CHAPTER 4 INVESTIGATION AND ANALYSIS

4.1 Land Use Analysis with Satellite Images

The JICA Study used satellite images to monitor the present land use. Satellite image can detect characteristics of land cover on the surface with the multi spectral sensors on satellite. Database, produced from satellite images, consists of color composite maps, land cover maps and a preparatory map for topography and geology. Especially, the extraction of wetland distribution was taken account with the use of satellite image data since natural resources with precious ecosystem exist in the study area.

1) Data Acquisition of Satellite Image and Collection of Related Information

To acquire the latest satellite images for the purpose of the monitoring land cover in the study area, available images in the EOS Data Center (USA) were looked up for selection through its internet web page. Data of LANDSAT 7 were mainly searched together with LANDSAT 3 and 5. The data from LANDSAT 7 was mostly searched due to the provision of high resolution sensor with its extreme precise. LANDSAT-7 satellite was launched on April 1999 and carries the enhanced thematic mapper plus (ETM+) sensor as shown in Table-4.1.

Table-4.1 Spectral Bandwidth of Landsat 7

TM AND ETM+ SPECTRAL BANDWIDTHS								
Bandwidth (µ) Full Width - Half Maximum								
Sensor	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8
TM	0.45 - 0.52	0.52 - 0.60	0.63 - 0.69	0.76 - 0.90	1.55 – 1.75	10.4 - 12.5	2.08 - 2.35	N/A
ETM+	0.45 - 0.52	0.53 - 0.61	0.63 - 0.69	0.78 - 0.90	1.55 – 1.75	10.4 - 12.5	2.09 - 2.35	.52 - .90

From the search, two scenes of LANDSAT 7 quick look images were found necessary to cover the all study area and thus selected. The images are seen in Table-4.2;

Table-4.2 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

2) Software and Method of Analysis

For preprocessing of image data and land cover classification, the software, ERDAS, was used. A supervised classification method was adopted for classification of land cover image. Besides, a number of objects were surveyed by using GPS to attain accurate position for the image classification of the field sampling. This helped to improve a precision of the image classification. For this analysis, the software, IRWIS, was also used as well.

3) Images Analysis and Compilation of Present Land Cover Map

With the mosaic processing of two satellite image data, color composite images were produced for the whole study area and the urban area of Bogotá D.C. as shown in Figure-4.1 and Figure-4.2, respectively. Land use map was compiled as shown in Figure-4.3 through images classification by the method previously mentioned. Land use areas classification of the whole study area was shown in Table-4.3. Land use areas classification by river basin was shown in Figure-4.3. Results of these analyses were compiled as follows;

- Forest areas including natural and plantation are mainly distributed around the Bogotá Plain at more than 3000 meters height.
- Forest area in the northern part of Bogotá Plain is still remaining relatively comparing with another area of Bogota Plain.

- Cultivated land and grassland are mainly distributed at the swamp area and the flood plain along Bogotá River and its tributaries in Bogotá Plain and located in the area at the height of 2,400 to 2,900 meters above the sea level.
- The cultivated area is widely distributed along the rivers and on gentle slope area.
- The area of grassland including cow fields tends to increase in accordance with high elevation and steeper relief of topography.
- Bare land is distributed in the north, northeast, and southeast part of the study area where soil erosion and landslide are observed.
- There are dam sites and lagoon as water resources in the northeast t and southwest of Bogotá City.
- Greenhouses that cultivate flowers are distributed in dots mainly at the cultivated area along the Bogotá River and its tributaries in the Bogotá Plain.

