CHAPTER 3 INVESTIGATION AND ANALYSIS

3.1 Land Use Analysis with Satellite Images

To survey the present land use, the JICA Study carried out the data processing to support to analyze the present land cover and distributions of wetland, and to support to interpret geography and geology in the study area, by data acquisition of LANDSAT 7 ETM as shown in Table-3.1.

Table-3.1 List of data acquisition of satellite data

Path – Row:	SCENEID:	Date of data acquisition:
8 – 56	No. 2000724634	February 4, 2000
8 – 57	No. 2000431753	November 16, 1999

Based on the image data processing, the following maps were produced in the study area: Color composite image in Figure-3.1 and land cover map in Figure-3.2 with double checking between pre-data-processing of classification of and the sampling survey of land cover in the field. The following distribution of land cover was recognized according to the histogram and area of each land cover use unit in Table-3.2:

The distribution of forest area over 3,000 meter; increase of forest area to the north from Bogotá; wet land in Bogotá plain from 2,400 meter to 2,900 meter; cultivation land and grassland on gentle slope and on flood plain along Bogotá river; increase of grassland due to high elevation and relief; bare land, erosion and land slide in the north; the north east and the south, reservoir site in the north east of Bogotá; small lagoon and lake in the south west of Bogotá; and distribution of green house.

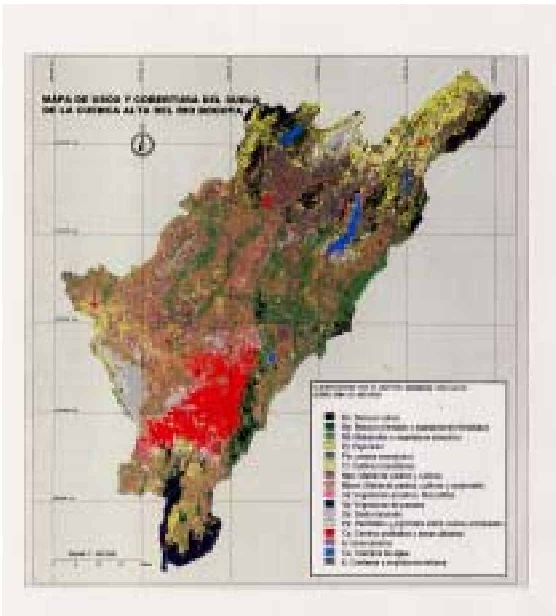

Figure-3.2 Land cover map in the study area

Figure-3.1 LANDSAT-7 Color Composite Images of the Whole Study Area.

Table-3.2 Land Use Areas of the Study Area

Classif. 1	Classification 2	Area (km^2)	(%)	Classif. 1	Classification 2	Area (km^2)	(%)
Forest	Natural forest	181.19	4.2	Cultivated land	Temporal crops	39.48	0.9
	Afforested area	17.25	0.4		Grass/crops mixed	551.96	12.9
	<Total>	***198.44***	***4.6***		Gras/crops/shrub mixed	1126.79	26.4
Grass	Weeds or Shrub/bush	644.20	15.1		***<Total>***	***1718.23***	***40.3***
	High grass	415.83	9.7	Bare land	Bare land	245.59	5.8
	Grass	137.02	3.2		Mining/ stone quarry	0.35	0.01
	Aquatic vegetation	6.48	0.2		***<Total>***	***245.94***	***5.8***
	Moor vegetation	303.23	7.1	Water	lakes/marshes, rivers	***39.61***	***0.9***
	Pasture/high grass bare land	188.06	4.4	Residential	Urban or densely populated	***300.16***	***7.0***
	<Total>	***1694.82***	***39.7***	Greenhouse	Floriculture	***71.49***	***1.7***
Total Areas of the Study Area: 4268.69km^2							

3.2 Environmental Field Survey

(1) Water Environment of Bogotá River

<Usage of Bogotá River>

Bogotá River originates in the western side of Villapinzon, Cundimarca Department (3,300 m above sea level). The river flows 130 km from the northeast to the southwest through flat Bogotá plain (water course gradient: 1/1,000) and reaches at the Tequendama waterfall (more precisely, water power generation plant of EMGESA: 1,000 MW), the lowest downstream of the river in the plain. Ultimately, the water body joins into the Magdalena River after running 80 km outside the area. Bogotá River is composed of several tributaries *i.e*. Sisga, Tomine, Neusa, Teusaca, Frio, Chicu, Subachoque, Tunjuelito and Muna Rivers (in the order from the upstream). Furthermore, there are two urban streams namely Salitre and Fucha Rivers in Bogotá City.

