 12,200 | Water level / discharge |
| Durveljin | Zavhan River | 1977 | -- | Water level / discharge |

Daily mean discharge was collected at Guulin station from 1972 to 1981 and at Durveljin station from 1977 to 1986. The data for 1981 and 1985 was not available because of damage of equipment used for the measurement. The monthly mean discharge was also collected in the same period at each station. The kind and period of the collected data are indicated in Figure 3.3.

### 3.3.2 Zavkhan River System

Zavkhan River whose length is measured to be about 780km, flows in the northwestern part of Mongolia. The river flows southward originating in Khangai Mountains. The flow changes its direction to west near Guulin Village, and runs to the north of Altai City. The river changes again its flow direction to northwest near Tayshir, and flows into Hyargas Lake (See Figure 3.6).

Zavkhan River system originates in the high mountain range at an altitude of about 3,500m, and flows into Hyagas Lake at an altitude of 1,034m passing by wet land at the downstream of Taishir and deserts. Vegetation of the basin, therefore, varies from place to place depending on its altitude and topography. Foothill zones along the river are considered low land which is covered mainly by shallow root grass suitable for grazing for cattle, sheep, cows, horses, and goats. The other higher mountain areas in Khangai Mountains are covered with forests consisting of a kind of cedar and beech, but such forest area expands only on the northern slope of the range due to difference of climate condition.

### 3.3.3 Hydrological Characteristics

Seasonal Variation of River Discharge

The data on monthly mean discharges of the Guulin and Durveljin stations were collected from 1971 to 1981 and from 1977 to 1986, respectively. Daily mean discharges at these stations were also collected from 1972 to 1981 and from 1977 to 1986, respectively. Average monthly discharges are calculated based on those data as tabulated below.

| Station | Average Monthly Discharge ($m^3/s$) | | | | | | | | | | | | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | ($m^3/s$) |
| Guulin | - | 0.01 | 0.22 | 7.27 | 16.11 | 13.82 | 24.08 | 21.38 | 18.62 | 9.61 | 2.52 | 0.21 | 9.49 |
| Durveljin | 1.09 | 0.95 | 2.44 | 13.66 | 16.75 | 23.23 | 32.48 | 28.52 | 29.30 | 15.23 | 4.81 | 1.62 | 14.17 |

Note: Guulin data from 1971 to 1981; Durveljin data from 1977 to 1986 (missing: 1981, 1985)

Average annual discharges are calculated to be $9.49m^3/s$ and $14.17m^3/s$ for Guulin and Durveljin stations, respectively. Average specific discharges are calculated to be $0.78\ l/s/km^2$ for Guulin station. The discharge reaches its peak in July. The river water at Guulin station becomes frozen at the end of November or beginning of December, while that at Durveljin station happens in December normally. After winter season the frozen river starts to melt in March, the discharge gradually increases and reaches its maximum during the rainy season between June and August. Maximum and minimum daily mean discharges were also calculated based on the collected daily mean discharge data as presented below.

| Station | Maximum and Minimum Daily Mean Discharge ($m^3/s$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| Maximum Daily Mean Discharge | | | | | | | | | | | | |
| Guulin | - | 0.38 | 7.57 | 39.0 | 145.0 | 59.0 | 153.0 | 78.5 | 80.6 | 65.7 | 14.6 | 4.13 |
| Durveljin | 6.59 | 6.68 | 49.8 | 38.0 | 57.40 | 294.0 | 76.1 | 84.1 | 90.0 | 43.6 | 18.1 | 8.7 |
| Minimum Daily Mean Discharge | | | | | | | | | | | | |
| Guulin | - | - | - | - | 0.51 | 0.5 | 1.72 | 1.53 | 1.28 | 0.51 | - | - |
| Durveljin | 6.37 | - | - | 0.13 | 2.0 | 3.82 | 4.08 | 3.37 | 3.9 | 0.01 | - | - |

The recorded maximum daily mean discharges reach 153$m^3/s$ and 294$m^3/s$, in Guulin and Durveljin stations, respectively. While the minimum discharges during the rainy season ( June to August ) reach only 0.50$m^3/s$ and 3.37$m^3/s$, respectively.

Probability Analysis

Annual average runoff volumes at Guulin and Durveljin stations are calculated to be about 299 and 447 million $m^3$ respectively. As tabulated below, about 52% of annual runoff in average concentrates during rainy season from June to August.

| Station | Annual Runoff ($x10^6m^3$) | Runoff in Rainy Season($x10^6m^3$) | Percent to Annual Runoff |
|---|---|---|---|
| Guulin | 299.20 | 161.25 | 54% |
| Durveljin | 446.97 | 223.61 | 50% |
| Average | | | 52% |

Probability analysis was made for the annual runoff and for the runoff of rainy season at Guulin and Durveljin stations and also for the annual rainfall. The results of probability analysis by using Gumbel's distribution method are summarized in Table 3.1. The result indicates that even for a considerably long period of time such as 100 years, only a double amount of present annual rainfall is expected.

### 3.3.4 River Discharge of Small Rivers in the Study Area

JICA Study Team measured the river discharge in the Study Area for four (4) rivers (refer to Figure 3.2) :

Khadaasangyn Am river,

Mandaliin Aryn Am river,

Esuitiin Sair river, and

Khanginaagiin Hooloy River.

These river don't have flow normally. Some flow can be seen in some rivers only during or after heavy rainfall. The measurement was therefore carried out right after the rain had stopped. The river discharge was measured using a concrete pipe and a bucket because the flow was not large enough for the installation of the flowmeter. The results are as follows.

River discharge measured in 1997 (unit : liter/second)

| River | June 27 | July 18 | August 1 | Sept. 1 | Oct. 1 |
|---|---|---|---|---|---|
| Hadaasan river | 0.57 | 0 | 0.7 | 0 | 0.2 |
| Mandaliin Aryn Am River | 0 | 0 | 0 | 0 | 0 |
| Esuitiin Sair river | 0.51 | 62.5 | 0 | 0 | 0 |
| Kharginaagyn Khooloiy river | 1.03 | - | 0.7 | 0.65 | 0.3 |

June 23, 24, 25 were rainy days.
It rained heavily in July 16 and 17
Data could not be informed from Altai City

The result shows that even after a rainfall, no flow was observed at some rivers. However, in the field study in 1998, a considerable amount of flow was observed at Esuiitin Sair river in July after unusually heavy and long rain.

## Table 3.1 Results of Probability Analysis by Gumbel's Distribution Method

Rainfall for Altai City and Khan Taishir

| Return Period (Years) | Annual Rainfall (mm) | | Rainy Season's Rainfall (mm) | |
|---|---|---|---|---|
| | Altai City | Khan Taishir | Altai City | Khan Taishir |
| **2** | 174 | 191 | 112 | 118 |
| **5** | 218 | 241 | 152 | 161 |
| **10** | 247 | 274 | 178 | 189 |
| **20** | 275 | 306 | 203 | 215 |
| **30** | 291 | 325 | 217 | 231 |
| **50** | 311 | 348 | 235 | 250 |
| **70** | 324 | 363 | 247 | 263 |
| **100** | 338 | 379 | 260 | 276 |

* rainy season: June to August

Runoff for Guulin and Durveljin

| Return Period (Years) | Annual Maximum Discharge ($m^3/s$) | | Rainy Season's Runoff (mill. $m^3$) | |
|---|---|---|---|---|
| | Guulin | Durveljin | Guulin | Durveljin |
| **2** | 66 | 86 | 144 | 203 |
| **5** | 114 | 165 | 239 | 316 |
| **10** | 146 | 217 | 302 | 391 |
| **20** | 176 | 267 | 362 | 463 |
| **30** | 193 | 296 | 397 | 505 |
| **50** | 215 | 332 | 440 | 557 |
| **70** | 229 | 356 | 468 | 591 |
| **100** | 245 | 381 | 499 | 627 |