Table-4.3 Land Use Areas of the Study Area

Classif. 1	Classification 2	Area (km2)	(%)	Classif. 1	Classification 2	Area (km2)	(%)
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: 4268.69km2							

Table-4.4 Land Use Areas by River Basin

River Basin	Classification	Forest	Cultivated	Grass	Bare	Aquatic	Urban	Green house	Total
Bogotá River Basin (1)	Area (ha)	0,00	0,52	1,07	0,12	0,00	0,02	0,05	1,78
	Ratio (%)	0,00	29,14	60,00	6,86	0,00	1,14	2,86	100,00
Soacha River Basin	Area (ha)	1,07	54,60	60,37	6,96	0,00	5,91	0,31	129,22
	Ratio (%)	0,82	42,25	46,72	5,38	0,00	4,58	0,24	100,00
Bogotá River Basin (2)	Area (ha)	0,29	24,72	30,21	29,91	0,00	26,30	1,52	112,95
	Ratio (%)	0,26	21,88	26,74	26,48	0,00	23,28	1,35	100,00
Subachoque River Basin (1)	Area (ha)	0,00	14,95	5,62	10,11	0,00	0,30	0,49	31,47
	Ratio (%)	0,00	47,50	17,85	32,13	0,00	0,97	1,55	100,00
Bojaca River Basin	Area (ha)	1,44	92,10	75,18	38,89	0,07	1,72	9,14	218,55
	Ratio (%)	0,66	42,14	34,40	17,79	0,03	0,79	4,18	100,00
Subachoque River Basin (2)	Area (ha)	7,62	105,84	189,10	29,01	1,22	74,50	0,98	408,27
	Ratio (%)	1,87	25,92	46,32	7,11	0,30	18,25	0,24	100,00
Tunjuelito River Basin	Area (ha)	2,97	243,24	99,69	28,55	0,16	0,68	13,24	388,54
	Ratio (%)	0,76	62,61	25,66	7,35	0,04	0,17	3,41	100,00
Bogotá River Basin (3)	Area (ha)	23,25	182,49	106,61	40,28	0,22	176,04	9,93	538,81
	Ratio (%)	4,31	33,87	19,79	7,48	0,04	32,67	1,84	100,00
Chicu River Basin	Area (ha)	2,05	83,00	43,16	3,21	0,00	0,06	3,41	134,88
	Ratio (%)	1,52	61,54	32,00	2,38	0,00	0,05	2,53	100,00
Bogotá River Basin (4)	Area (ha)	1,30	38,71	17,09	1,61	0,00	0,08	4,42	63,21
	Ratio (%)	2,05	61,23	27,04	2,55	0,00	0,13	7,00	100,00
Neusa River Basin	Area (ha)	6,70	107,47	75,51	2,79	0,00	0,28	3,97	196,72
	Ratio (%)	3,41	54,63	38,38	1,42	0,00	0,14	2,02	100,00
Bogotá River Basin (5)	Area (ha)	5,42	51,64	41,45	2,91	0,00	0,13	4,25	105,79
	Ratio (%)	5,12	48,81	39,18	2,75	0,00	0,12	4,02	100,00
Teusaca River Basin	Area (ha)	9,54	140,46	192,20	5,89	2,41	0,62	3,08	354,22
	Ratio (%)	2,69	39,65	54,26	1,66	0,68	0,17	0,87	100,00
Bogotá River Basin (6)	Area (ha)	5,03	36,27	17,43	1,35	0,21	4,49	2,25	67,04
	Ratio (%)	7,50	54,11	25,99	2,01	0,32	6,70	3,36	100,00
Neusa River Basin	Area (ha)	46,21	180,68	172,21	22,19	8,71	4,33	0,86	435,20
	Ratio (%)	10,62	41,52	39,57	5,10	2,00	1,00	0,20	100,00
Bogotá River Basin (7)	Area (ha)	7,27	82,57	70,74	6,72	0,04	1,33	7,48	176,15
	Ratio (%)	4,13	46,87	40,16	3,82	0,02	0,75	4,24	100,00
Tomine River Basin	Area (ha)	10,64	143,56	183,56	10,03	22,44	0,07	1,93	372,23
	Ratio (%)	2,86	38,57	49,31	2,70	6,03	0,02	0,52	100,00
Bogotá River Basin (8)	Area (ha)	5,41	32,83	59,10	4,79	0,00	1,64	0,32	104,10
	Ratio (%)	5,19	31,54	56,78	4,60	0,00	1,58	0,31	100,00
Sisga River Basin	Area (ha)	18,79	64,02	65,69	0,64	4,43	0,46	0,11	154,14
	Ratio (%)	12,19	41,54	42,62	0,41	2,88	0,30	0,07	100,00
Bogotá River Basin (9)	Area (ha)	25,46	83,23	160,10	1,81	0,00	4,77	0,06	275,42
	Ratio (%)	9,24	30,22	58,13	0,66	0,00	1,73	0,02	100,00
Total of the Study Area	Area (ha)	180,46	1762,90	1666,07	247,78	39,92	303,75	67,81	4268,69
	Ratio (%)	4,23	41,30	39,03	5,80	0,94	7,12	1,59	100,00