Each 4 tributaries in the upper stream have large size water reservoir type dams i.e. Sisga Dam (CAR, 102 million m^3, irrigation and water supply), Tomine Dam (EEEB, 690 mil m^3, power generation, water supply and flood control), Neusa Dam (CAR, 100 million m^3, irrigation and water supply) and San Rafael Dam (EAAB, 750 million m^3, water supply).

The average runoff of the river is 36.69 m^3/s in accordance to the result of water balance analysis (based on runoff observation and water usage data between 1973-1999). Around 11.10 m^3/s and 5.10 m^3/s of the water are taken up for the purposes of irrigation, including industrial use and water supply, respectively. A representative facility is Tibitoc water treatment plant, which locates at the upper stream of the junction with Teusaca River and the plant takes water from Bogotá River. The amount of sewer water returning to the river is estimated at 10.24 m^3/s. This includes 6.16 m^3/s of sewer water from outside the area (mainly introduced from Chingaza Dam). Although the detail is not clear, it is assumed a large quantity of agricultural sewer water flows into the rivers. This water mass balance is the average of the past 27 years. According to latest data, it is estimated the amount of water taken from the rivers and sewer water (majority is untreated) reaches at approximately 7 m^3/s and 12 m^3/s, respectively. This indicates 40 percent of the volume of the river flow (approximately 31 m^3/s) is the sewer water from urban areas at the edge of the bottom stream.

The above confirms Bogotá River has important role in the aspect not least as drainage course of floodwater and water resources for irrigation, industry and urban use, but also as the watercourse of sewer water. In response to this, the water purification plants locate in the upper streams of Bogotá River (Tibitoc water purification plant) and Tributaries (Vitelma water purification plant in San Cristobal River, San Diego water purification plant in Sand Francisco River and Laguna and El Dorado water purification plants in Tunjueto River)

<Water Quality of Bogotá River>

It is appropriate to focus on several aspects as follows when the water quality of Bogotá River is argued with considering the current usage.

(i) Is it safe water as source for water supply?
(ii) Does the river have a good quality of water although it flows through urban area?
(iii) Does the contaminated river influence on the contamination of groundwater?

For examining these questions, river water and bottom sediment at 26 and 12 locations, respectively, were sampled and contamination in water and sediment quality was examined. The following is the summary of the result. The influence of surface water contamination on groundwater is referred to the result of “Water Quality Test for Well” discussed in the later section.

160 small scale leather factories in the Villapinzon area are the main cause of pollution in the upper stream of Bogotá River above Tibitoc water purification plant. The wastewater contains organic wastes, chromium, sulfuric compounds, tannin, *etc*. Copper and chromium were detected in the bottom sediments in this section. There is no sign of agricultural contamination and the river satisfies the raw water quality standard for drinking purpose. Furthermore, there is no substance exceeding the standard in the result of 9 months water quality test at the stream. Although iron and manganese exceed the standard values, it is far less than the concentrations of the substances in groundwater.

When Bogotá River reaches in Bogotá City, urban rivers such as Salitre, Fucha and Tunjuelito Rivers, which contains a mass quantity of house and industrial wastewater, joins in on after another. The river water starts to reduce dissolved oxygen and shows anoxic condition. Although a sewage treatment plant on Salitre River start to operate, the other rivers have not equipped sewage treatment plant yet.

There is no evidence that contaminated surface water deteriorates groundwater. It is hypothesized that silt and colloid materials in river water has accumulated on the riverbed over years due to gentle slope angle of the floor and slow flow. This might have lead to creation of impermeable layer on the riverbed.

The characteristic of the groundwater in Bogotá Plain is high concentrations of hydrogen sulfide and ammonia-nitrate observed in broad area. This is a very rare case as deep groundwater. These substances are suspected to originate from the surface activity (fertilizer, domestic wastewater, cattle, industrial wastewater, *etc*.). However, the accumulated amount of ammonia and hydrogen sulfide in groundwater is much higher than the one from surface activity. Therefore, it is understood that these substances yielded by the natural geological conditions. It is thought that hydrogen sulfide is stemmed from pyrite and volcanic ash, which are richly contained in Tertiary layer. On the other hand, ammonia is considered to originate in organic materials, which had been accumulated in the process of forming Bogotá Plain (*i.e*. lake sediments).

<Wetlands>

There used to be 50,000 ha of wetlands in Bogotá Plain. However, there are currently solely 700 ha and 800 ha of wetland left in the western and eastern side, respectively. These wetlands are back marsh, formed after flood. The area of the wetland has diminished in recent years because dams, constructed in the area, for flood control, and river water table has decreased due to increase of intake volume of the water for irrigation and water supply. These wetlands have not been registered in the Ramsal Treaty.