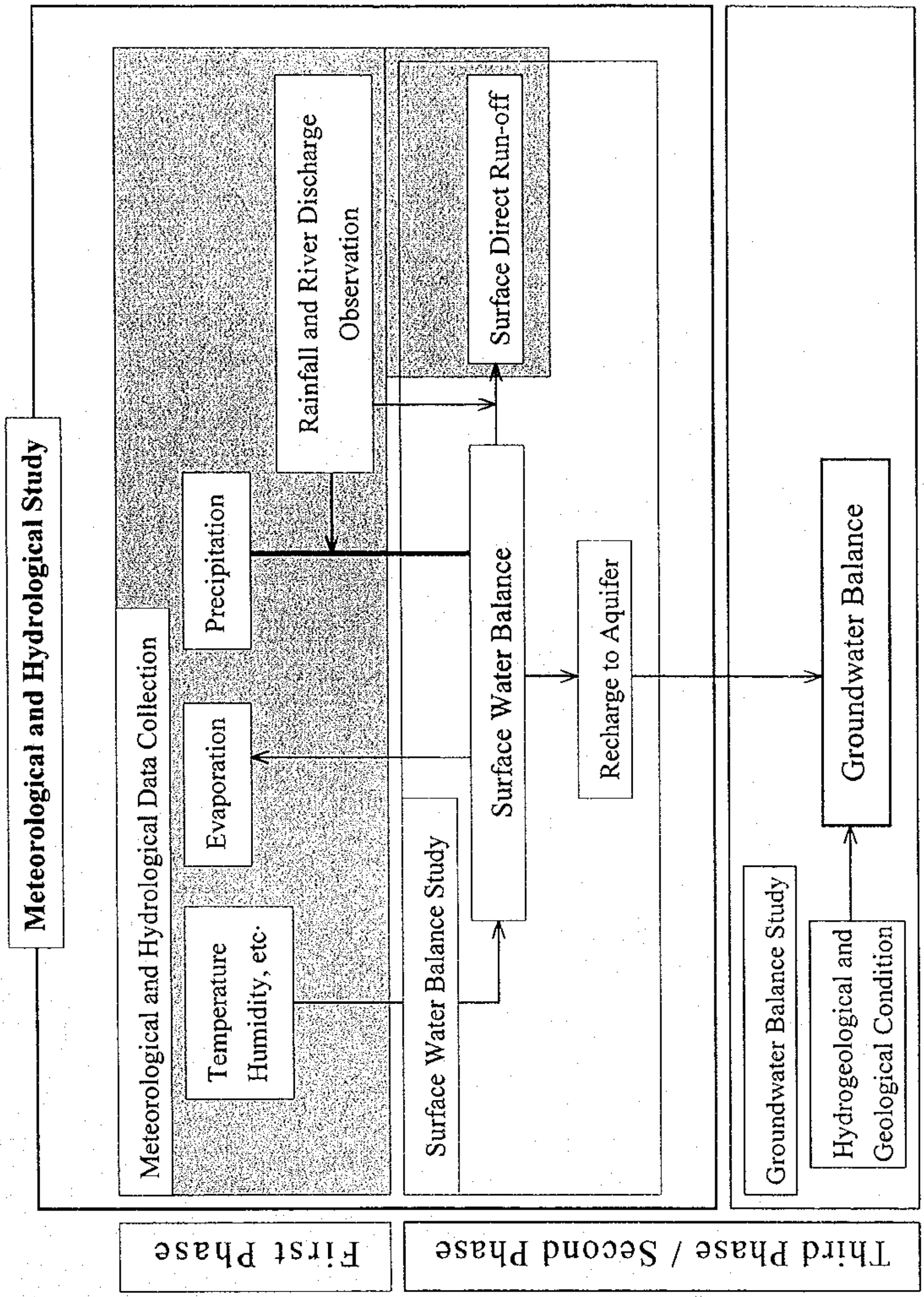



Figure 3.1 Flow Chart of Meteorological and Hydrological Study

JICA The Study on Groundwater Development for Altai City

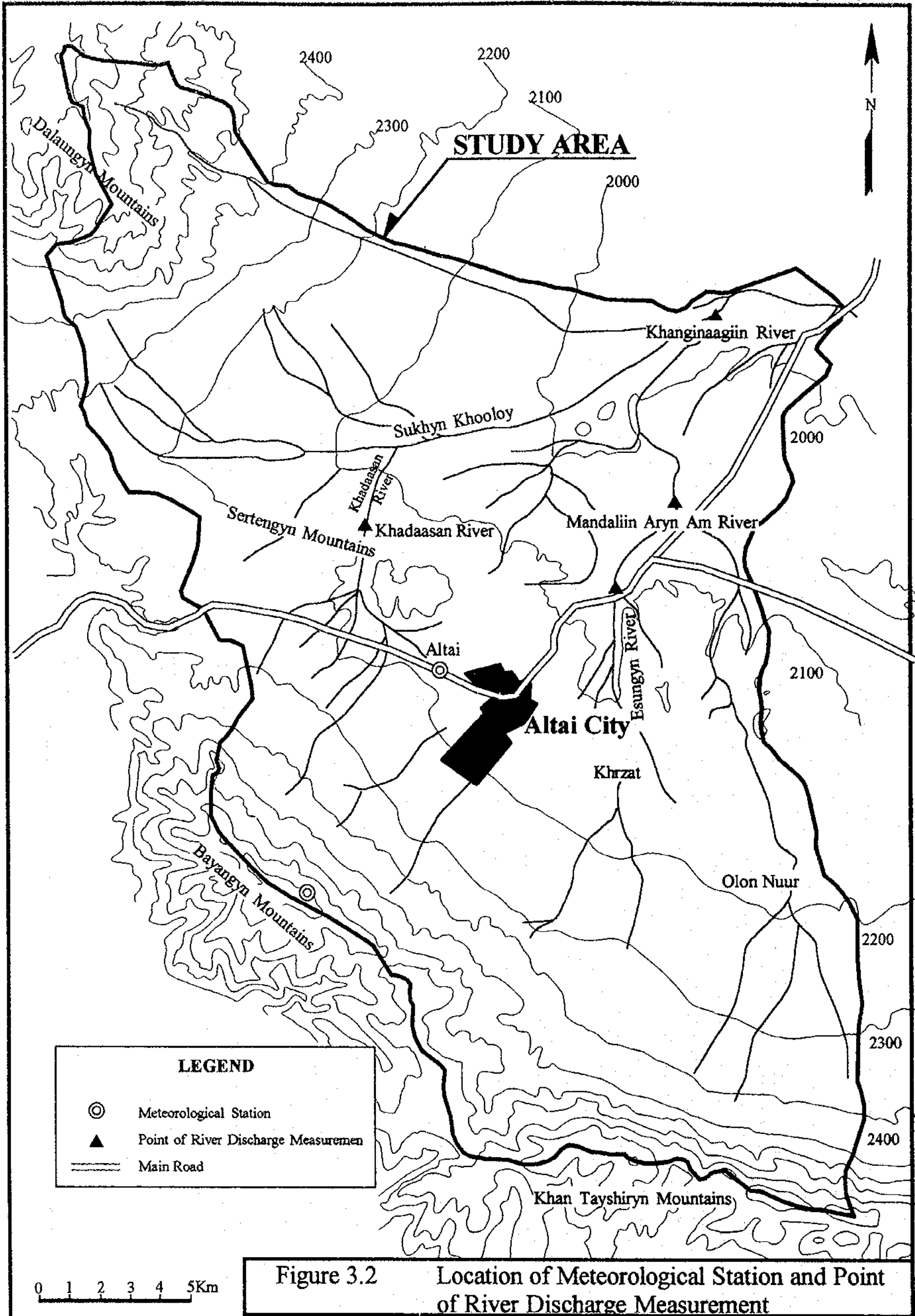
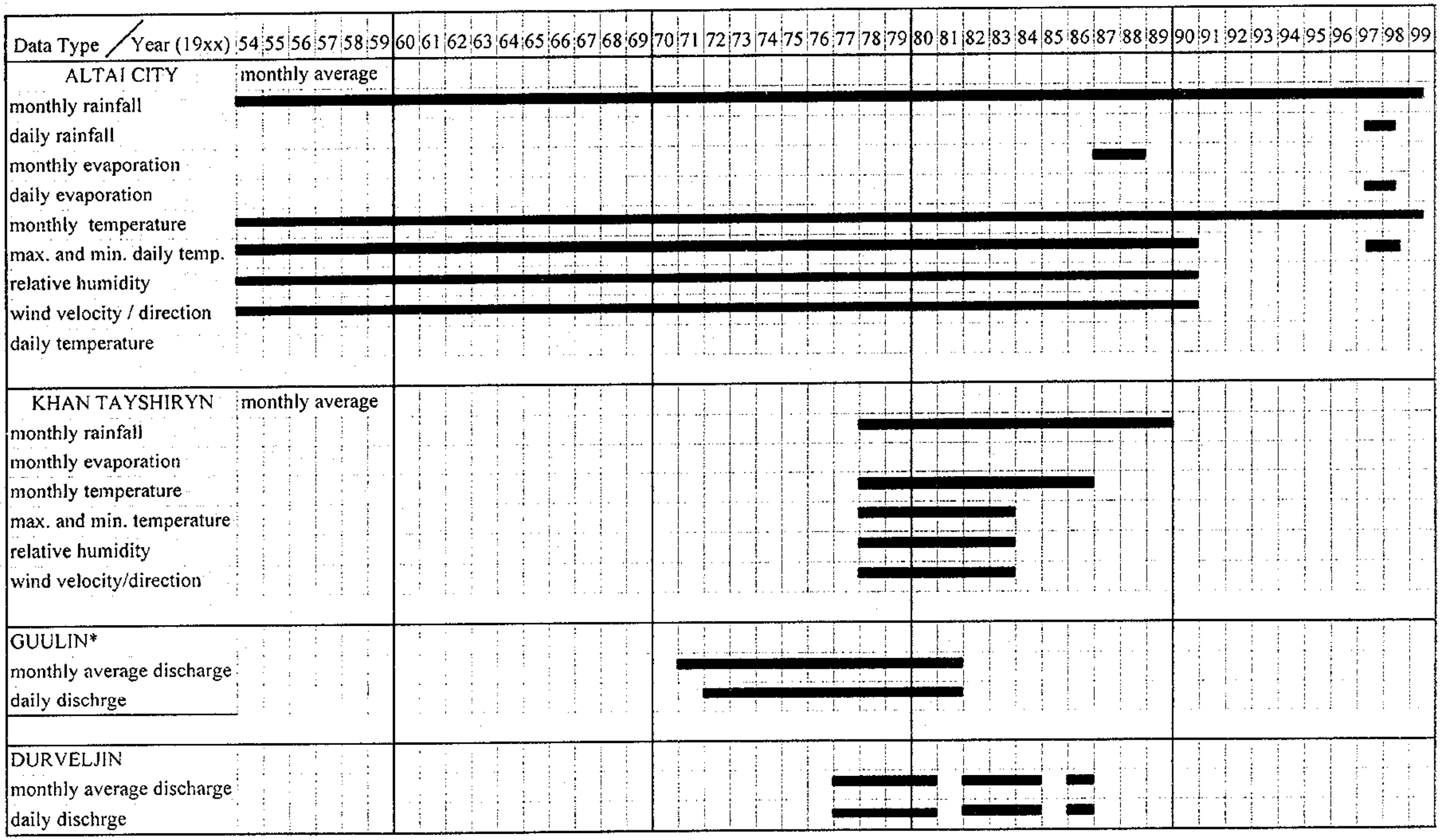



Figure 3.2 Location of Meteorological Station and Point of River Discharge Measurement

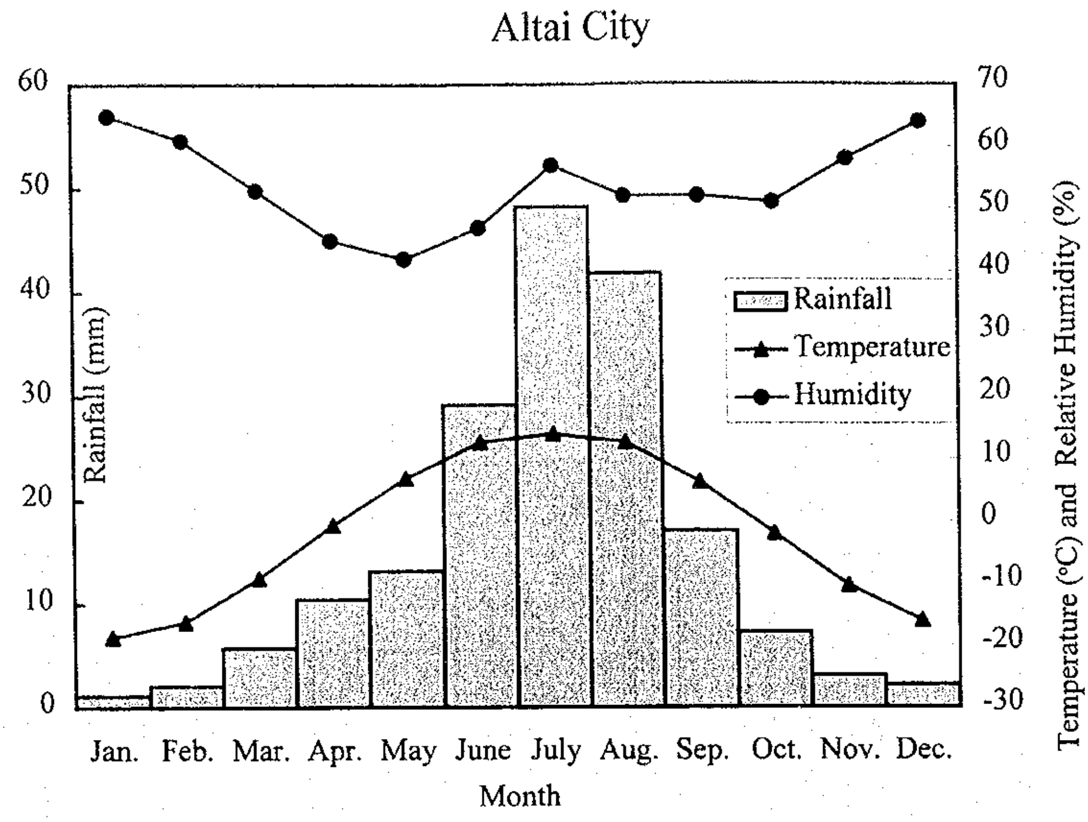
**JICA** | **The Study on Groundwater Development for Altai City**

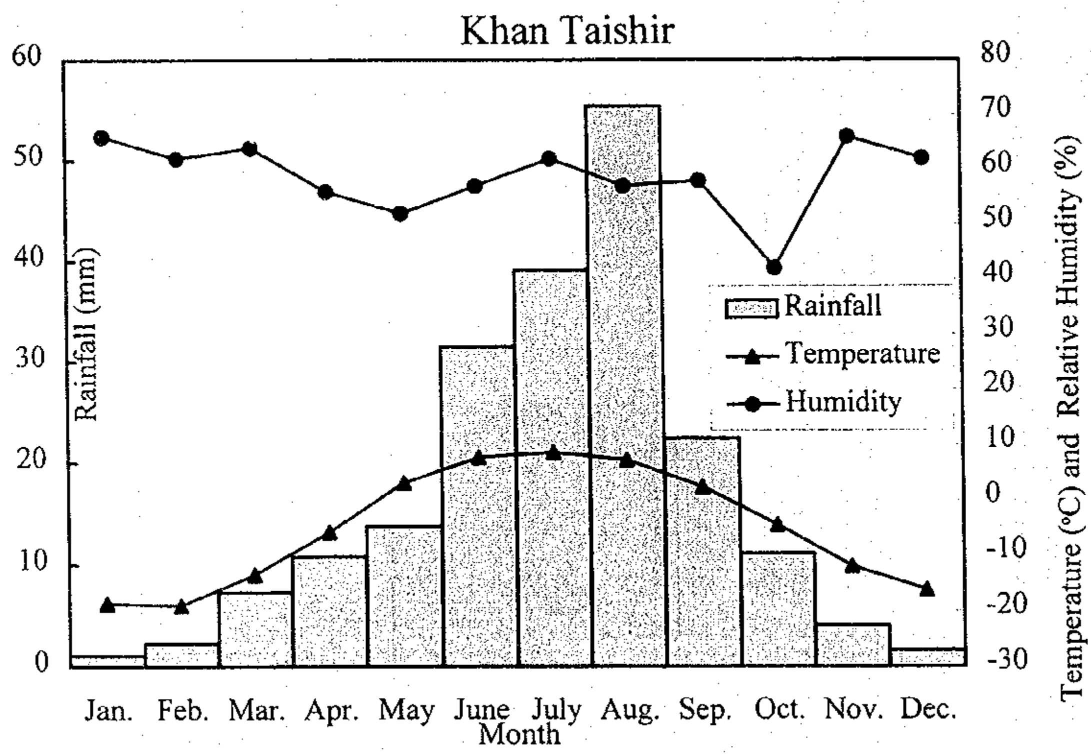



* : Catchment area = 12,000Km$^2$

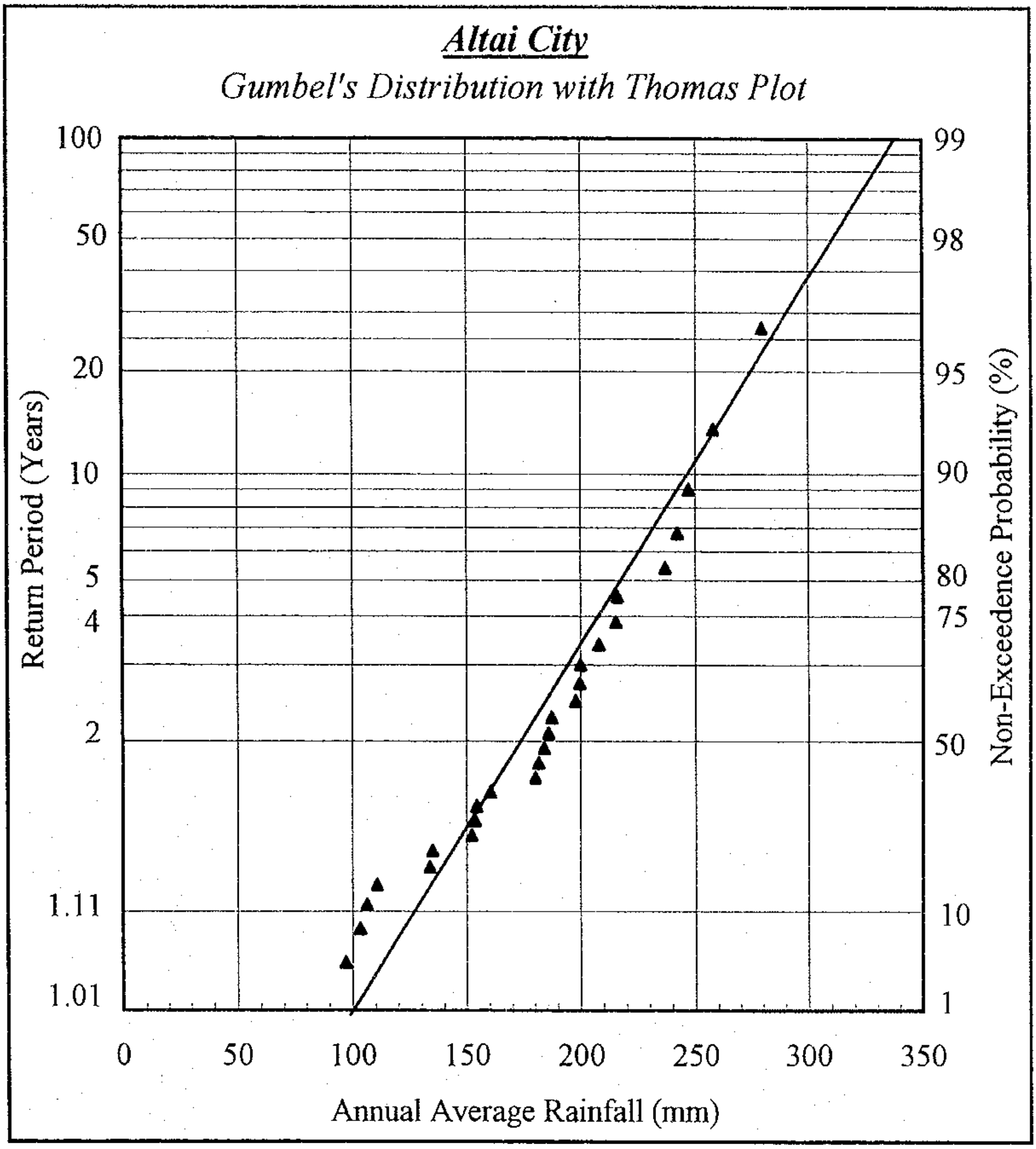
Figure 3.3 Collected Meteorological and Hydrological Data