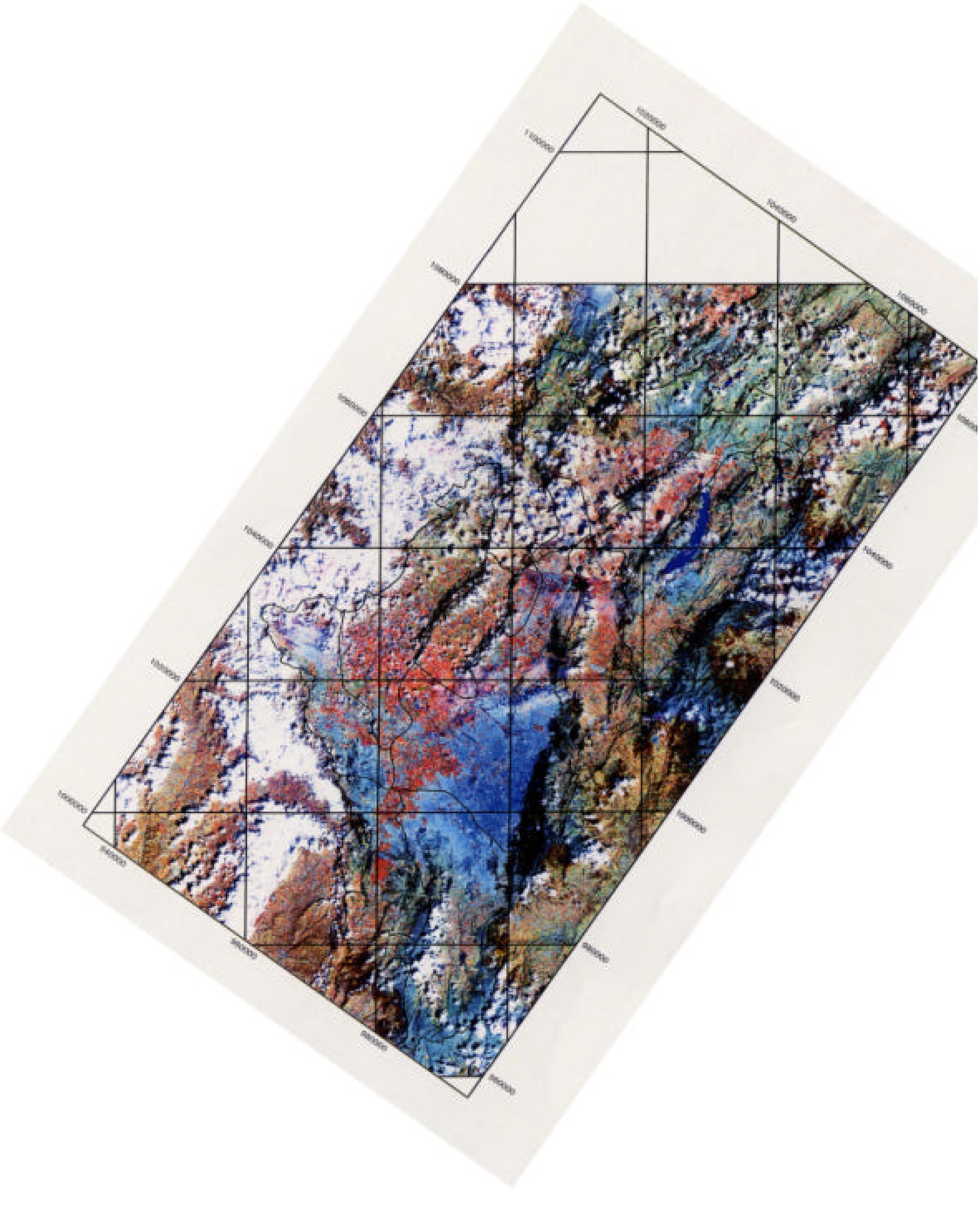

Figure-4.1 LANDSAT-7 Color Composite Images of the Whole Study Area