It has been confirmed that 53 avian and vertebrates presently live in the wetlands. There are 12 wetlands (such as Conejera, Cordoba, Juan Amarillo, Jaboque) in Bogotá City. However, the water quality has been drastically deteriorating due to development of urban area, inflow of urban sewage water, illegal waste dumping and eutrophication caused by organic materials. The effects on the ecosystem are greatly anxious matters.

EAAB, DAMA and CAR has involved in managing and improving projects of the wetlands in accordance to an environmental management plan (based on the agreement in the Ramsal conference and the DAMA's and CAR's guideline). Positive conservation measure plan for protecting valuable wetlands is expected.

<Improvement of Water Environment>
Deterioration of water quality in Bogotá River arises from low rate of industrial and domestic wastewater treatment. Industrial wastewater treatment should be enhanced by administrative guidance. The rate of wastewater treatment is low in Bogotá City. Three wastewater treatment plants have been planned whereas there is solely one treatment plant, Salitre, completed its construction.

On the other hand, one of the causes contributing deterioration of the water quality attributes to the decrease of the river water table. It should be considered for improving the water quality to permanently increase the water volume of Bogotá River. For instance, reduction of uptake river water at Tibitoc water purification plant (alternatively groundwater can be utilized for water supply purpose) and introduction of extra water for improving quality by dilution from other basins via Chingaza System are promised plans.

(2) Groundwater and Land Subsidence

<Use of Groundwater>
There are approximately 7,000 deep wells in Bogotá Plain and the usage rate of the groundwater is at 3.7 m^3/s. A large portion of it is used in agricultural and industrial purposes although groundwater is also utilized for urban water supply in some cities (approximately 0.2 m^3/s in Funza and Facatativa). According to well inventory survey in this study, the main aquifer of deep wells belongs to Quaternary layer. It amounts to 93 percent in the total number of deep well and 78 percent of the total pumped-up volume. Cretaceous layer is also promising aquifer, but this layer has not been fully utilized (5 percent in the total number of well and 20 percent in the total pumped-up volume).

Groundwater is highly used in the following basins: Bogotá (downstream), Bogotá (middle reach), Bojaca, Subachoque, Chicu and Frio Basins. Among them, usage rate of groundwater is especially high in Chicu Basin.

<Over Pumping-up of Groundwater and Land Subsidence>
Land subsidence has been frequently described in relation with over extraction of groundwater in the plain. However, the examples of subsidence in Bogotá Plain are (i) wave-shaped crack on concrete road, (ii) crack on walls and floors in houses and buildings possibly due to disparity subsidence and (iii) local subsidence near eucalyptus in parks and other urban areas. These phenomena do not have any relationship with over pumping-up of groundwater and consolidate subsidence, which occurs in a great depth has not been observed. It is unlikely that land subsidence owing to groundwater extraction would occur since the water balance in Bogotá Plain is stable. However, it is necessary to observe land subsidence in the area where groundwater is highly ustilized.

3.3 Geophysical Exploration

The purpose of the geophysical survey is as follows;

- To know Aquifer structure of the Study Area
- To know the depth of the distribution of Cretaceous aquifers

(1) Method of Geophysical Exploration and Observation Site

In this Study, CSAMT method was employed for the geophysical survey. Fourteen frequencies shown below were used to detect the geological structure up to 1,000 - 1,500m in depth.

Frequencies to be used in the CSAMT (Hz);	5120,	2560,	1280,	640,	320,	160,	80,	40,
	20,	10,	5,	2.5,	1.25,	0.625		

Observation points of CSAMT survey are shown in Figure-3.3.

(2) Result of CSAMT Exploration

(a) Result for Analysis

In interpretation of the CSAMT exploration results, the criteria below are applied;

- Electric resistivity of Quaternary is less than 30 Ωm
- Electric resistivity of Tertiary is less than 50Ωm
- Electric resistivity of Cretaceous is more than 50Ωm

A area (No.1, 3, 4)

Guadalupe Group distributes at least deeper than GL-1,200m.

B area (No. 2, 5)

Guadalupe Group distributes at least deeper than GL-1,000m.

C area (No.14, 15)

Guadalupe Group distributes continuously from GL-100m to deeper than GL-1,000m.

D area (No.6, 7, 8, 9)

Guadalupe Group distributes from near the ground surface (0 to GL-200m).

E area (No.10, 11, 12, 13)

Guadalupe Group distributes from deeper than GL-200m.

F area (No.20, 21, 22)

Guadalupe Group distributes deeper than GL-250m with thickness of more than 1,000m.

