Report III - 3

Agro-Ecology

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1. Introduction

On a regional scale, the Sana'a Basin can be classified as an intermontane plain of predominantly arid nature. Locally, however, there are a number of sharply contrasting features, which suggest the prevalence of different micro climatic and agro- ecologic conditions within the basin. This is mainly due to wide range of elevation, rainfall, temperature, and surface features as outlined below:

Elevation: Absolute elevations range mainly from 1900 – 3000 m .a.s.l. With a number of mountains across the basin whose peaks are usually between 3200 and 3600 m.a.s.l.

Rainfall: Is distributed non- uniformly throughout the basin from a minimum of 170 mm/yr in the N-NE areas to a maximum of 350mm/yr at the southwestern corner.

Temperature: Annual temperature ranges between 12° and 20 C$^{\circ}$ with an average of 18.5 C$^{\circ}$ in the urban center (City of Sana'a); the hottest month is July (22.2 C$^{\circ}$) and the coldest is December (14.3 C$^{\circ}$). In addition to these seasonal variations, there are significant diurnal differences of up to 15 C$^{\circ}$.

Surface Features: On the average, there is a difference of 1000 m in relief between the central plain (2200 – 2300 m.a.s.l), and surrounding mountains forming the catchment area (3200 – 3600 m.a.s.l), the morphology and land-forms observed to be extending between these two zones range from sharp mountain peaks, upland plateaus (peneplains), intermontane plains hill slopes, terraced volcanic terrains with or without elevated cones from recent volcanism, and isolated alluvial basins with limited flood plains with local base levels above the level of the central plains (usually along faulted zones).

Considering the relatively large area of the Basin (3200 –3300 km^2) and the spatial variation of the natural conditions developing mainly from the interaction of the above factors, several agricultural regions have developed where local farming and/or pastoral, societies survived for centuries until 2 or 3 decade ago.

Dryland cultivation based on rainfall and/or runoff and spring discharge has been the main activity of agricultural practice for self – sustainment. In recent years, however, groundwater irrigation has rapidly intensified with growing market for cash crops in the city. In the absence of controlling measures, what so ever, depletion of the main aquifer occurred so quickly and gravely that the entire Basin is on the verge of drying up. The situation is so bad that many decision makers (Gov. officials as well as Donors representatives) are beginning to think in terms of how long can it be delayed!!

Two important issues are most relevant to any policies and future plans to this effect: (1) The quantity of groundwater available and accessible by present-day technology and the nations, financial economic capabilities, and (2) the agricultural land still available for expansion in groundwater based irrigation.

This report deals with the second aspect. It describes the different types of agricultural lands in the Basin and the aerial distribution of these lands total the cultivable land, rain fed – runoff cultivated areas and remaining virgin lands which are more likely to be used for any future expansive in pump irrigation. Following this introduction the main agro-ecological issues from the point of view of water resources are presented in three main chapters. Chapter one (Agricultural land) gives a practical classification of the potential agricultural land zones based on the natural characteristics and the present land-use features. Chapter two (Soils) describes the different types of soils occurring across the Basin, with a special focus on the potential limitation of the major types from the management point of view. Chapter three (Towards an Integrated management of water resources: Agro-Ecological Considerations) attempts to integrate the main findings from Chapters 1 and 2 for the purpose of contributing to the information required for an integrated water resources management throughout the Basin

2. Agricultural Land

2.1 Land Holdings

Table (1.1) shows the distribution of holding sizes in the Basin. Mosgiprovodkhoz (1986) indicated that about 40% of the holdings are 1 ha or less, which means that family income from agricultural production is limited. The data also shows that about 95% of the holdings are 10 ha or less. As such, rationalization of groundwater through well sharing would be possible, provided that yields of wells are sufficient and farmers are convinced of the advantages. Data on holding fragmentation, which could be the major constraint on collective and efficient use of water, are not available.