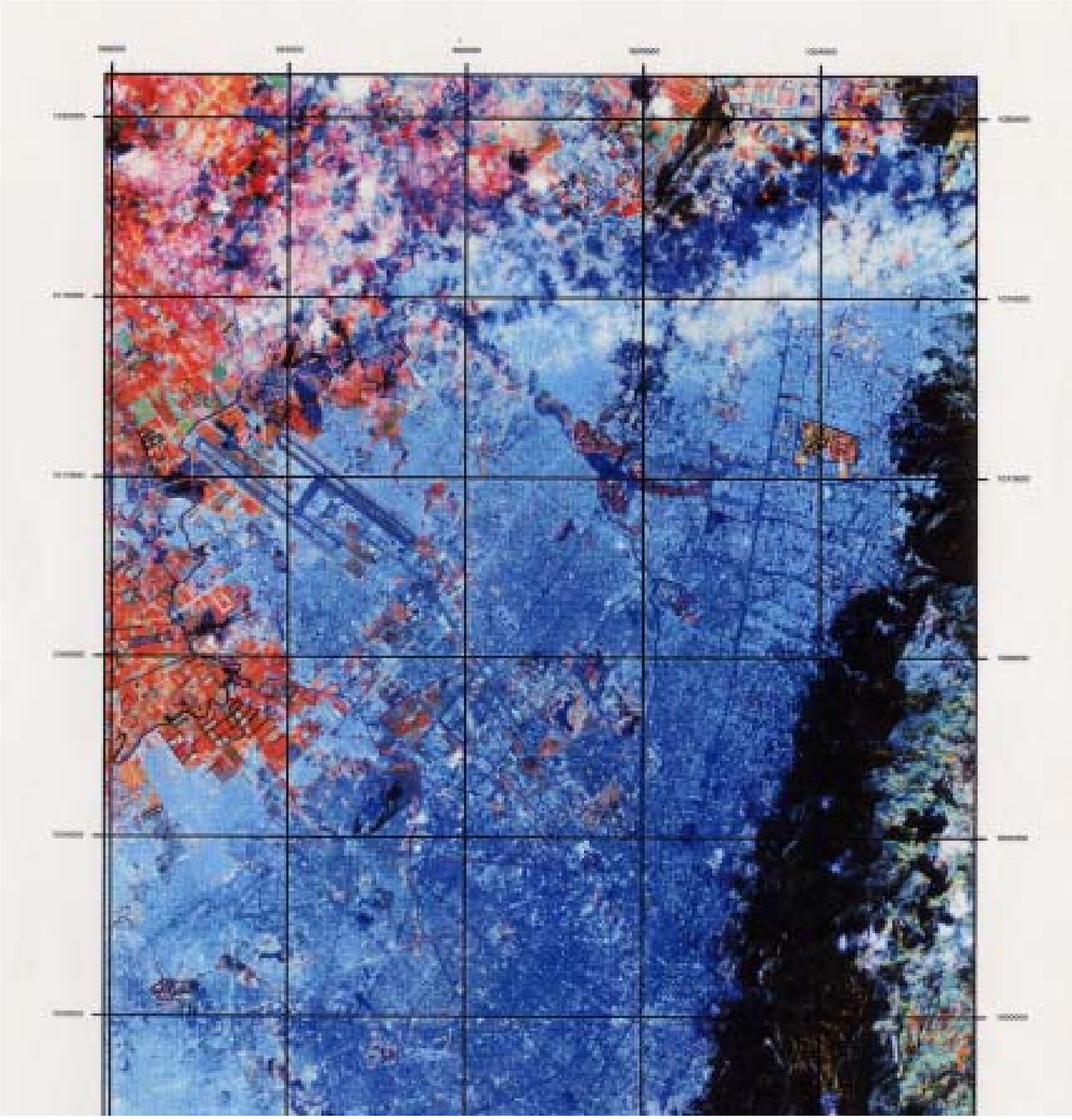

Figure-4.2 LANDSAT-7 Color Composite Images of the Urban Area of Bogotá D.C.