JICA | The Study on Groundwater Development for Altai City

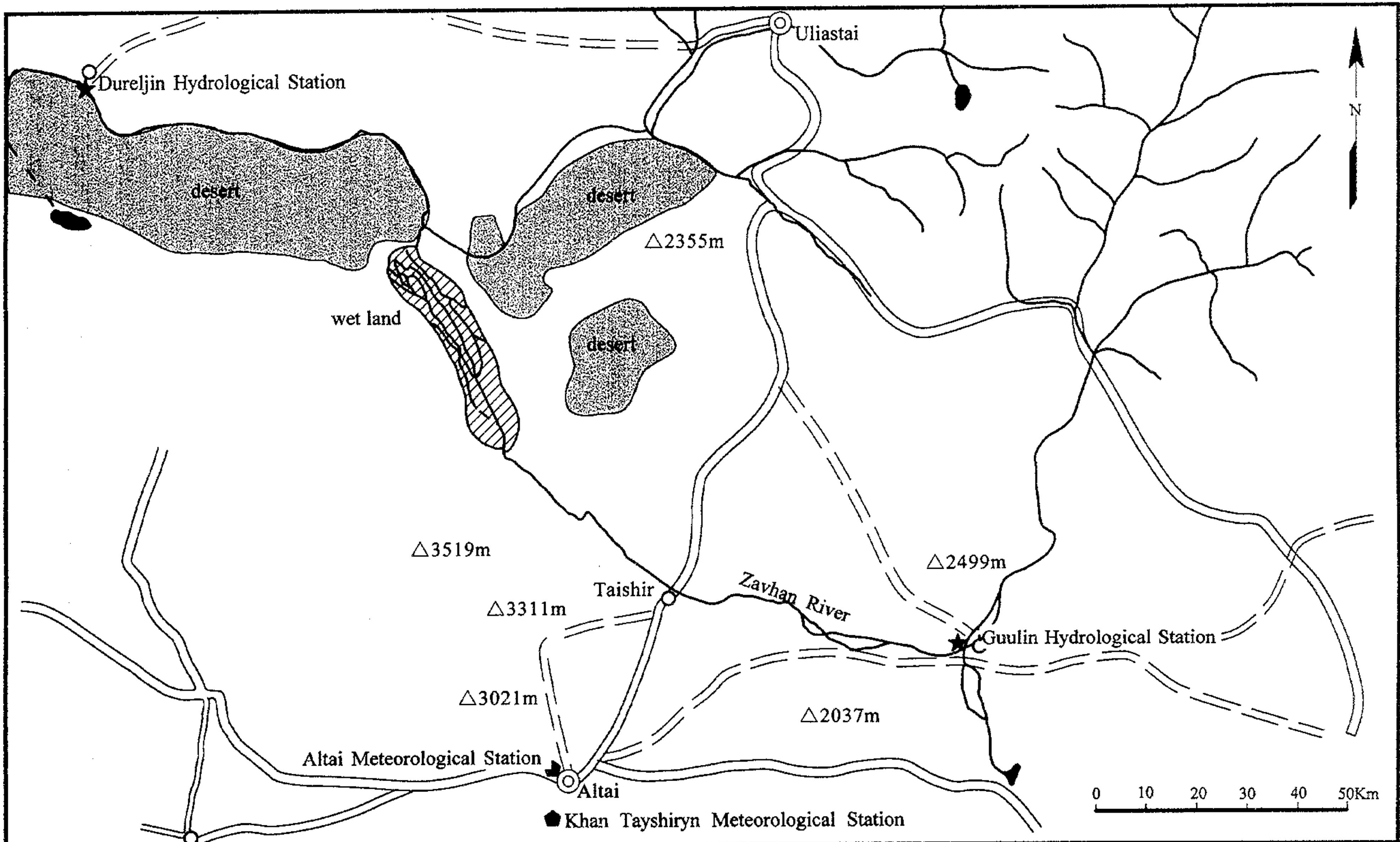



| | |
|---|---|
| Figure 3.4 Monthly Average Rainfall, Temperature and Relative Humidity | |
| JICA | The Study on Groundwater Development for Altai City |




| Figure 3.5 Probability of Annual Average Rainfall in Altai City | |
|---|---|
| JICA | The Study on Groundwater Development for Altai City |




| Figure 3.6 | Location of Hydrological Stations |
|---|---|
| **JICA** | **The Study on Groundwater Development for Altai City** |

# 4 TOPOGRAPHY AND GEOLOGY

## 4.1 GENERAL

### 4.1.1 Outline of the Investigation

This hydrogeological study aims to estimate the capacity of groundwater resources that are roughly classified into the following two sources, unconsolidated deposits of Quaternary and Tertiary and fractured zone in basement rocks that are expected to form good aquifers. Therefore, geological survey was first conducted to clarify the distribution and property of unconsolidated deposits and fractured zones. Survey items are as follows:

- collection of existing geological data ,
- interpretation of satellite images and aerial photographs,
- analysis of collected data,
- geological field reconnaissance, and
- making a geological map.

### 4.1.2 Regional Geology

Mongolia is a mountainous country. Basically, its topography is characterized by mountains, hummocks and high denudation plains, forming three major regions on its surface. Mountains (1,500~3,000m) occupy more than 40 percent of Mongolia's total territory, hummocks (1,000~1,500m) 40 percent and denudation plains about 15 percent. Within Mongolia, mountains are found mainly in the northern and western regions, and denudation plains in the southeast; hammocks, equally distributed on its entire territory, are highly developed in the desert area which is a closed-drainage region south of the continental watershed.

Tectonically, Mongolia comes under the Ural-Mongolian Paleozoic fold belt, and only a portion of it belongs to the Mediterranean - Central Asiatic branch of Tethys. The country is divided into seven structural units of folded zones as follows (refer to Figure 4.1).

I. Mongolian Altai Folded Zone
II. North Mongolian Folded Zone
III. Mongol Pre-baigalian Folded Zone
IV. Central Mongolian Folded Zone
V. South Mongolian Folded Zone
VI. South Gobian Folded Zone
VII. Inner Mongolian Folded Zone

The geology of Mongolia comprises metamorphic, magmatic and clastic complexes of all geological ages. The surface of the mountains usually has Precambrian and Paleozoic geosynclinal complexes, characterized to a significant extent by deformations and metamorphic changes. In inter-mountain hollows and in a considerable part of Gobi, Mesozoic and Cenozoic sediments cover the faulted foundations.

The Study Area belongs to North Mongolian Folded Zone. Vendo and Riphean Systems of Precambrian period are mainly distributed in the area( refer to Figure 4.2 ). Cambrian system is intercalated with these basement rocks which are intruded by granitic rocks of the Devonian and Permian period, and covered locally by the Tertiary and Quaternary deposits.
These systems are generally distributed in zonal arrangement extending from northwest to southeast. Every system is unconformable to the others and complexly folded and faulted.

## 4.2 INTERPRETATION OF SATELLITE IMAGES

### 4.2.1 General

Using satellite images with a scale of 1/100,000 and 1/250,000 which cover the entire Study Area, interpretation of the images was conducted with the aim of finding out general features of the fault system. The aerial photographs of the Study Area with a scale of 1/47,000 was also interpreted. The results are shown in Figure 4.3 .

Definition of Lineament

A lineament is defined as a linear characteristic that reflects directly and/or indirectly geological conditions and geological structures on satellite images and on aerial photographs. In other words, lineaments indicate faults, fractured zones, lithological boundaries, beddings, joints, and schistosities.

### 4.2.2 Method of Data Processing

#### (1) Data Selection

Landsat supplies two kinds of data, MSS (Multi Spectral Scanner) data and TM (Thematic Mapper) data. The general performance characteristics of MSS and TM are shown in the following table.

Characteristics of MSS and TM

| Sensor | Bands | Wave length (km) | Ground resolution | Swath width |
|---|---|---|---|---|
| | 4 | 0.5 ~ 0.6 | | |
| MSS | 5 | 0.6 ~ 0.7 | 80 m | 185 km |
| | 6 | 0.7 ~ 0.8 | | |
| | 7 | 0.8 ~ 1.1 | | |
| | 1 | 0.45 ~ 0.52 | | |
| | 2 | 0.52 ~ 0.60 | | |
| | 3 | 0.63 ~ 0.69 | 30 m | 185 km |
| TM | 4 | 0.76 ~ 0.90 | | |
| | 5 | 1.55 ~ 1.75 | | |
| | 7 | 2.08 ~ 2.35 | | |
| | 6 | 10.4 ~12.5 | 120 m | |

Resolution of TM data is higher than that of MSS. TM data is preferred to analyze the topographical and geological feature in the Study.
TM data was selected according to the following criteria.

- Most recent data
- Less cloud coverage
- High image quality

The finally selected data are Path 137 & Row 028 in September 20, 1990 from EOSAT CO. (U.S.A.).

### (2) Color composite photo print production from CCT

Color composite photo print was produced to make images suitable for topographic and geological interpretation work. Details of the process are explained below.

1) Format Conversion
Data from EOSAT was converted to make subsequent data processing work efficient by using a software of EASI/PACE.

2) Noise Reduction
Irregular line noises were not found in the data.

3) Stripe Noise Correction
Stripe patterns appearing on images due to uneven sensitivity of sensors were not found.

4) Geometric Restoration
Geometric transformations caused by earth rotation, deviation from flight course, etc. were corrected.

5) Band Selection
3 (blue), 5 (green), and 7 (red) band were selected. This selection is easy to clarify topographical and geological feature.

6) Edge Enhancement
Edge enhancement is an efficient technique for image interpretation. Based on processing of original image by a laplacian conversion, subtle brightness variation is changed to a pair of plus and minus brightness elements. Images processed by a laplacian conversion is then overlapped with the original image to make images having enhanced local contrast.

### 4.2.3 Results

Lineaments are classified into three types from the view points of their clearness and geological significance as the following.

Solid line ______ clear and continuous lineaments that displace another lineament and geological structure.

Broken line ------- rather unclear lineaments that are continuation of aforementioned clear lineaments.

Dotted line · · · · · indistinct lineaments that develop irrelevantly to the geological structures.

Figure 4.3 shows the result of lineament interpretation.
Lineaments observed in the Study Area also can be divided into some groups based on their shape and orientation as shown in the following.

(1) NW-SE~NWW-SEE:
Lineaments with this direction harmonizes with the Khan Tayshiryn Mountains trend and its geological structure, and this may be one of the oldest lineaments.

(2) NE- SW:
Lineaments with this direction may have been formed simultaneously as NW~NNW lineament.

(3) N-S:
Lineaments with this direction develop in granitic rocks.

(4) Ring-shaped:
Ring-shaped lineaments represent peculiar topographical and geological conditions, such as contacts of intrusive granitic rocks with the surrounding country rocks.

Generally, these lineaments are clear in Khan Tayshiryn Mountains located in the northwestern and the southern part of the Study Area, but indistinct in the northern and eastern part of the Study Area. This phenomenon may reflect the topographical deference in the Study Area which is an inter-mountain tectonic depression of Altai Mountains.

### 4.2.4 Possible Groundwater Resources Area

Most lineaments may correspond with faults and fractured zones which are expected to be a fissure aquifer. Faults and fractured zones may form either pervious or impervious zones which control groundwater flow in the ground. From this point of view, possible groundwater sreources are expected in the following locations shown in Figure 4.3. These locations were reassessed with the help of further field survey and VFL-MN geophysical survey.

## 4.3 TOPOGRAPHY AND GEOLOGY IN THE STUDY AREA

### 4.3.1 Topography

The Study Area is located at the northern part of Altai Mountains, and has almost triangular shape elongated in the northwest-southeast direction with maximum width of 25 km and maximum length of 46 km covering about 600 km$^2$. Altai City has an altitude of about 2,040 to 2,180 meters above sea level (m A.S.L).

The Study Area is closed in by two mountain ranges bounded mostly by large regional faults that run northwest-southeast (NW-SE) and west-northwestern - east-northeastern (NWW-SEE) in direction. The former mountain range is Khan Tayshiryn Bayangyn mountains and the latter is Sertengyn mountains. Both of them are the derivations of the Altai Mountain range that is a part of the continental watershed between the Arctic and Pacific Ocean Basins and the closed drainage basin of Central Asia. The altitude of Khan Tayshiryn mountain range varies between about 3,000 and 2,300 m A.S.L. Principal peaks are; Khuryn ovoo(2,836 m), Serven uul (2,890 m) and Tsagaan indert uul (3,008 m). Sertengyn mountains range is located at the north of Altai City and extending in NWW-SEE direction with elevation between 2,150 and 2,260 m A.S.L. This mountain range separates the Study Area into two hydrographic basins; the northern basin named Sukhyn Khooloy area and the southern basin named Harzat - Olon Nuur area. The former basin has an area of about 320 square kilometers ( km$^2$) and the latter over 240 km$^2$.

The Study Area is situated in the southern margin of the catchment area of Zavkhan river. Hydrographycally, the Study Area corresponds to Hanginaagiin Khooloy River catchment area, and it's five sub-catchment areas; Sukhyn Khooloy River (aprox.201 $km^2$), Undur Tsakhirsayr River (aprox. 55 $km^2$), Hadaasan River (aprox.56 $km^2$), Mandaliin Aryn Am River (more than 123 $km^2$), and Euitiin Sair River (aprox.155 $km^2$), from the north to the south as shown in Figure 4.4.

Each river system originates from neighboring mountains and flows in mountain area as surface water and/or in undulated area as groundwater. In the undulated area and flat plain area, majority of river courses are dry and filled with angular gravel and sand. Fluvial current is only seen during and shortly after heavy rainfall.

Based on the field reconnaissance and the aerial photograph interpretation, the following five topographic units were established in the Study Area:

Mountain I,
Mountain II,
Hilly Area,
Undulated Area, and
Flat Plain Area

Their distribution is mapped in Figure 4.5. General characteristics for each unit is shown in Table 4.1.

**(1) Mountain I**

Mountain I unit has zonal distribution parallel to Khan Tayshiryn mountain range in the NNW-SSE direction. Its altitude is over 2,500 m A.S.L. with the nameless highest peak of altitude 3,010 m A.S.L. of Khar Ovgor range in the northern area and Tsagaan Indert Uul of 3,008 m A.S.L., where major precipitation occurs. The slope gradient of this unit varies between 10 and 20 degrees. Slopes are engraved with many drainage courses and some of them flow as small currents. This unit is made up of a series of metamorphic, carbonate and granitic rocks including basic and ultrabasic rocks of Precambrian-Proterozoic.

**(2) Mountain II**

Mountain II unit is widely distributed in the Study Area; lower part of Khan Tayshiryn mountain range, Sertengyn mountain range located immediately north of Altai City and around Undur Tsakhiram eastward from the city. Their altitude varies from 2,300 to 2,500 m A.S.L., 2,100 to 2,250 m A.S.L. and 2,050 to 2,150 m A.S.L., respectively. The slope gradient is slightly steep with 3 to 10 degrees. Hydrographic condition is almost the same as that of the former unit. But, some drainage (gully) originate at presumed regional faults. Precambrian metamorphic and granitic rocks are distributed in this unit. In the Khan Tayshiryn mountain range, regional faults extends and form gentle slopes. The Mountain I unit gradually changes into Mountain II unit on account of accumulation of detritic deposit.

**(3) Hilly Area**

Hilly area is distributed around Tsahir Tolgoy located near the northeastern border of the Study Area ranging in altitude from 1,950 to 2,050 m A.S.L. Slope gradient varies between 1 and 3 degrees. River courses are poorly developed. It is mainly characterized by distribution of weathered metamorphic and granitic rocks of Precambrian. This unit gradually changes into the undulated area.

**(4) Undulated Area**

Undulated area overlaps piedmont of mountain area, and inclines toward river course and its tributaries. Its altitude varies between 2,050 and 2,300 m A.S.L. in Sukhin Hooloi area, 2,150 to 2,300 m A.S.L. in Harzat area and 2,150 to 2,400 m A.S.L. in Olon Nuur area. The amplitude of its wavy topography is 3 to 5 meters. The slope gradient ranges from 1 to 3 degrees. Many river courses have clear alluvial fans at their exists from mountain area. Moreover, some principal river courses are filled with fluvial sediments. In the majority of rivers, water does not flow except during heavy rainfall. Geology of this area is composed of fine fluvial sediments. Groundwater supplied in mountain area flows through this area, and some springs are seen at the end of fans which are important water sources for local people and livestock.

**(5) Flat Plain Area**

Flat Plain Area is arranged in narrow depressions like principal river courses, their tributaries, and lakes. In the Study Area, this unit can be seen at Sukhin Khooloi, Ulaan Ganga, Zadgay Khooloy in the northern basin extending from west to east, surroundings of Esun Bulagyn Shal at southeast of Altai City and Olon Nuur. The altitude varies between 1,950 and 2,500 m A.S.L., 2,000 and 2,150 m A.S.L. and 2,150 and 2,220 m A.S.L. in the same order aforementioned. The slope gradient is almost zero. Recent fluvial fine sediment is the principal geological component on the surface. Fine sandy and/or clayey layers are commonly observed along with pebble and cobble. Many heavily meandering river courses, swamps, and salt lakes are the principal features of this unit. These features indicate high groundwater level, poor drainage, underlying fine sediments, and flat terrain, etc.