G area (No.16,17,18,19,)

Tilata Formation distributes from GL-100 to GL-400m. Guadalupe Formation underlies Tilata Formation.

H area (No.23, 24, 25, 26)

Guadalupe Formation distributes deeper than GL-100m.

I area (No.28, 29, 30, 31)

Guadalupe Formation distributes deeper than GL-400m.

(b) Conclusion of CSAMT Survey

According to the CSAMT results, the top of Guadalupe Group distributes at least deeper than GL-1,000m or GL-1200m in the center of Bogotá Plain. Then the top of Guadalupe Group distributes gradually nearer to the ground surface toward the border of the Study Area. This result corresponds to result of the existing study.

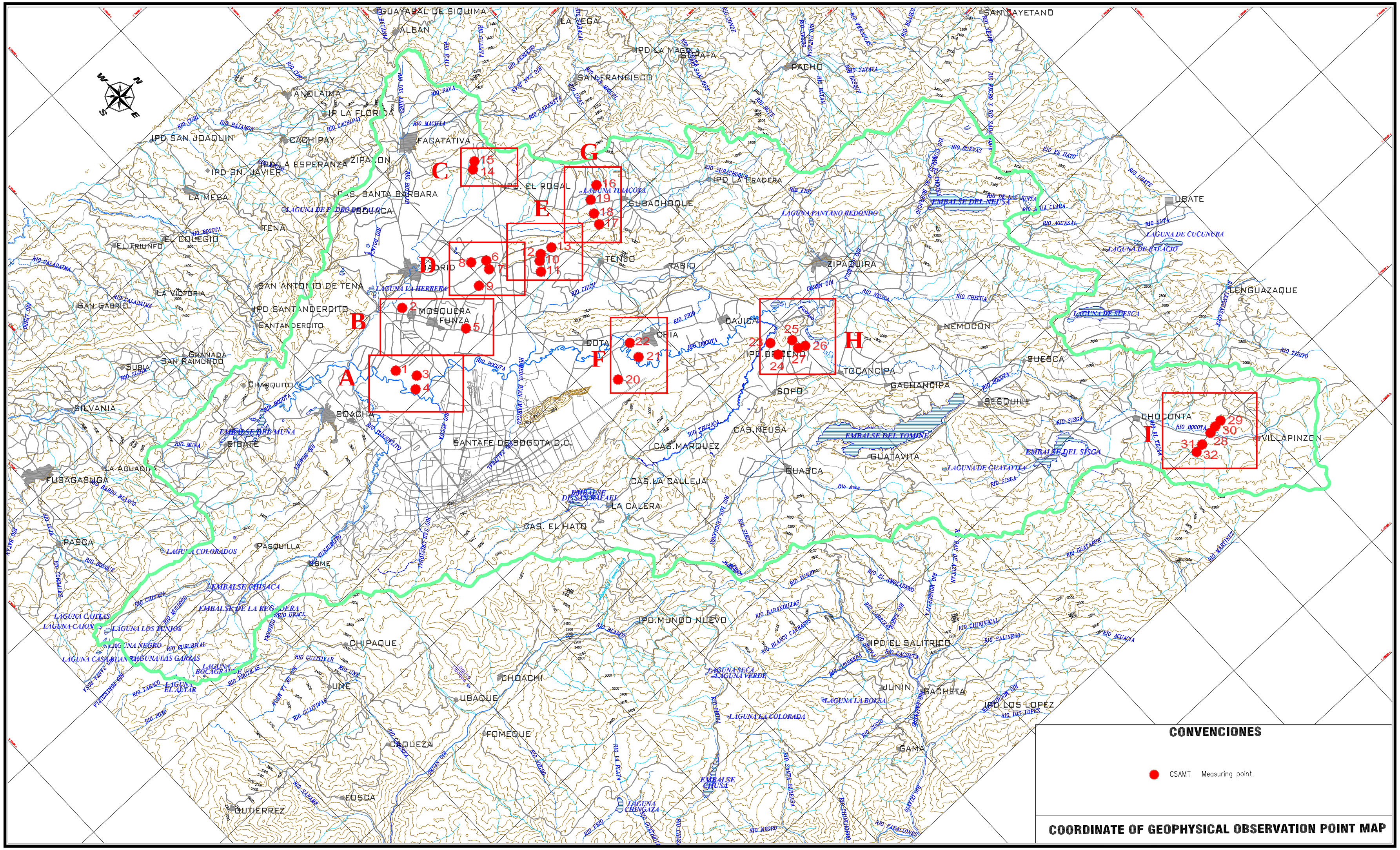

Figure-3.3 Site of CSAMT Exploration