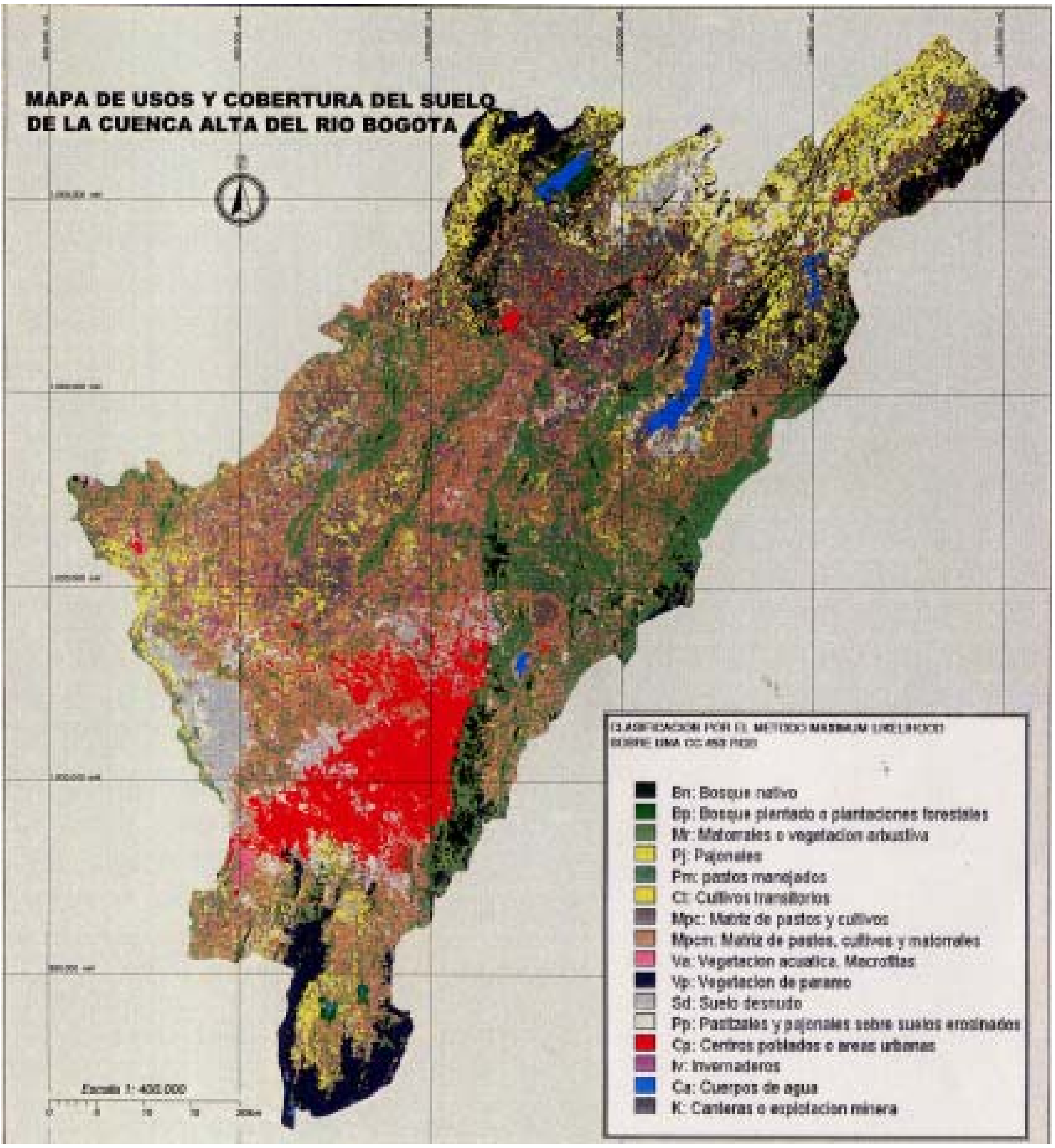

Figure-4.3 Land Use Map of the Study Area

4.2 Environmental Field Survey

4.2.1 Water Environment of Bogotá River

The water environment in Bogotá Plain is composed of two important water resources, namely Bogotá River and deep groundwater. There are also wetlands and mountainous small streams as sub-factors. The figure below shows the whole structure of the water environment in Bogotá Plain.

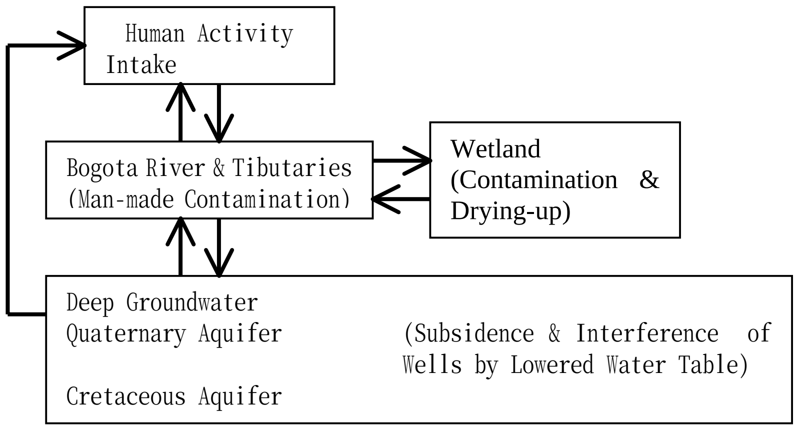

Figure 4.4 The structure of water environment in Bogotá Plain

4) 1) Use of Bogotá River

Bogotá River originates in the western side of Villapinzon, Cundimarca department (3,300 m in height 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 joints into 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 mil m^3, irrigation and water supply), Tomine Dam (EEEB, 690 mil m^3, power generation, water supply and flood control), Neusa Dam (CAR, 100 mil m^3, irrigation and water supply) and San Rafael Dam (EAAB, 750 mil 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)

5) Water Quality of Bogotá River

It is appropriate to focus on several aspects as followings 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 result is seen in the supporting report. The following describes the summary of the result.

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. The amount of major pollutants are described in Figure-4.5 and Figure-4.6.

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 is 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). To prove hydrogen sulfide and ammonia are not originated in the surface activity, the supporting report shows (i) the amount the substances generated on the surface, (ii) the amount of the substances penetrating through soil and (iii) years for accumulating the same amount of the substances based on the estimated stored quantity.

6) Wetland

There used to be 50,000 ha of wetlands in Bogotá Plain. However, there are currently sorely 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 floods 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. The location of wetlands is seen in Figure-4.7 and the supporting report shows the characteristics of these wetlands. It has been observed there are 53 avian and vertebrate living in the wetlands.

It has been confirmed that 53 avian and vertebrates presently live in the wetlands. There are 12 wetlands (such as Conejera, Coldoba, 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 eutrification caused by organic materials. The effects on ecosystem are greatly anxious.