### 4.3.2 Stratigraphy

In the Study Area, Lower-Proterozoic( Riphean, Vendian ), Cambrian, Devonian, Neogene geological systems are distributed. Quaternary sediments cover the aforementioned system. Every geological formation has unconformable relationship to each other. Details and distribution of geological components are shown in Table 4.2 and Geological map of the Study Area in Figure 4.6.

Briefly speaking, the Hilly and Mountainous areas are underlain chiefly by Precambrian metamorphic rocks, which are intruded by granitic rocks of Precambrian-Riphean series. Carbonate rocks of Cambrian period outcrop in the southern mountain area. On the other hand, in the undulated and flat plain area, Quaternary unconsolidated sediment is widely distributed and small outcrops of Devonian and Tertiary sedimentary rocks are scattered in the northern part of the study area.

Each geological system is described in order of time in the following.

**(1) Lower Proterozoic - Gobi Altai Series & Ulaantolgoy Series (PR1)**

Gobi Altai series & Ulaantolgoy series have a large distribution at Altai and its surroundings such as Khan Tayshiryn mountain range, Sertengyn mountain range and around Undur Tsakhiram, etc. This series is made up largely of metamorphic rocks such as banded gneiss, amphybolite, quarzite, and schist, also includes much leucocratic granodiorite, tonalite, aplite, and limestone. Specially, the amphybolite formation (PR1am) is characteristic to this series and presumed to be an upper sequence of this formation. This formation is considered to have undergone migmatization with pink granite and augen gneiss. It also shows folds and faults at the northern boundary of Sertengyn mountain and Tsahir Tolgoy range, and lies in regional fault extended along the northern boundary. Sertengyn mountain is principally composed of pink banded gneiss, amphybolite and schist, which are cut by many faults and form fractured zones. On the other hand, quarzite, leucogranodiorite, limestone, marl and tonalite are the principal lithology in the southern part. Generally, gneisosity and/or schistosity is clear, and fracture and joint tend to increase. Total thickness be about 2,950 meters.

**(2) Upper-Lower Riphean series**

Upper-Lower Riphean series is composed of serpentinite, peridotite, dunite, diabase, diorite, green rock, and green schist. This formation has a peculiar distribution along Khan Tayshiryn mountain range. The rocks lie in regional faults contact along the eastern boundary. This formation shows almost parallel disposition of different rocks from piedmont to mountain ridge; serpentine, peridotite, dunite and diorite, green rock, and green schist are distributed along faults on a small scale.

Serpentinite outcrops look greenish and forms many small hills. This lithology may be intrusive masses along regional faults. The rock easily crumbles. Peridotite and dunite zone has clear boundaries with the serpentinite and form low mountain slopes and hills such as monadnocks. These rocks are hard and dark gray with some fractures. Khan Tayshiryn mountain range is composed of hard friable diorite showing sawlike ridges. In the ultrabasic rock zone, possibly Cambrian limestone is intermittently found on intermountain gentle slopes as small rock bodies or clots parallel to the regional faults. Sheared schist is found along the extended regional faults.

**(3) Intrusive Rock of Riphean series ($\gamma$ R2-3)**

Intrusive Rock of Riphean series is principally granitic rocks and composed of granite, granodiorite, tonalite, diorite, gabbro, amphybolite, and marble. This intrusive rock shows sporadic distribution at Kharginaagyn Khooloy, Undur Tsakhiram near the branch road to Bayanhongol and Khan Tayshiryn mountain range. These granitic rocks form a small rock mass accompanied by metamorphic rocks of Lower Proterozoic formation and cause a contact metamorphism to the former formation. Some granitic bodies are cut by faults. The same granitic rock even has lithological variation. Generally, this granitic rock is coarse, granular, hard and fractured.

**(4) Vendian - Khan Tayshiryn series (Vht)**

Southwestern Khan Tayshiryn mountain range exposes Vendian green rock and green schist of originally basic rocks. This formation is sporadically distributed and shows fractured feature as a result of faulting. This rock is fine grained, hard and looks greenish. It is commonly found along the regional faults. Total thickness is about 4,000 meters.

**(5) Cambrian - Tsagaan Olom series (E1-2)**

Tsagaan Olom series is largely made up of Cambrian carbonate rocks such as dolomite, dolomitized limestone, marble, chalkstone of light gray and is intercalated with some shales. Exposures of the rocks are confined to comparatively limited area near Suvilalyn Amaralt settlement. As aforementioned, some carbonate rock of this formation is occasionally found in ultra-basic rocks. Clearly banded foliation with gentle deformation, and synclinal folds are widely found. The total thickness is about 2,000 meters.

**(6) Lower and Middle Devonian series**

Lower and Middle Devonian series is slightly distributed around Zadgay Khooloy and Khatuugyn sayr located in the northeastern corner of the Study Area. This formation is composed of sandstone and conglomerate in small quantity. Stratigraphy of this formation is almost horizontal.

**(7) Neogene System**

Neogene system is widely distributed in the northern basin, particularly at the center of the Sukhyn Khooloy, but the majority of this system is covered by Quaternary sediments. Small outcrops are exposed around Zadgay Khooloy. Lithological component is represented mainly by friable reddish clay with sand and gravel layers. Total thickness of this system at Sukhiin Khooloi is within 41 meters. This clayey material is used for brick making.

**(8) Dike Rocks**

Many dike rocks are widespread in the study area. They are composed of dolerite, diabase, porphyrite, aplite, and pegmatite, etc. Vertical dikes are commonly exposed and their width varies between some meters and several tens of meters. Especially, large distribution of dikes is well-exposed with general trend northwest-southeast around Tsahir Tolgoy. Continuous outcrops of these dikes with gentle folds can be traced over areas of many kilometers.

**(9) Quaternary Deposits**

In the Study Area, the Quaternary deposits are widely distributed at central lower part of the relief such as undulated and flat plain unit areas including intermountain valleys. The distribution of the Quaternary deposits is bounded from the pre-Quaternary rocks by faults of steep inclination along the margin of each basin. This type of deposit is mainly composed of alluvial fan, talus, flood plains, and recent river deposits. The age may vary from lower Pleistocene to upper Holocene.

Fan deposits (Q II-III)

Fan deposits are distributed at mouths of rivers and its tributaries along skirts of mountain area. The fan deposits consist of gravel rich deposits that originated in the surrounding mountain area. The thickness of the fan deposits is estimated at 30 meters or more at southwestern - southern boundary of the basin. The fan deposits form a phreatic aquifer as far as they are saturated. In Sukhyn Khooloy, many springs at the fringes of fan deposits are found.

Talus deposits (Q II-III)

Talus deposits are widely distributed in undulated area including piedmont. Their lithological components are clay, sand and pebble to boulder that are angular to sub-angular with poor sorting.

Recent river deposits (QIV)

Recent river deposits are distributed along the principal river courses (traces) like Sukhyn Khooloy, Mandaliin Aryn Am, Euitin Sair, Kharginaagyn Khooloy, etc. and along their main tributaries. This deposit consists of silt, sand, and partly gravel. The gravel is angular to subangular with poor sorting because of short river length, low frequency of flood, and fractured rocks exposed in the mountain area. Impermeable clay layers exist near the land surface in some depressions, where many swamps with salty water-ponds are commonly observed.

### 4.3.3 Geological Structure

Geological structure of the study area is rather complicated with presence of medium grade metamorphic rocks of acidic to basic rock origin. The area is considered to have been at an active continental margin in the past. It is located at the southern edge of North Mongolian Folded Zone, where the direction of folding axis is deflected northward, extending NW-SE, NWW-SEE in direction. Faults with similar orientation are develop along the northern boundary of Sertengyn and southeastern wing of Khan Tayshiryn mountain range along its midslope. These regional faults are detected by satellite images, aerial photographs and field survey. Along the regional faults, neighboring formations are complexly folded, sheared, fractured, and faulted. Fissure water is commonly found along these regional faults with sheared and fractured zone. Springs are found along these regional faults as well. The diastrophism that caused these regional faults may have taken place toward the Late Riphean-Cambrian.

## 4.4 GEOPHYSICAL PROSPECTING

### 4.4.1 Outline of the Survey

In order to understand hydrogeological settings of the study area, geophysical survey was carried out. The survey was mainly concentrated near Altai City with some reconnaissance survey in remote area.
Geophysical method used for the study are DC resistivity sounding method and VLF electromagnetic method both of which intend to detect changes in electrical conductivity in the earth for the purpose of obtaining more information on the subsurface geological structure.

### 4.4.2 DC Resistivity Survey

DC resistivity sounding was carried out between June 22 and July 26, 1997. Schlumberger electrode array was used for DC resistivity sounding. One half of a maximum current electrode spacing is 400 meters.
The average annual temperature of Altai City is 1.7 degrees below freezing in Celsius. Some part of the survey area is a few hundred meters higher in elevation than Altai City Meteorological Observatory. Permafrost of the earth may exist in the survey area. Permafrost layer may make DC current impermeable. Therefore, if there is a permafrost layer in the ground, it prevents us to see under it by DC resistivity method. DC resistivity survey was carefully carried out to avoid interference by permafrost

zones and very dry and resistive surface layer.

## (1) Field Survey

Equipment

The equipment used in electrical sounding (SYSCAL R1 PLUS) are as follows.

Name: Syscal R1 PLUS,

manufactured by Iris Instruments, Orleans, France

| Specifications: |
|---|
| **Transmitter**<br>・Maximum output voltage: 400V<br>・Maximum output current: 1.2A<br>・Maximum output power: 125W<br>・Internal ground energization power supply: 12, 50, 100, 200, 400V<br>・Intensity resolution: 0.01mA<br>・Intensity accuracy: 0.3%<br>**Receiver**<br>・Input impedance: 10 M ohm<br>・Protection against input voltage range: -5V to +5V<br>・Automatic compensation of self potential (-5V to +5V) with correction for linear drift up to 1mV/s<br>・High voltage rejection = 0.1ppm(one tenth of a millionth)<br>-Voltage resolution during measurement = 10microV<br>-Voltage resolution after stacking = 1microV<br>-Voltage accuracy = 0.3% topical, 1%max over the whole temperature range<br>・Internal memory: Storage and recall are available. Maximum storage: 818 |

## (2) Stations

DC resistivity sounding occupied 70 stations to cover most of the survey area. Locations of each station are measured by Global Positioning System (GPS) receiver. DC resistivity soundings are carried out in four areas of Undur Tsahir: Northeast side of Altai City, Bayan tolgpy: Southwest side of Altai City, Kharzat: Southeast side of Altai City, and Olon nuur: Southeast side of Altai City. Locations of the DC resistivity stations and bearings of electrodes spread are tabulated in Table 4.3 and mapped on Figure 4.7.

### (3) Result

DC resistivity sounding data are interpreted by RESIX by Interpex, Golden Colorado USA. In RESIX program, layered earth models are derived from apparent resistivity data by a "ridge-regression (Inman, 1975)" inversion technique.
The data of DC resistivity sounding of each area are given in Table 4.4.

Most of the collected data do not show an apparent insulated layer near the surface as an evidence of permafrost layer. Patterned ground or obvious geographic features showing existence of permafrost layer is not found at the surface of the ground. Therefore, it is estimated that permafrost layers, even if it exists, exist only in a limited area.

The resistivity distribution in the survey area is as follows( refer to Figure 4.8 (1) – (4) )

1) Undur Tsahir ( a-line, b-line, c-line )

An alluvial fan deposit is distributed in this area. The thickness of the alluvial fan deposit corresponds approximately to the depth to the basement. The resistivity of the alluvial fan deposit ranges from less than 100 ohm-m to several hundred ohm-m. The depth to the basement along a-line ranges from 5 m to 100 m dipping toward northwest.
Depth to the basement along b-line ranges from 20 m to 40 m, relatively flat.
Depth to the basement along c-line ranges from 13 m to 40 m dipping toward northeast.

2) Bayan Tolgoy (d-line)

The line is along the abandoned power line, connecting Altai City and the old Meteorological Observatory at the top of Kahn Tayshiryn Mountain. The basement rock outcrops at the locations southwest of the station 2. Since elevation of d-line is higher than that of Altai City, existence of permafrost layer is presumed. Some of the resistivity values collected along d-line are very high near the surface and it is assumed to be caused either by permafrost layer or basement rock. The depth to the basement or permafrost layer ranges from 1 m to 22 m. The depth to the basement rock or permafrost layer becomes very shallow at the southwest of the station 7.

3) Kharzat (e-line)

The basement rock outcrops along e-line. Resistivity survey revealed a very conductive layer (resistivity less than a few ohm m) a few meters to tens meters in the ground which may corresponds to saline ground water in the ground. The ground surface of the area is covered with marsh and saline water.

4) Olon nuur (f-line)

Quaternary sediments are widely distributed in this area. Mongolian government carried out seismic refraction survey and several electrical soundings in this area. According to their result, Quaternary sediments accumulate on a basin in this area and its maximum thickness is 100m.

DC resistivity measurement was carried out in consideration of their results. The resistivity of Quaternary sediments in this area ranges from less than 50 ohm-m to several hundred ohm-m. The basement depth ranges from less 10m (at the station 43, 44, 45) to over 70m (at the station 47,48,49,50).

### 4.4.3 VLF-EM Survey

#### (1) General

VLF electromagnetic (VLF-EM) survey is to detect conductive or resistive zones within a depth of 20 to 30 meters in the ground. It uses electromagnetic guide waves generated by military transmitters for communication with submarines. There are many VLF signal-transmitting stations operated by military services of many countries in the world. Frequency of VLF-EM wave lies between 15 kHz and 30 kHz.

The advantage of VLF-EM method is economical and quick to cover wide survey area because of not needing to have own personal transmitter. However operation of VLF transmitters is often halted for maintenance and their operation schedules cannot be known. Because VLF signal is used for communication with submarines, which are in the ocean, VLF-transmitter does not aim to transmit signal to the center of a continent like Mongolia.

VLF-EM survey is most sensitive when strike of a targeted conductive sheet is parallel to the direction to a VLF signal transmitter, and it cannot sense a conductive sheet when its strike is perpendicular to a direction toward a VLF signal transmitter.

VLF-EM method detects conductive anomalies to a depth depending on resistivities of surrounding rocks and a shape and a volume of conductivity anomaly. Survey depth is deeper with higher surrounding resistivity. If resistivity of surroundings is about 100 ohm-m and 1000 ohm-m, maximum depth to survey by VLF-EM method is respectively about 20 meters and about 50 meters.

## (2) Field Survey

1) Equipment

The following equipment is used for the survey:

Model: T-VLF

Manufactured by Iris Instruments, Orleans, France.

2) Signal strength at the survey area

Magnetic field strength of VLF signals is tested because distance to the closest ocean and the closest known VLF transmitting stations from Altai City (longitude: 96 degrees 15 minutes east and latitude: 46 degrees 22 minutes north) is several thousands kilometers.

Tests are conducted on June 22, 1997 and June 23, 1997 on all 24 VLF frequencies which are preset on the T-VLF receiver. Field strengths of 24 VLF frequencies at in front of the state capitol building of Gobi-Altai Province (longitude: 96 degrees 15.25 minutes east and latitude: 46 degrees 22.46 minutes north) are tabulated on Table 4.5. The field strengths of all preset VLF frequencies received did not exceed five micro A/m which is at least one magnitude smaller than it in the most places where VLF-EM method has been successfully conducted. The field strength of 22.2kHz signal received in Tokyo on June 23, 1997, which is transmitted from Ebino, Japan with power of 500 kW and not included in preset frequencies of the T-VLF receiver, confirmed transmission of VLF signal. The field strength of 22.2kHz at in front of the state capitol building in Altai City on June 24, 1997 was about double of it of other preset frequencies.