Table(1.1): Distribution of holding sizes in Sana'a Basin (after Mosgiprovodkhoz, 1986)

Holding size (ha)	*Total Area ('000) ha*	*Percentage (%)*
< 0.25	3.03	11.0
0.25 – 0.5	2.84	10.3
0. 5 – 0.75	2.70	9.8
0.75 –1.0	1.90	6.9
1-2	4.46	16.2
2-3	3.53	12.8
3-4	2.26	8.2
4-5	1.6	5.8
5-10	3.77	13.7
10-20	1.21	4.4
20-50	0.25	0.4
Total	27.55	100.0

2.2 Agricultural Regions

Broadly speaking, the exploitation of natural lands within the Basin is determined by a number of factors related to water resources availability and land suitability. A common factor which to a great extent determines the availability of both water and suitable land is moisture variation which is in turn related mainly topography and altitude position of a particular zone with respect to moist winds passing through the region using a number of indices related to these two parameters (i.e. topography. & altitude). Mosgip. (1986) divided the Basin into six agricultural regions. Figure 1.1A shows that these regions occur across the main hydrologic water divide within the Basin. Regions A and B fall largely inside the Wadi Al-Kharid hydrologic unit while the other four (C, D, E and F) are within the Musayreka Hydrologic unit forming the lager and more important (from the management point of view) part of the Basin. For the purpose of evaluating this change the newly prepared cropping pattern map (WEC – ITC, 2001) has been superimposed on the 1986 maps. Figure.1.1B indicates a reasonable good fit of the 16 WEC – ITC zone within the main boundaries of the 6 agricultural regions. The only " sort of problematic " zone is Wadi Shahik (zone 15), which is practically in between regions D and F. Fortunalety, a good part of the zone north of the main wadi course falling within D consists practically of barren rocks. Hence Shahik will be considered as part of region F in all calculations.

2.3 Available Land

The 15 years period, which lapsed since the delineation of the agricultural regions has witnessed a dramatic change in land use. Groundwater availability has played the key role in effecting this change as the irrigated areas sharply increased from 7500 ha to 23400 ha. A significant part of traditionally rainfed or spate-irrigated zone has been converted to groundwater irrigation while vast areas of cultivable lands were subjected to new exploitation

The main statistics on land availability, updated on the basis of the above approach, are shown in table1.1. The following discussion is related to table1.1 together with figures 1.1 (A and B) and 1.2 (A and B).

Figure1.1A: Natural Agriculture map (modified after Mosgiprovodkhoz, 1986)

Figure 1.1B: Agricultural Zones in Relation to Water Management Zones as proposed in this study (modified after Mosgiprovodhhoz, 1986 and WEC-ITC, 2001)