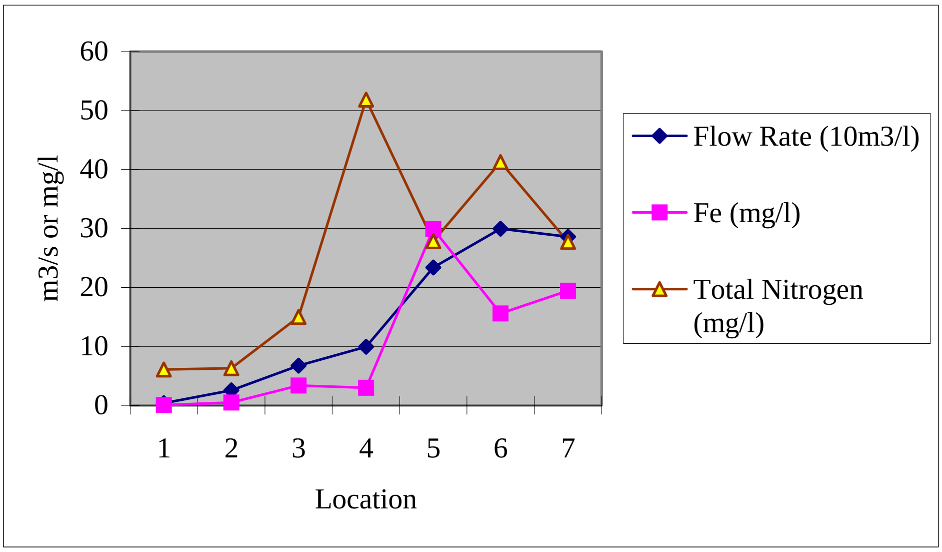

Figure 4.5 Flow Rate, Total N, and Fe in Bogotá River

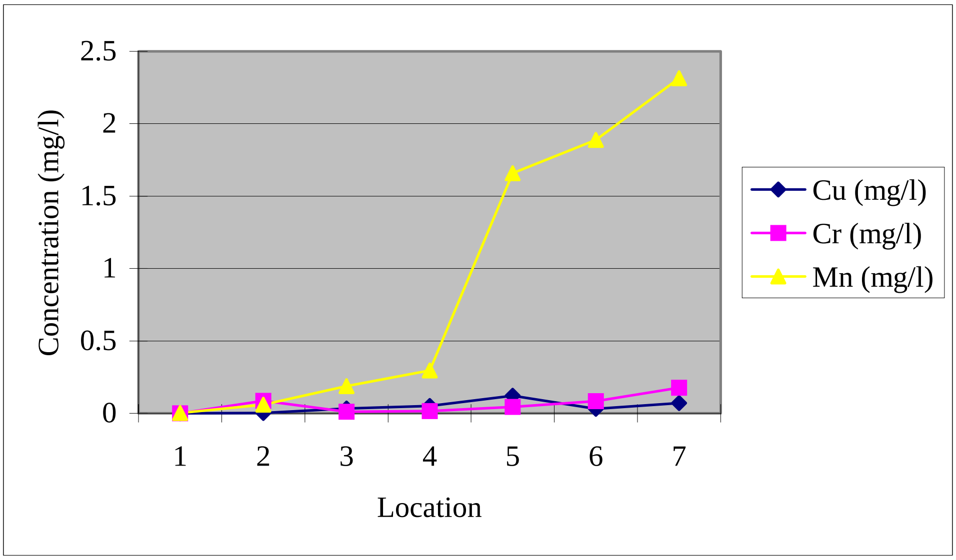

Figure 4.6 Cu, Cr, Mn, Fe in Bogotá River

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.

7) 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 sorely 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.

4.2.2 Groundwater and Land Subsidence

8) 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 Facatatiba). 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 (bottom), Bogotá (middle), Bojaca, Subachoque, Chicu and Frio Basins. Among them, usage rate of groundwater is especially high in Chicu Basin.

2) 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 utilized.