It is decided to use 22.2 kHz VLF signal transmitted from Ebino, Japan throughout the survey regardless of strikes of expected geological structures.

3) Survey lines

Survey lines are set to cut across lineaments inferred from photo-geological and geological reconnaissance survey. Locations of the base stations of each lines, which are the station 0 except the line 4, are measured by a Geodetic Positioning

System (GPS) receiver and marked by white or yellow paint on the ground. Spacing of survey stations along survey lines is ten meters. Bearings of survey lines are measured by a magnetic compass in degrees clockwise from the magnetic north.

Total numbers of survey lines and stations are 30 lines and 2,053 stations. Total length of survey lines is 20,230 meters. The survey specifications are listed on Table 4.6. The base stations are illustrated on Figure 4.9.

The survey lines are in five areas, the northeast foothill of Bayangyn Nuruu: line 1 to line 6, the northeast side of Altai City: line 7 to line 11, the northwest side of Altai City: line 14 to line 17, line 22 and line 30, the area along Khadaasangyn am: line 18 to line 27, and the northeast edge of the survey area: line 12, line 13 and line 29.

## (3) Result

The survey results are interpreted into fractured zones as Table 4.7. VLF anomalies around the city park, the northwest area of Altai City, is shown in Figure 4.10.

In general, VLF results of survey lines in east-west direction, line 24, line 27 and line 29 do not show much variation, because the direction of expected lineament is perpendicular to the direction to the location of the transmitter, Ebino, Japan. Therefore, detection of less numbers of fractures along those three lines does not necessarily mean existence of fewer fractures along those lines.

1) The northeast foothill of Bayangyn Nuruu

The survey lines were set to detect northwest-southeast lineaments along the foothill of Bayangyn Nuruu (mountain range).

Several fractures were detected along each line. Spacing of each lines was taken to be over one kilometer, so that detected fractures cannot be correlated. Although the survey result shows sufficient capability of detecting fractures by VLF-EM survey in the area. If it is decided to drill to some lineaments in the area, VLF-EM data can help to pinpoint location of the fractured zone.

2) The northeast side of Altai City

The survey lines were set to northeast-southwest lineaments.

Several fractures were clearly detected. Some fractures may be traced through two to three lines in northwest-southeast direction.

3) The northwest side of Altai City

The survey lines were set to detect northeast-southwest and northwest-southeast lineaments.

VLF anomalies in the area are mapped in Figure 4.10. It is apparent that anomalies along the park fence and anomalies at the southwest ends of lines 17, 22 and 30 and the northwest end of line 16 are artificially made by metal fences. Other anomalies can be interpreted to be created by underground fractures.

Fractures along lines 14, 15, 21 and 16 can be traced northeast-southwest direction and fractures along lines 12, 30 and 22 can be traced northwest-southwest direction.

Inferred fractured zones are shown in broken lines on Figure 4.10.

4) The area along Khadaasangyn am

There are many lineaments meeting in and around the area. Some lines were intended to detect nearly north-south direction lineaments, but those could not be detected clearly, probably due to the inappropriate direction to the transmitting station, Japan. Several other fractures were detected along each line. Detected fractures cannot be correlated.

5) The northeast edge of the survey area

Lines 12 and 13 were set to detect several lineaments in northwest-southeast direction in granite.

Several fractures were detected by the survey, but in some places data show unusually large noise. The noise may be caused by topographic relieves and some thick ovelying layers.

Line 29 is to detect northwest-southeast lineament along Khukh Chuluut Nuruu. Several fractures were detected along the lines where topographic changes occur.

### 4.4.4 Distribution of Faults and Basement Rocks

As a result of the previsous geological and geophysical survey in combination with the past geological and hydrogeological data from the Mongolian side, the Study Teams was able to picture more minute geology of the Study Area. Especially the distribution and characteristics of fault zone and of the basement rocks.

Fault Zones

Several lineament zones were recognized as a result of satellite image interpretation as described in section 4.2. (See also Figure 4.3)
The geological field survey was conducted with the aim of further investigate the lineament zones which are expected to form large fractured zones in the basement rocks. These fractured zones could hold water and serve as aquifers. The study team also obtained some additional data on geophysical surveys conducted at Harzat and Olon-Nuur area in 1980. This study consisted of seismic survey, Vertical Electric Sounding (VES) and dipole electric prospecting. The results are incorporated into Figure 4.11. It shows lineaments from satellite image and aerial photographs analysis and faults, sheared zones and fractured zones detected by the survey.
Although some of the lineaments are clear and stretch out over the study area, neither the VLF survey nor the field survey indicated presence of such conspicuous fractured zones at most sites. Presumably this is because the geology of the study area is quite old and there has been no recent tectonic movements that could have generated cracks in basement rocks on a large sale. In fact, in most of such lineament zones, disruption of the formation, remarkable folding and intrusion of dikes and even surpentinites are observed but no open fractures directly associated with these structures.
In spite of the absence of such fractures, a lot of open cracks and joints are observed in the rocks exposed in Khadaasan area, which are expected to convey and keep at least some amount of water. In this case, the fractures are thought to develop uniformly in a web like structure with no particular permeable zone.

Basement Rock

In 1980, there was an in-depth study on the hydrogeological conditions of the Study Area, especilly in Kharzat and Oloon Nuur. Although any systematic and complete set of data were not available, the Study Team somehow obtained the data of more than hundred wells drilled in this study. The data was combined with the DC resistivity survey result to produce more reliable data on the underground geological structure. The outcome is presented as Figure 4.12 (2) – (4) showing the depth of the basement rocks and the thickness of the overlying Tertiary and Quaternary formations (Location of these section are also shown in Figure 4.12 (1)). The sites where the most permeable Quaternary sediment is thickest are expected to be the best sites for test well drilling.

## 4.5 POSSIBLE GROUNDWATER RESOURCES

What is expected of good water resources is, first of all, sufficient amount and good quality. Although availability and accessibility are as important as the former two factors. This is because the cost of construction of a well and cost of transportation of the water are affected by its availability and accessibility; how easily good water can be obtained and how far the water has to be carried to the site of consumption. The selection of sites for future development will be done in consideration of these factors mentioned above.

In this chapter however, the potential sites are selected primarily from the geological point of view. The detailed hydogeological characteristics of the study area and all the test wells will be dealt with in the following chapter in order to evaluate the potential of each test well and hydrological area. The selection of sites for future development will be done based on that result.

### 4.5.1 Possible Sites for Alluvial Aquifer

Based on the survey data obtained, three potential areas were selected for exploration of alluvial aquifer. They are

Kharzat - Olon nuur area,
Northeast of Altai, and
West of Altai

as shown in Figure 4.13.

The groundwater in Kharzat area has been long exploited by the Mongolian. It is the best studied and probably the most potential area within the study area. Olon nuur area is the southeastern extention of Kharzat area and covered by thick alluvial deposit likewise. Although the distance from the city center is a few kilometers more than Kharzat area, it is as promising as Kharzat area in terms of groundwater potential due to the presence of thick alluvial deposit.

The field geological survey and the DC resistively survey indicated presence of relatively thick alluvial deposit in the northeast of Altai City as well. In this area this alluvial deposit is underlain by thick Tertiary red clay formation which is basically impermeable. However the upper permeable layers alone can form good aquifer collecting water from Kharzat and Olon nuur and from the eastern margin of the study

area where quality of the water is known to be good.
The west of Altai is on the northeastern edge of alluvial sedimentary blanket where the past studies indicate relatively thick sediment at some parts. On top of this fact, water quality is expected to be relatively good as well.

### 4.5.2 Possible Sites for Fissure Aquifer

Five sites were selected for exploration of fissure aquifer based mainly on the field geological study and satellite image interpretation since most VLF anomalies turned out to be irrelevant to any of essential geological elements.
The five sites are

1) Right west of Altai City apartment area,
2) Northeast of Altai City across the road to the petrol reservation station,
3) Northeast of Altai City north of the bridge over Esungyn am river
4) Northwest of Altai City upstream of Khadaasan am river
5) Northwest of Altai City downstream of Khadaasan am river

All the above are located on one of the main lineaments or on their intersections.

**No.1** is located on a large clear photo-lineament that stretches SW to NE across Altai City. This lineament seems to be an old one, because the western part of it is obscured by alluvial fan deposit and other younger geological structures. However, this is still one of the largest lineament in the study area.

**No.2** is located on the eastern side of the same lineament as No.1. The rocks exposed at around the site show massive appearance with few cracks and joints.

**No.3** is on the intersection of a major photo-lineament running NWW to SEE and a rather unclear one. This area is mainly outcropped by acidic gneiss and plutonic rocks, which would give better quality of water.

**No.4** is located on an intersection of two lineaments, Khadaaasan valley axis and an unclear one extending NE from Altai City. The lithology of this area is characterized by intermediate to basic banded gneiss and massive amphibolite. Joints parallel to the gneissosity are common in these rocks. Water running into this valley comes from north western part of Khaan Tayshiryn mountain range where basic to ultrabasic rocks suck as gabbro, peridotite and serpentinite are abundant. This fact about the lithology implies comparatively high contents of Mg, Ca and other heavy metals in the water.

**No.5** is located at the exit of Khadaasan valley and also on the western extension of the same lineament on which No.3 is located. The background geological condition is similar to that of No.4 although cracks and joints are more prevalent.

### 4.5.3 Surface Water

Utilization of surface water has been proposed as an alternative water source in the preliminary study in 1996. The sites proposed are Tsagaan Tokhoy and Tayshir that are both located on Zakhan river about 50km north and 100km northeast of Altai City respectively (See Figure 4.13).

Zavkhan river is the largest river in Gobi-Altai province and has a good water supply potential. It has about 9.5 $m^3$/second of average discharge and never dries up or completely be frozen. Although the river becomes fairly cloudy during and after heavy rain fall, extraction of clean water could be easily achieved by installing radial collector wells along the river course (refer to chapter 3 for details of hydraulic characteristics of the river). In spite of the high water supply potential of the river itself, the two sites are not considered a good candidate for the future water source because of its low accessibility. It is as far as 45km away from Altai City and there is no paved road or relay town on the way. In addition to this, freezing temperature in winter will make special protection of transmission pipes inevitable. Therefore, either carrying water by car or transportation by pipeline will be a very costly choice.

The condition is similar for Tsagaan Tokhoy and even worse in terms of accessibility. The Technical and Economic analysis of this matter is given in chapter 6 in more detail.

# Table 4.1 Topographic Classification of the Study Area

| Topographic Unit | Mountain I | Mountain II | Hilly Area | Undulated Area | Flat Plain Area |
|---|---|---|---|---|---|
| Altitude (m A.S.L) | >2500 m | 2300-2500 m<br>2100-2250 m ( N of Altai )<br>2050-2150 m ( E of Altai ) | 1950-2050 m (NE of Altai ) | 2050-2300 m (Sukhiin Hooloi)<br>2150-2300 m (Harzat Area)<br>2150-2400 m (Olon Nuur Area) | 1950-2150 m along river course (Sukhiin Hooloi)<br>2000-2150 m ( SE of Altai )<br>2150-2220 m (Olon Nuur Area) |
| Slope Gradient (degree) | Steep (10-20°) | Moderately Steep (3-10°) | Gentle (1-3°) | Very Gentle (1-3°) | Almost Horizontal (0-1°) |
| Distribution | Khan Tayshiryn mountain range | Khan Tayshiryn mountain range, Sertengyn mountain range & around Undur Tsakhiram | Around Tsahir Tolgoy | Sukhin Hooloi area, Harzat area & Olon Nuur area | Around river course at Sukhin Hooloi -Ulaan Gaugazadgay Hooloi-Khanginaagyn Hooloi, Esun Bulagyn Shal-Olon Nuur |
| River System | Straight small course with sporadic current | Almost straight small course with sporadic current | Slightly irregular small course ordinarily without water | Underflow groundwater, but current water during heavy rain | Heavily meandering river course with current of sometimes salty water |
| Geology | Metamorphic & Granitic Rocks | Metamorphic & Granitic Rocks | Metamorphic & Granitic Rocks & dikes. Locally weathered as monadnocks | Alluvial deposits of good permeability such like fan and talus. | Fine sandy and/or clayey sediments |
| Hydrological System | Recharge Area Major precipitation area | Recharge Area | Partly Recharge Area | Discharge Area | Poor Drainage Area With Concentration of Salt Minerals |
| Hydrogeological Characteristics | Little possibility of development | Possibility of fissure aquifer along the regional faults | Possibility of fissure aquifer | Actual groundwater production area | Not feasible for exploitation because of bad water quality |

# Table 4.2 Geological Components

| ERA | PERIOD | SYMBOL | SYSTEM | LITHOLOGICAL COMPONENT | REMARKS |
|---|---|---|---|---|---|
| CENOZOIC | Quaternary | QIV | Upper Quaternary Recent River Deposite | Sand, Sandy Loam, Loam, Clay, Gravel | *Unhomogeneous alluvial sediments distributed along river courses and their surroundings. |
| CENOZOIC | Quaternary | QII-III | Middle & Upper Quaternary Fan & Talus Deposits | Gravel, Sandy gravel, Clay, Sand | *Unhomogeneous sediments distributed in piedmont, undulatede area, flat pla<br>*Large distrubution in the study area.<br>*Hydrogeologically the most important formation. |
| CENOZOIC | Tertiary | N2at | Neogene System | Redstone with sandy and clayey layers | *Small scale distribution along Zadgay Khooloi. |
| PALEOZOIC | Devonian | D1-2 | Lower & Middle Devonian Series | Sandstone, Conglomerate | *Small scale distribution at north end of the Study Area<br>*Almost horizontal formation. |
| PALEOZOIC | Cambrian Lower & Middle | Є1-2 | Tsagaan Olom Series | Limestone, Dolomitic Limestones, Shale, Marble | *Zonal distribution at south end of the Study Area<br>*Gently deformated. |
| Proterozoic | | Vht | Vendian Series Khan Tayshiryn Series | Green Rock and Greenschist of Basic Rock Origen | *Linear sporadic distribution affected by regional faults in the southwestern mountain area. |
| Proterozoic | | R1-3gb | Upper-Lower Riphean Series | Serpentinite, Peridotite, Dunite, Diabase, Diorite, Green Rock, Greenschist | *Zonal distribution along Khan Tayshiryn mountain range & regional faults<br>*Friable basic and/or ultrabasic rocks |
| Proterozoic | | PR1 | Gobi Altai & Ulaantolgoy Series | Banded Gneiss, Quarzite, Leucocratic Granodiorite & Tonalite, Aplite, Biotite Schist | *The basement of the study area. Large distribution in the northern area of Altai city |
| Proterozoic | | PR1am | Gobi Altai & Ulaantolgoy Series | Banded Amphybolite with gneiss, granite alternated in small scale | *One unit of PR1, Strongly deformated. |
| Proterozoic | | γR2-3 | Intrusive Rock of Riphean Series | Granite, Granodiorite, Tonalite, Diorite, Gabbro, Amphybolite, Marble | *Stock type intrusive. More acidic granitic rock is the product of later granitic activity. |
| Unknown | | | Dike Rocks | Dolerite, Diabase, Porphyrite, Aplite, Pegmatite | *Width varies from some meters to scores of meters.<br>*Gently folded, Large distribution in the NE sector of the study area |

# Table 4.3 Location of DC Resistivity

| St.No. | Latitude(N) | Longitude(E) | Area Code | St.No. | Latitude(N) | Longitude(E) | Area code |
|---|---|---|---|---|---|---|---|
| 1 | 46 21.57 | 96 17.47 | K | 36 | 46 24.72 | 96 21.05 | U |
| 2 | 46 20.37 | 96 12.35 | B | 37 | 46 25.43 | 96 19.13 | U |
| 3 | 46 20.80 | 96 13.12 | B | 38 | 46 25.22 | 96 19.65 | U |
| 4 | 46 20.97 | 96 13.43 | B | 39 | 46 21.78 | 96 17.50 | K |
| 5 | 46 20.20 | 96 12.05 | B | 40 | 46 20.32 | 96 17.15 | K |
| 6 | 46 20.07 | 96 11.83 | B | 41 | 46 20.13 | 96 17.07 | K |
| 7 | 46 20.55 | 96 12.70 | B | 42 | 46 19.92 | 96 16.93 | K |
| 8 | 46 19.98 | 96 11.67 | B | 43 | 46 19.67 | 96 21.52 | O |
| 9 | 46 19.77 | 96 11.35 | B | 44 | 46 19.57 | 96 21.27 | O |
| 10 | 46 21.17 | 96 13.77 | B | 45 | 46 19.42 | 96 21.00 | O |
| 11 | 46 19.63 | 96 11.15 | B | 46 | 46 19.27 | 96 20.78 | O |
| 12 | 46 19.42 | 96 10.70 | B | 47 | 46 19.15 | 96 20.57 | O |
| 13 | 46 19.48 | 96 10.90 | B | 48 | 46 19.03 | 96 20.30 | O |
| 14 | 46 21.55 | 96 17.48 | K | 49 | 46 18.92 | 96 20.02 | O |
| 15 | 46 21.42 | 96 17.42 | K | 50 | 46 18.75 | 96 19.72 | O |
| 16 | 46 21.17 | 96 17.42 | K | 51 | 46 18.62 | 96 19.45 | O |
| 17 | 46 20.73 | 96 17.53 | K | 52 | 46 18.48 | 96 19.22 | O |
| 18 | 46 20.63 | 96 17.32 | K | 53 | 46 18.28 | 96 19.00 | O |
| 19 | 46 21.35 | 96 16.55 | K | 54 | 46 25.17 | 96 19.33 | U |
| 20 | 46 21.25 | 96 17.00 | K | 55 | 46 24.88 | 96 19.00 | U |
| 21 | 46 20.30 | 96 18.73 | K | 56 | 46 24.60 | 96 18.67 | U |
| 22 | 46 20.68 | 96 18.75 | K | 57 | 46 24.62 | 96 18.48 | U |
| 23 | 46 20.47 | 96 17.25 | K | 58 | 46 24.87 | 96 18.48 | U |
| 24 | 46 20.75 | 96 16.85 | K | 59 | 46 25.25 | 96 18.53 | U |
| 25 | 46 24.78 | 96 18.20 | U | 60 | 46 25.63 | 96 18.57 | U |
| 26 | 46 25.07 | 96 17.95 | U | 61 | 46 25.87 | 96 18.57 | U |
| 27 | 46 24.50 | 96 18.48 | U | 62 | 46 26.13 | 96 18.58 | U |
| 28 | 46 24.70 | 96 18.80 | U | 63 | 46 26.40 | 96 18.58 | U |
| 29 | 46 25.30 | 96 17.72 | U | 64 | 46 24.92 | 96 18.03 | U |
| 30 | 46 25.08 | 96 18.57 | U | 65 | 46 25.18 | 96 17.85 | U |
| 31 | 46 25.00 | 96 19.15 | U | 66 | 46 25.42 | 96 17.62 | U |
| 32 | 46 25.45 | 96 18.57 | U | 67 | 46 25.58 | 96 17.38 | U |
| 33 | 46 24.85 | 96 20.07 | U | 68 | 46 25.73 | 96 17.18 | U |
| 34 | 46 25.00 | 96 20.38 | U | 69 | 46 25.83 | 96 17.00 | U |
| 35 | 46 24.75 | 96 20.70 | U | 70 | 46 28.80 | 9614.37 | T |

U: Undun Tsakhir　　O: Olon Nuur　　T: Tsagaan Dersny
K: Kharzat　　B: Bayan Tolgoy

# Table 4.4 List of Estimated Resistivity Structure (1/4)

| Area Name : Undur Tsahir a-Line | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m) | R4 (ohm-m | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 27 | 15 | 94 | 173 | 78 | 251 | 0.5 | 13 | 36 | 222 |
| 57 | 44 | 91 | 412 | 174 | | 7 | 12 | 70 | |
| 25 | 24 | 431 | 25 | | | 5 | 142 | | |
| 64 | 11 | 90 | 722 | 153 | | 2 | 46 | 20 | |
| 26 | 1,209 | 24 | 115 | 14,550 | | 1 | 38 | 83 | |
| 65 | 203 | 30 | 58,706 | | | 9 | 98 | | |
| 29 | 57 | 3 | 22 | 37,293 | | 4 | 2 | 63 | |
| 66 | 212 | 46 | 11 | 32 | 20,047 | 1 | 8 | 8 | 70 |
| 67 | 191 | 28 | 242,357 | | | 8 | 60 | | |
| 68 | 28 | 5 | 11 | 75,586 | 69 | 0.6 | 9 | 8 | 76 |
| 69 | 50 | | | | | | | | |

| Area Name : Undur Tsahir b-LINE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m) | R4 (ohm-m | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 27 | 15 | 94 | 173 | 78 | 251 | 0.5 | 13 | 36 | 222 |
| 57 | 44 | 91 | 412 | 174 | | 7 | 12 | 70 | |
| 58 | 33 | 3 | 20 | | | 1 | 1 | | |
| 30 | 21 | 38 | 208 | 13,679 | | 5 | 35 | 201 | |
| 59 | 113 | 14 | 1,974 | 451 | | 2 | 19 | 4 | |
| 32 | 1,027 | 16 | 514 | | | 0.5 | 24 | | |
| 60 | 786 | 16 | 24,938 | | | 2 | 39 | | |
| 61 | 90 | 42 | 8 | 11,244 | | 1 | 11 | 25 | |
| 62 | 52 | 44 | 6 | 1,721 | 10,173 | 1 | 13 | 18 | 31 |
| 63 | 14 | 2 | 545 | 68,305 | | 2 | 11 | 10 | |

# Table 4.4 List of Estimated Resistivity Structure (2/4)

| Area Name : Undur Tsahir c-Line | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m) | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 27 | 15 | 94 | 173 | 78 | 251 | 0.5 | 13 | 36 | 222 |
| 56 | 951 | 80 | 361 | 9 | | 2 | 14 | 138 | |
| 28 | 10 | 82 | 248 | 267 | | 2 | 19 | 36 | |
| 55 | 4 | 32 | 25 | 196,880 | | 0.1 | 22 | 19 | |
| 31 | 7 | 44 | 4 | 63,240 | | 0.6 | 7 | 6 | |
| 54 | 16 | 144 | 752 | 267 | 927 | 0.9 | 7 | 3 | 301 |

| Area Name : Undur Tsahir | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m) | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 33 | 41 | 99 | 14 | 898,365 | 11 | 2 | 19 | 20 | 456 |
| 34 | 139 | 58 | 14,741 | 54 | 3,249 | 10 | 8 | 4 | 42 |
| 35 | 18 | 48 | 154 | 296 | 22,874 | 2 | 18 | 2 | 232 |
| 36 | 431 | 35 | 431 | | | 6 | 30 | | |
| 37 | 694 | 10 | 137 | 29,439 | | 4 | 3 | 88 | |
| 38 | 342 | 44 | 6,570 | 538 | | 3 | 2 | 3 | 12 |

## Table 4.4 List of Estimated Resistivity Structure (3/4)

| Area Name : Undur Tsahir d-Line | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m) | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 12 | 188 | 2,718 | 1,004 | 14,789 | | 1 | 4 | 297 | |
| 13 | 60 | 707 | 1,892 | | | 0.4 | 353 | | |
| 11 | 134 | 803 | 645 | 546 | | 1 | 2 | 87 | |
| 9 | 22 | 198 | 1,177 | 148,376 | | 0.9 | 26 | 220 | |
| 8 | 36 | 614 | 311 | 24,717 | | 2 | 38 | 180 | |
| 6 | 37 | 292 | 1,028 | | | 2 | 64 | | |
| 5 | 522 | 127 | 5,198 | 320 | | 0.7 | 21 | 23 | |
| 2 | 16 | 3,009 | 53 | 962 | | 0.5 | 3 | 4 | |
| 7 | 330 | 1,869 | 82 | 263 | | 6 | 2 | 2 | |
| 3 | 1,660 | 34 | 192 | | | 0.7 | 0.5 | | |
| 4 | 78 | 948 | 318 | | | 0.8 | 0.7 | 240 | |
| 10 | 47 | 288 | 23,108 | | | 3 | 261 | | |

| Area Name : Undur Tsahir e-LINE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m) | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 42 | 392 | 280 | 370 | | | 3 | 33 | | |
| 41 | 67 | 2,157 | 90 | 310 | | 6 | 2 | 157 | |
| 40 | 237 | 560 | 104 | 277 | | 6 | 5 | 101 | |
| 23 | 155 | 15 | 388 | 49 | 163 | 2 | 1 | 5 | 57 |
| 18 | 68 | 331 | 53 | 135 | 44 | 0.3 | 13 | 29 | 158 |
| 17 | 36 | 57 | 125 | 8 | | 3 | 10 | 106 | |
| 16 | 442 | 167 | 356 | 119 | | 0.8 | 13 | 71 | |
| 15 | 116 | 369 | 1,659 | 152 | | 2 | 20 | 11 | |
| 14 | 32 | 1,184 | 230 | 2 | | 0.4 | 9 | 33 | |
| 1 | 17 | 3,259 | 14 | | | 0.7 | 4 | | |
| 39 | 197 | 835 | 15,394 | 218 | 20 | 2 | 10 | 3 | 14 |

# Table 4.4 List of Estimated Resistivity Structure (4/4)

| Area Name : Kharzat | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 19 | 233 | 183 | 372 | 30 | | 0.5 | 7 | 46 | |
| 20 | 28 | 9,662 | 322 | | | 1 | 4 | | |
| 21 | 88 | 182 | 21 | 67 | | 5 | 18 | 29 | |
| 22 | 17 | 481 | 35 | 115 | 245 | 2 | 3 | 7 | 206 |
| 24 | 21 | 79 | 335 | 77 | | 1 | 9 | 6 | |

| Area Name : Olon nuur f-Line | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.No. | R1 (ohm-m | R2 (ohm-m | R3 (ohm-m | R4 (ohm-m | R5 (ohm-m | T1 (m) | T2 (m) | T3 (m) | T4 (m) |
| 53 | 351 | 157 | 400 | 151 | | 6 | 1 | 24 | |
| 52 | 177 | 65 | 207 | 93 | 319 | 5 | 5 | 26 | 146 |
| 51 | 29 | 252 | 98 | | | 4 | 37 | | |
| 50 | 27 | 183 | 265 | 51 | 140 | 3 | 0.8 | 52 | 160 |
| 49 | 115 | 44 | 104 | 689 | 43 | 2 | 3 | 19 | 20 |
| 48 | 40 | 251 | 241 | 40 | | 4 | 0.5 | 67 | |
| 47 | 50 | 196 | 114 | 36 | | 5 | 37 | 31 | |
| 46 | 17 | 266 | 39 | | | 0.6 | 42 | | |
| 45 | 18 | 70 | 197 | 27 | | 2 | 5 | 21 | |
| 44 | 115 | 3 | 23 | 443 | | 5 | 2 | 142 | |
| 43 | 5,096 | 18 | 528 | 66 | 176 | 0.6 | 2 | 5 | 25 |

# Table 4.5 Field Strength of VLF Signal

Measured at in Front of the Altay State Capitol
(Latitude: 46 deg. 22.46 min., Longitude: 96 deg. 15.25 min.)

| Frequency (kHz) | Code | Field Strength (June 22, '97) | | Field Strength( June 23, '97) | |
|---|---|---|---|---|---|
| | | Horizontal(μA/m) | Vertical(μA/m) | Horizontal(μA/m) | Vertical(μA/m) |
| 15.100 | FUO | 1.00 | 1.38 | 0.57 | 1.69 |
| 15.975 | GBR | 3.05 | 1.20 | 0.64 | 1.46 |
| 16.000 | GBR | 3.40 | 1.15 | 0.12 | 0.97 |
| 16.400 | JXZ | 4.94 | 1.09 | 0.09 | 1.13 |
| 16.800 | FUB | 1.00 | 2.96 | 0.44 | 0.82 |
| 17.000 | ROR | 0.75 | 0.69 | 0.17 | 0.37 |
| 17.100 | UMS | 1.33 | 0.79 | 0.34 | 0.90 |
| 17.400 | NDT | 0.21 | 0.68 | 0.36 | 0.68 |
| 18.300 | FUX | 0.33 | 1.62 | 4.33 | 9.91 |
| 19.000 | GQD | 1.16 | 1.45 | 1.53 | 3.19 |
| 19.025 | GQD | 0.54 | 1.80 | 1.09 | 3.03 |
| 19.200 | SOA51 | 3.69 | 2.73 | 0.10 | 2.26 |
| 19.575 | GBZ | 0.07 | 0.64 | 0.01 | 1.08 |
| 19.600 | GBZ | 0.08 | 0.75 | 0.53 | 0.95 |
| 20.270 | ICU | 0.61 | 0.55 | - | - |
| 20.760 | IDR | 0.14 | 0.92 | 0.04 | 0.80 |
| 21.400 | NSS | 0.36 | 0.62 | 0.06 | 0.78 |
| 22.300 | NWC | 0.20 | 1.38 | 0.81 | 1.02 |
| 23.400 | NPM | 1.68 | 2.80 | 0.65 | 1.94 |
| 23.600 | LPZ | 2.51 | 3.59 | 0.32 | 1.35 |
| 24.000 | NAA | 0.46 | 0.73 | 0.22 | 1.07 |
| 24.800 | NLK | 0.07 | 0.87 | 0.38 | 0.84 |
| 28.500 | NAU | 0.04 | 0.79 | 0.71 | 1.71 |
| | | | | | |
| 22.200 | | | (June 24, '97) | 5.61 | 2.35 |
| | | | | | |