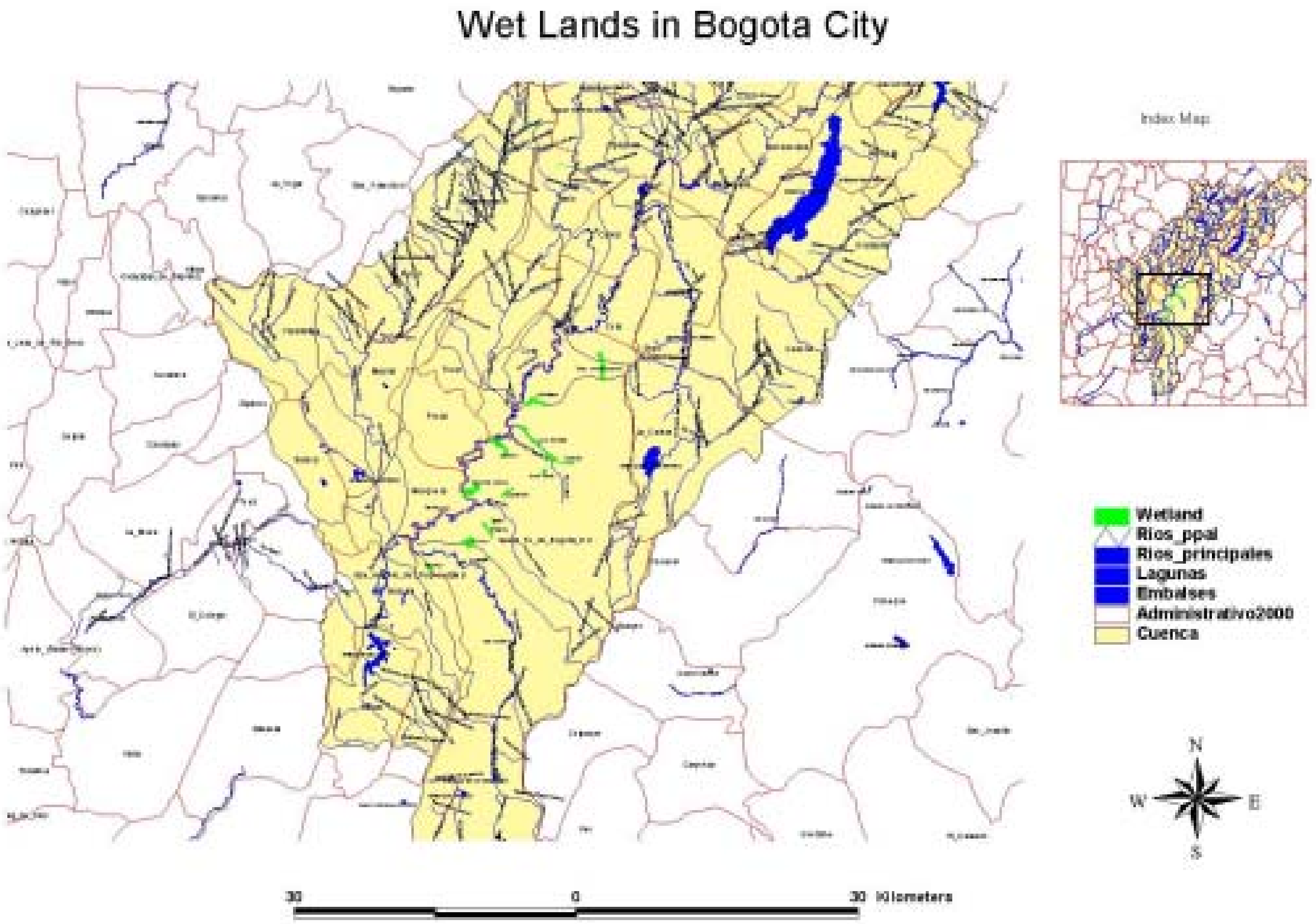

Figure 4.7   A distribution map of wetlands in Bogotá D.C.