# Table 4.6 VLF Survey Specification

VLF Survey in Altai City, MONGOLIA

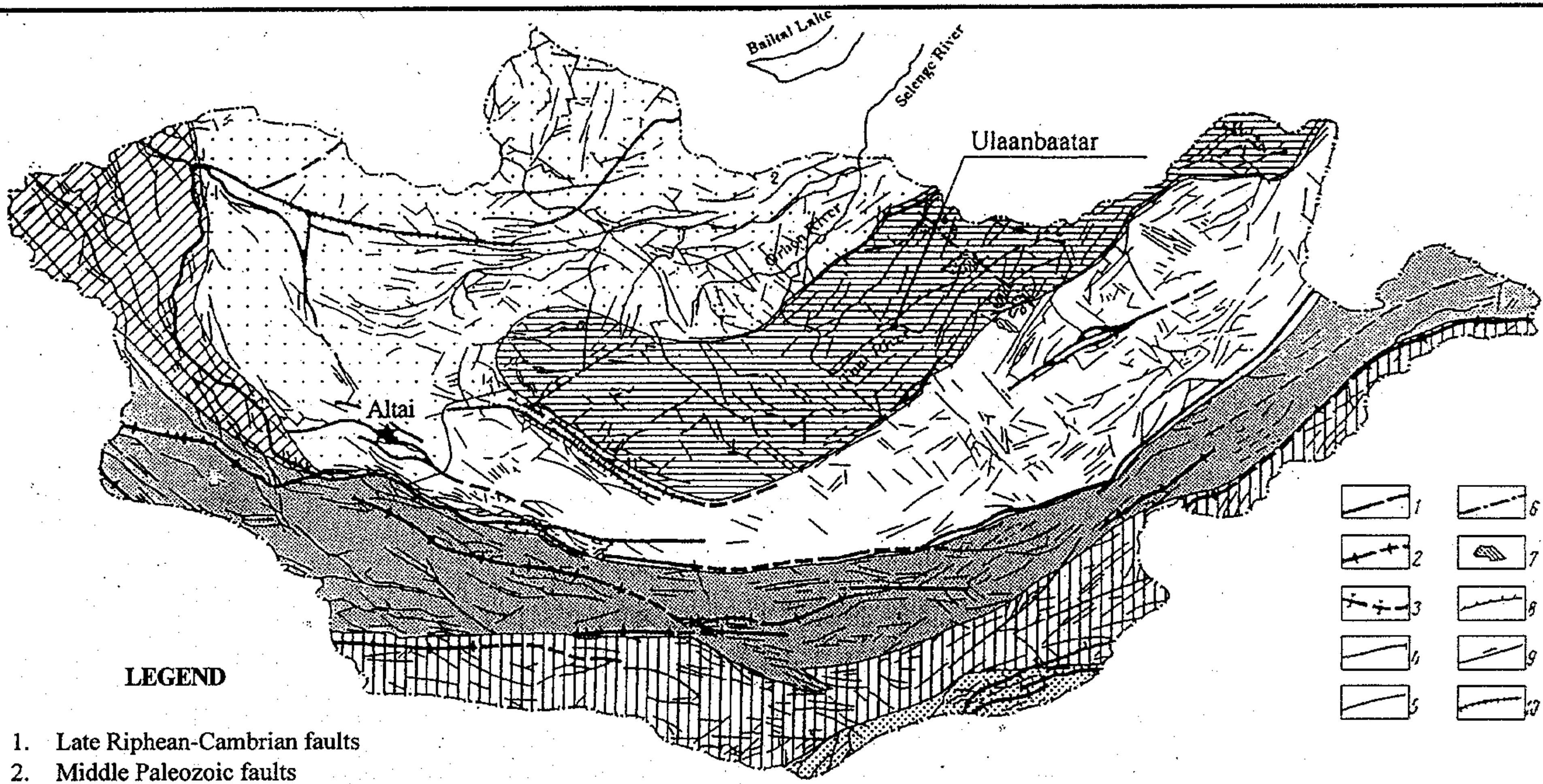
| | |
|---|---|
| Total line length | 20,230 meters |
| Total number of stations | 2,053 points |

| Line Numbe | Base station Number | Base Station(min. & sec.) Longitude(46deg) | Latitude(96deg) | Base Station (min..) Longitude(46deg. | Latitude(96deg.) | line bearings (deg) | line length (meters) |
|---|---|---|---|---|---|---|---|
| State Capitol | | 22.15 | 15.08 | 22.25 | 15.13 | | |
| Old Meteorological Observatory | | 19.05 | 10.16 | 19.08 | 10.27 | | |
| | | | | | | | |
| | | | | | | | |
| 1 | 0 | 19.54 | 11.17 | 19.90 | 11.28 | 225 | 690 |
| 2 | 0 | 20.28 | 10.18 | 20.47 | 10.30 | 225 | 400 |
| 3 | 0 | 19.27 | 12.04 | 19.45 | 12.07 | 225 | 690 |
| 4 | 200 | 18.60 | 12.52 | 19.00 | 12.87 | 225 | 500 |
| 5 | 0 | 19.08 | 13.34 | 19.13 | 13.57 | 225 | 800 |
| 6 | 0 | 18.30 | 14.16 | 18.50 | 14.27 | 225 | 300 |
| 7 | 0 | 23.04 | 16.17 | 23.07 | 16.28 | 135 | 500 |
| 8 | 0 | 23.30 | 16.33 | 23.51 | 16.56 | 135 | 500 |
| 9 | 0 | 23.17 | 16.50 | 23.29 | 16.83 | 135 | 500 |
| 10 | 0 | 23.12 | 15.44 | 23.21 | 15.73 | 135 | 640 |
| 11 | 0 | 23.04 | 15.36 | 23.07 | 15.59 | 135 | 1,000 |
| 12 | 0 | 24.52 | 19.09 | 24.87 | 19.15 | 225 | 1,700 |
| 13 | 0 | 24.46 | 19.42 | 24.76 | 19.70 | 225 | 2,200 |
| 14 | 0 | 22.35 | 14.59 | 22.59 | 14.99 | 315 | 700 |
| 15 | 0 | 22.34 | 14.40 | 22.56 | 14.66 | 315 | 1,100 |
| 16 | 0 | 22.26 | 14.23 | 22.43 | 14.38 | 315 | 670 |
| 17 | 0 | 23.02 | 14.05 | 23.04 | 14.09 | 225 | 540 |
| 18 | 0 | 24.03 | 12.09 | 24.05 | 12.15 | 225 | 490 |
| 19 | 0 | 24.03 | 12.09 | 24.05 | 12.15 | 315 | 490 |
| 20 | 0 | 24.22 | 11.35 | 24.36 | 11.58 | 315 | 790 |
| 21 | 0 | 22.31 | 14.31 | 22.51 | 14.52 | 315 | 1,300 |
| 22 | 0 | 22.44 | 14.27 | 22.74 | 14.45 | 45 | 360 |
| 23 | 0 | 25.24 | 11.46 | 25.40 | 11.76 | 45 | 500 |
| 24 | 0 | 25.24 | 11.46 | 25.40 | 11.76 | 0 | 300 |
| 25 | 0 | 25.24 | 11.46 | 25.40 | 11.76 | 135 | 300 |
| 26 | 0 | 24.22 | 11.35 | 24.37 | 11.59 | 90 | 400 |
| 27 | 0 | 25.06 | 11.54 | 25.10 | 11.90 | 0 | 300 |
| 28 | 0 | 26.58 | 20.02 | 26.96 | 20.04 | 225 | 600 |
| 29 | 0 | 24.24 | 15.14 | 24.41 | 15.24 | 0 | 500 |
| 30 | 0 | 23.00 | 14.17 | 23.00 | 14.28 | 225 | 470 |
| Total 30 | - | - | - | - | - | - | 20,230m |

# Table 4.7 Locations of Fractured Zones (Conductivity Anomalies), interpreted from VLF EM survey

| Line No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 m | 70 m | 125 m | 50 m | 180 m | 50 m | 220 m | 10 m | 70 m | -280 m | | 170 m | 510 m | -265 m | -560 m |
| Stations | 160 m | 200 m | 160 m | 110 m | 240 m | 60 m | | 85 m | 200 m | 120 m | | 230 m | 560 m | -240 m | -370 m |
| where | 370 m | 300 m | 600 m | 270 m | 540 m | 70 m | | 430 m | 310 m | 200 m | | 330 m | 570 m | -120 m | -235 m |
| Possible | 380 m | 400 m | 650 m | 330 m | 670 m | 240 m | | | 360 m | 310 m | | 420 m | 620 m | 90 m | -70 m |
| Fractures | 450 m | | | | | | | | 440 m | | | 630 m | 630 m | 170 m | -10 m |
| are. | | | | | | | | | | | | 890 m | 690 m | 280 m | 0 m |
| | | | | | | | | | | | | 970 m | 770 m | 350 m | 10 m |
| | | | | | | | | | | | | 1040 m | 1850 m | | 490 m |
| | | | | | | | | | | | | 1110 m | 1860 m | | |
| | | | | | | | | | | | | 1280 m | 2080 m | | |
| | | | | | | | | | | | | | 2170 m | | |

| Line No. | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -410 m | 160 m | 220 m | 70 m | 160 m | -960 m | -130 m | | | 270 m | 100 m | 0 | 200 m | 330 m | 20 m |
| | -235 m | 200 m | 230 m | 150 m | 180 m | -780 m | 40 m | | | | 110 m | 40 m | 260 m | | 30 m |
| Stations | -60 m | 260 m | 310 m | | 520 m | -760 m | 155 m | | | | 190 m | 160 m | 430 m | | 160 m |
| where | -10 m | 490 m | 340 m | | | -670 m | | | | | 260 m | | 590 m | | 170 m |
| Possible | 40 m | 540 m | 440 m | | | -570 m | | | | | | | | | 460 m |
| Fractures | 70 m | | | | | -245 m | | | | | | | | | |
| are. | 150 m | | | | | 0 | | | | | | | | | |




**LEGEND**

1. Late Riphean-Cambrian faults
2. Middle Paleozoic faults
3. Late Paleozoic faults
4. Regional faults
5. Other faults
6. Faults accompanied by stems of Mesozoic intrusions
7. Mesozoic granitoids within "intrusive rocks"
8. Thrust faults
9. Lateral faults
10. Faults accompanied by recent seismic activity

I Mongolian Altai Folded Zone
II North Mongolian Folded Zone
III Mongol Pre-baigalian Folded Zone
IV Central Mongolian Folded Zone
V. South Mongolian Folded Zone
VI. South Gobian Folded Zone
VII. Inner Mongolian Folded Zone

Figure 4.1 Geological Structure of Mongolia

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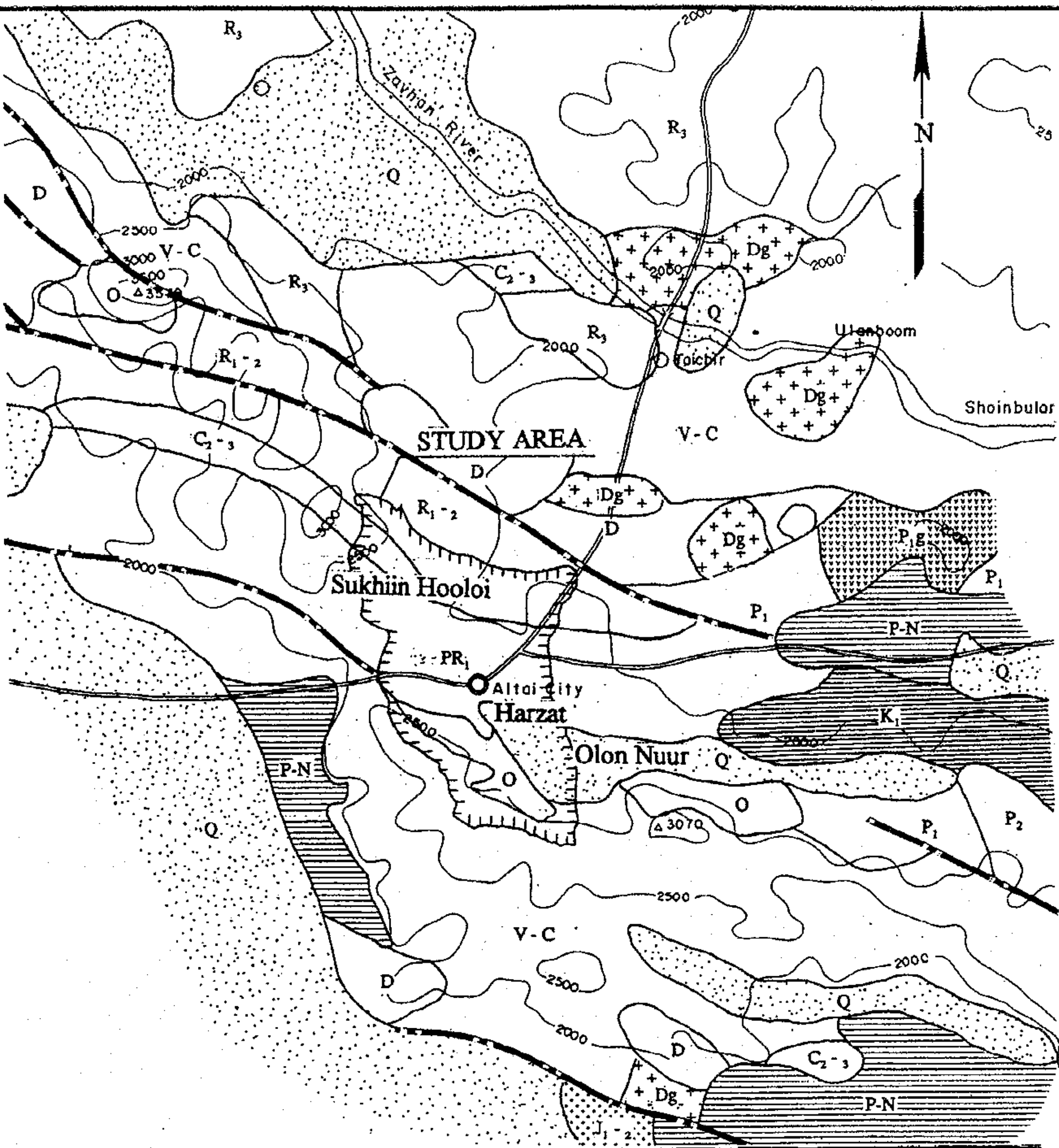


fault

| Era | period | symbol | | lithology |
|---|---|---|---|---|
| Cenozoic | Quaternar | Q | | clay, sand, gravel |
| | Tertiary | P-N | | siltstone, sandstone, conglomerate |
| Mesozoic | Cretaceou | K 1 | | siltstone, sandstone, conglomerate, shale |
| | Jurassic | J 1,2 | | sandstone, conglomerate, rhyoritic porphyry |
| Paleozoic | Permian | P 1,2 | | siltstone, sandstone, conglomerate |
| | Devonian | D | | sandstone, siltstone, rhyolitic porphyry |
| | Unknown | O | | gabbro |
| | Cambrian | C 2,3 | | slate, phylite, metasandstone, siltstone |
| Proterozoic | | V-C | | diabase, limestone, sandstone, phylite, shale |
| | | R 3 | | gneiss, schist, amphibolite |
| | | R 1,2 | | gneiss, schist, amphibolite |
| | | PR 1 | | gneiss, schist, amphibolite |
| Intrusive rocks | Permian | | | granite, adamerite |
| | Devonian | | | granite, granodiorite, adamerite |

| Figure 4.2 Geological Map of Altai City and Surrounding Area | |
|---|---|
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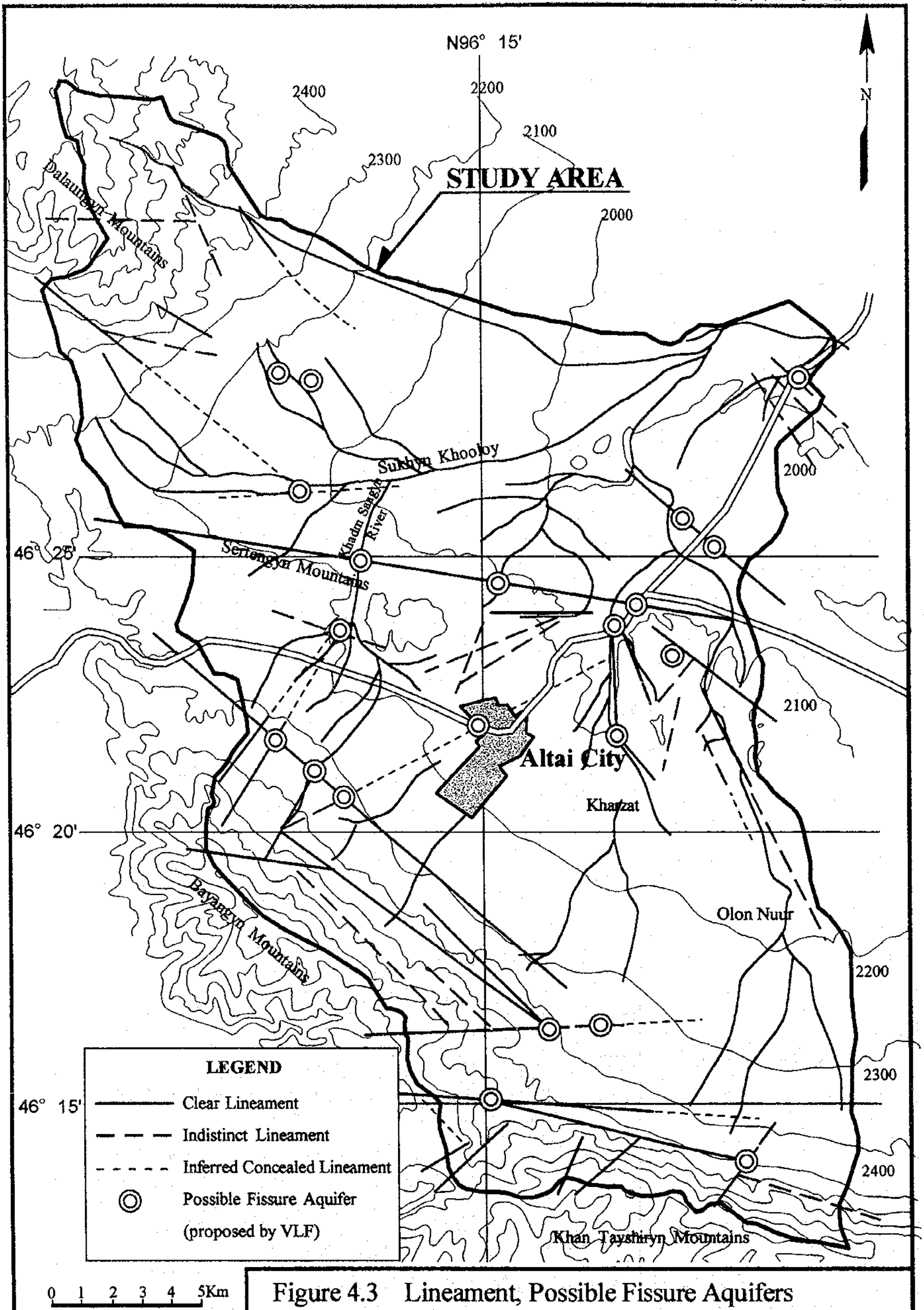



Figure 4.3 Lineament, Possible Fissure Aquifers

| JICA | The Study on Groundwater Development for Altai City |
|---|---|

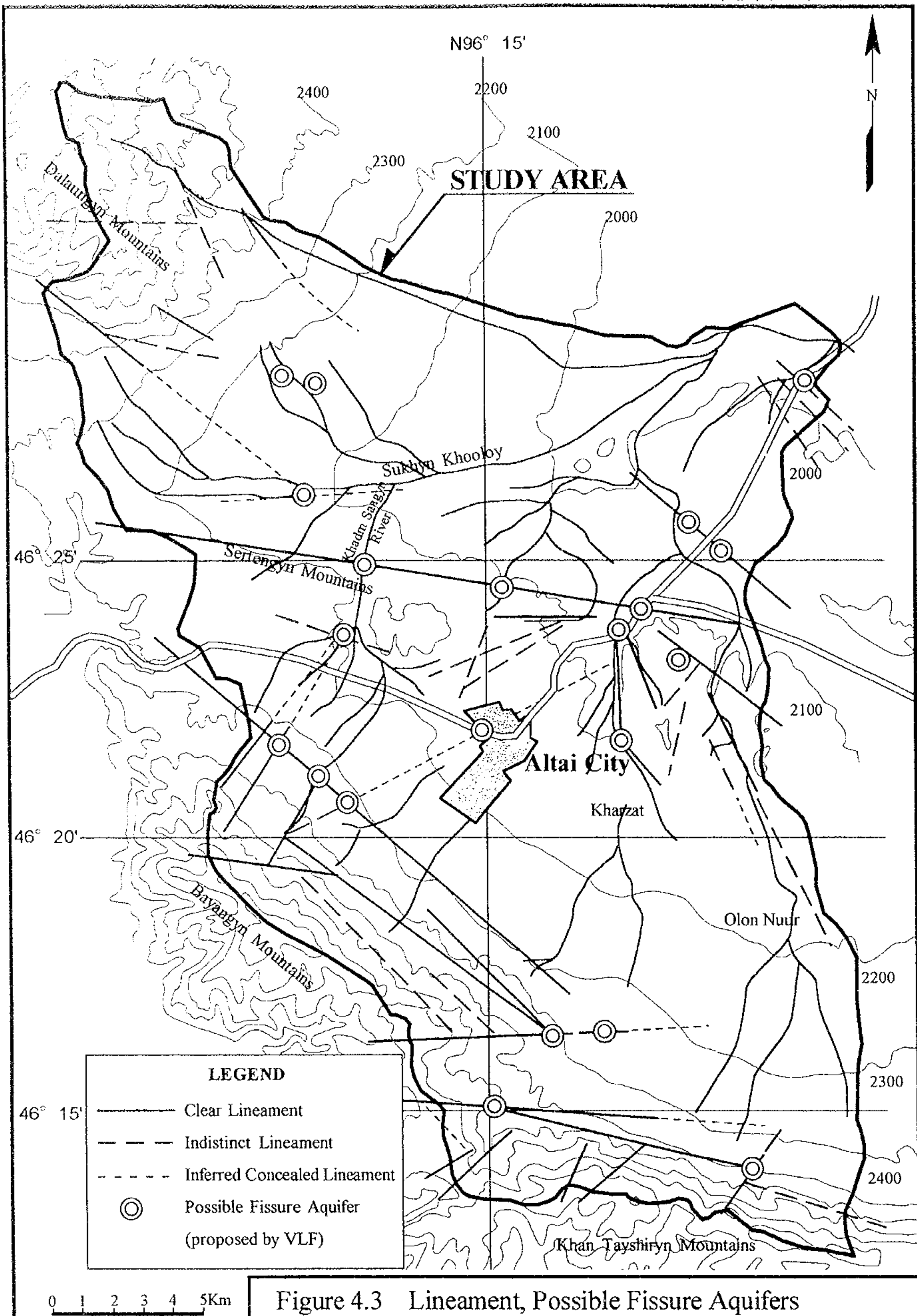
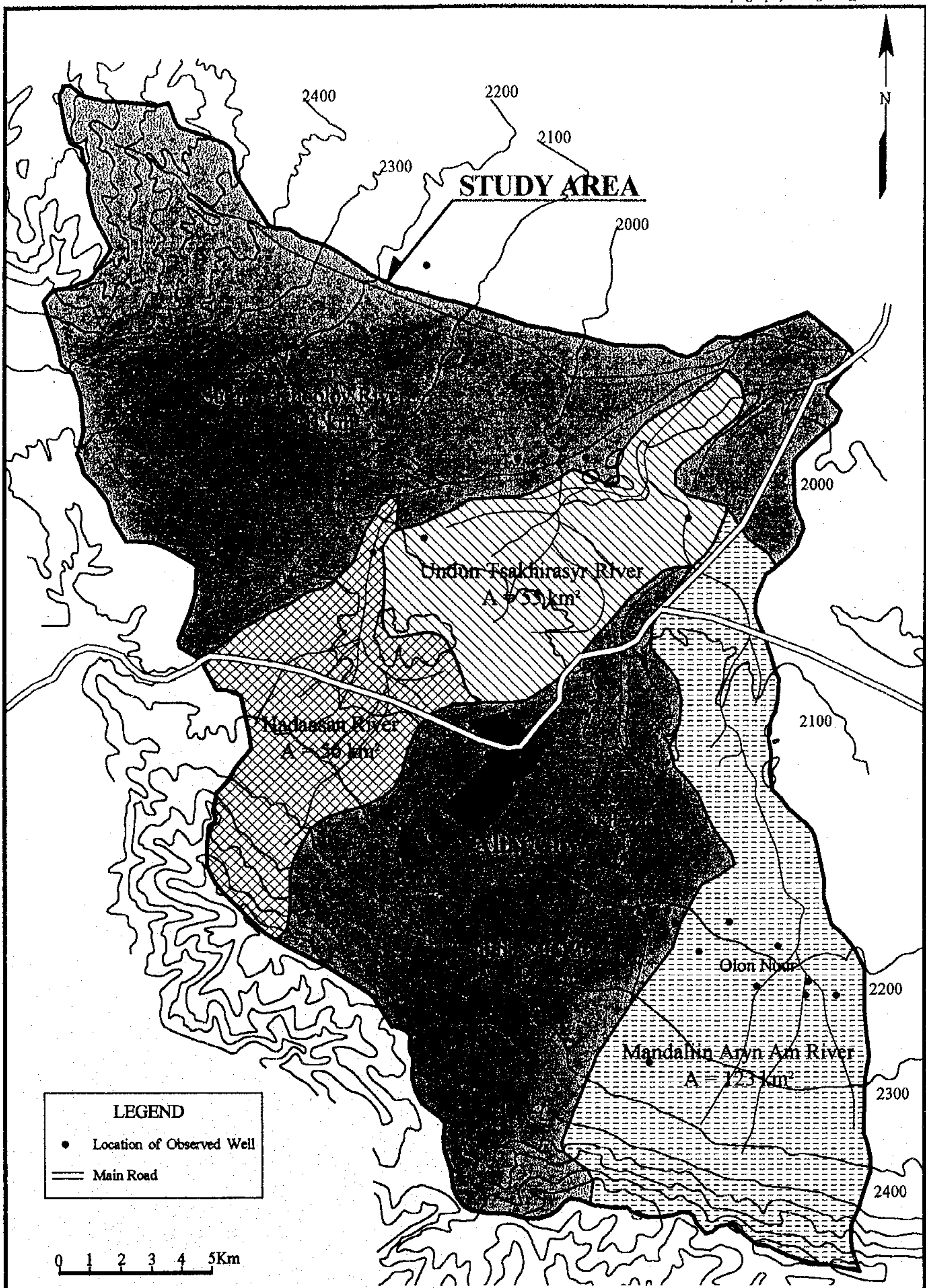



Figure 4.3 Lineament, Possible Fissure Aquifers

| JICA | The Study on Groundwater Development for Altai City |
|---|---|




| Figure 4.4 Division of Catchment Area | |
|---|---|
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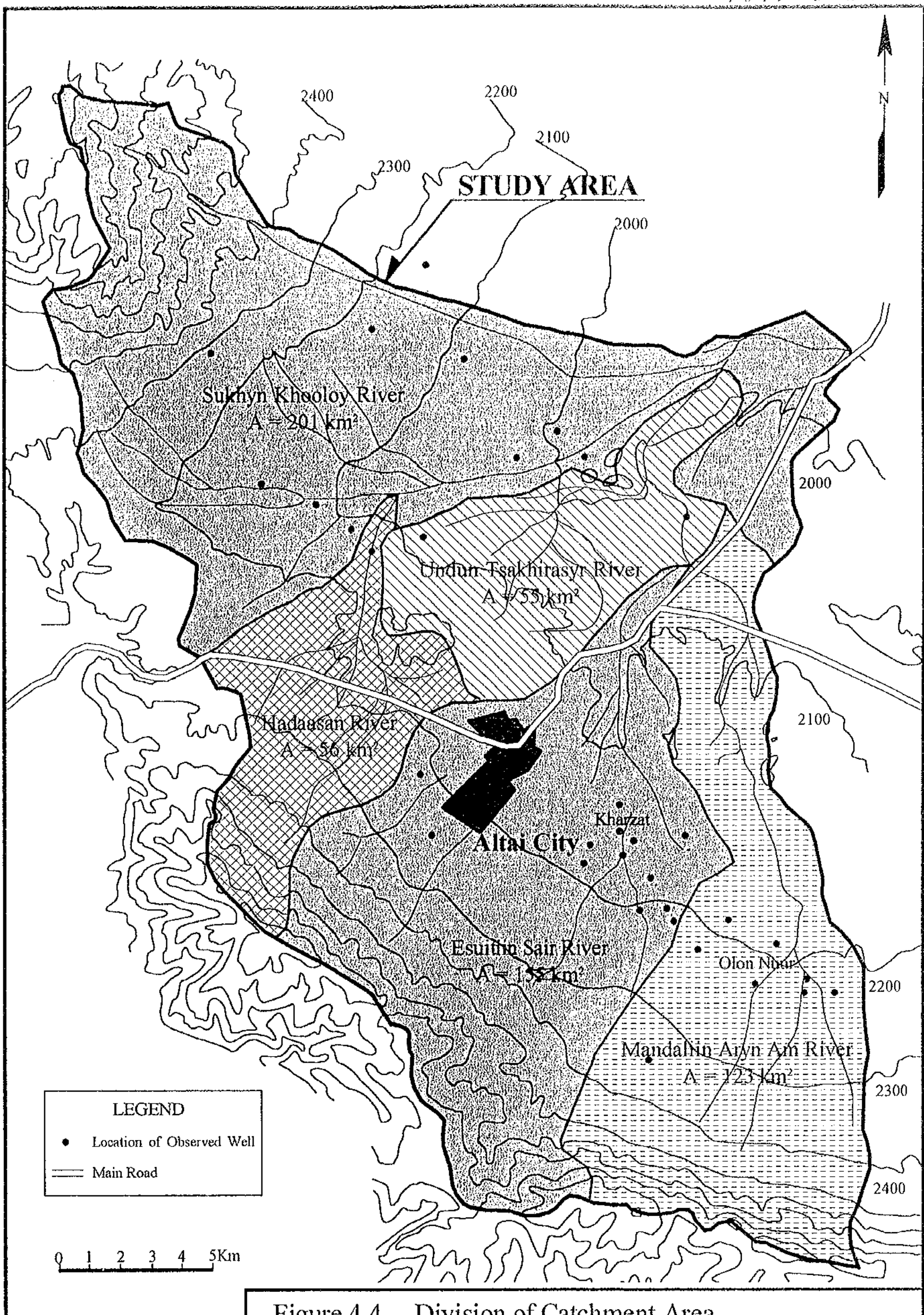


| Figure 4.4 Division of Catchment Area | |
|---|---|
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