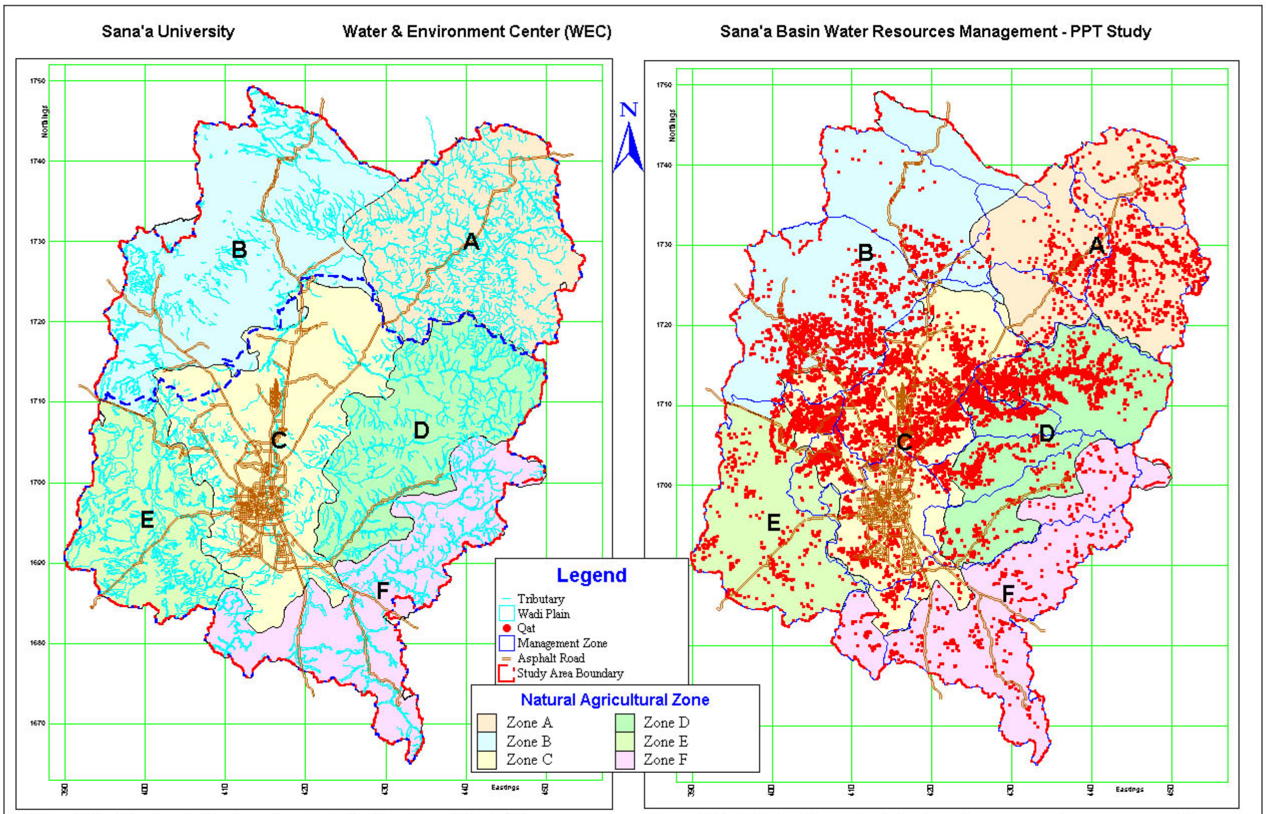

Figure 1.1A : Natural agricultural map (modified after Mosgiprovodkhoz, 1986)

Figure 1.1B : Agricultural zones in relation to water management zones as proposed in this study (modified after Mosgiprovodkhoz, 1986 and WEC - ITC, 2001)

Cultivable VS pasture land

Total agriculture land across the Basin is estimated at 1937.4 km^2 or 60 % of its total area. Of this, 1065.8 km^2 is cultivable while the remaining 871.6 km^2 constitutes pastureland, giving a ratio 55 % to 45 % for cultivable and pasture land respectively. Significant differences in the spatial distribution of these two basic types of agricultural land are also observed. Of particular importance is the occurrence of vast areas of cultivable land in the plateau areas of regions B 115.1 km^2 and E (100.1 km^2). These areas represent 71.2 % and 45.5 % of the total cultivable land in these regions, respectively. Considering that these two regions are characterized with a higher proportion of plateau zones, in comparison will the other four regions, it is important to observe the relatively very low pasture land in region E. This may be attributable to the significantly higher altitude of the plateau areas in this region compared with similar land type in region B.

2.3.1 Available cultivable land

The total area of cultivable land has been estimated by Mosgiprovodkchoz (1986) as 1065.6 km^2 as stated above. About 43 % of this land (457 km^2) is in the central plain area and the surrounding non-terraced slopes. The remaining 608.6 km^2 is distributed throughout the plateau areas (236.7 km^2 or 22.2 %) and the terraced slopes descending from this high plains (372.1 km^2 or 34.8%). In terms of the relative proportion across the agriculture regions, it is observed that region C has significantly more cultivable land, mostly within its plain areas and non-terraced slopes. The other regions however, are characterized with more cultivable land in terraced than in non-terraced slopes. The occurrence of large areas of cultivable land in the plateau of regions B and E, in addition, distinguishes these two regions with the potential for more expansion in cultivation within the middle to higher altitude zones.

2.3.2 Irrigated areas expansion

Up until the mid 80s, the agricultural land throughout the Basin was predominantly rainfed, with only 30.1 km^2 (or less than 3 %) irrigated. Over the past 15 years, however, the irrigated areas increased by almost an order of magnitude to 233.8 km^2 (22 % of cultivable land). This increase is observed in all six regions but with significant differences in rate. Thus, while the highest irrigated lands in terms of both absolute and relative areas are still in regions C and D, significant expansion in region A is particularly noteworthy. It can be seen that 75 % of the cultivable land in this region is already exploited compared to, for example, less than 10 % in region F where least expansion has occurred so far.

Figure 1.2: Land use changes between 1984 (A) and 2000 (B).

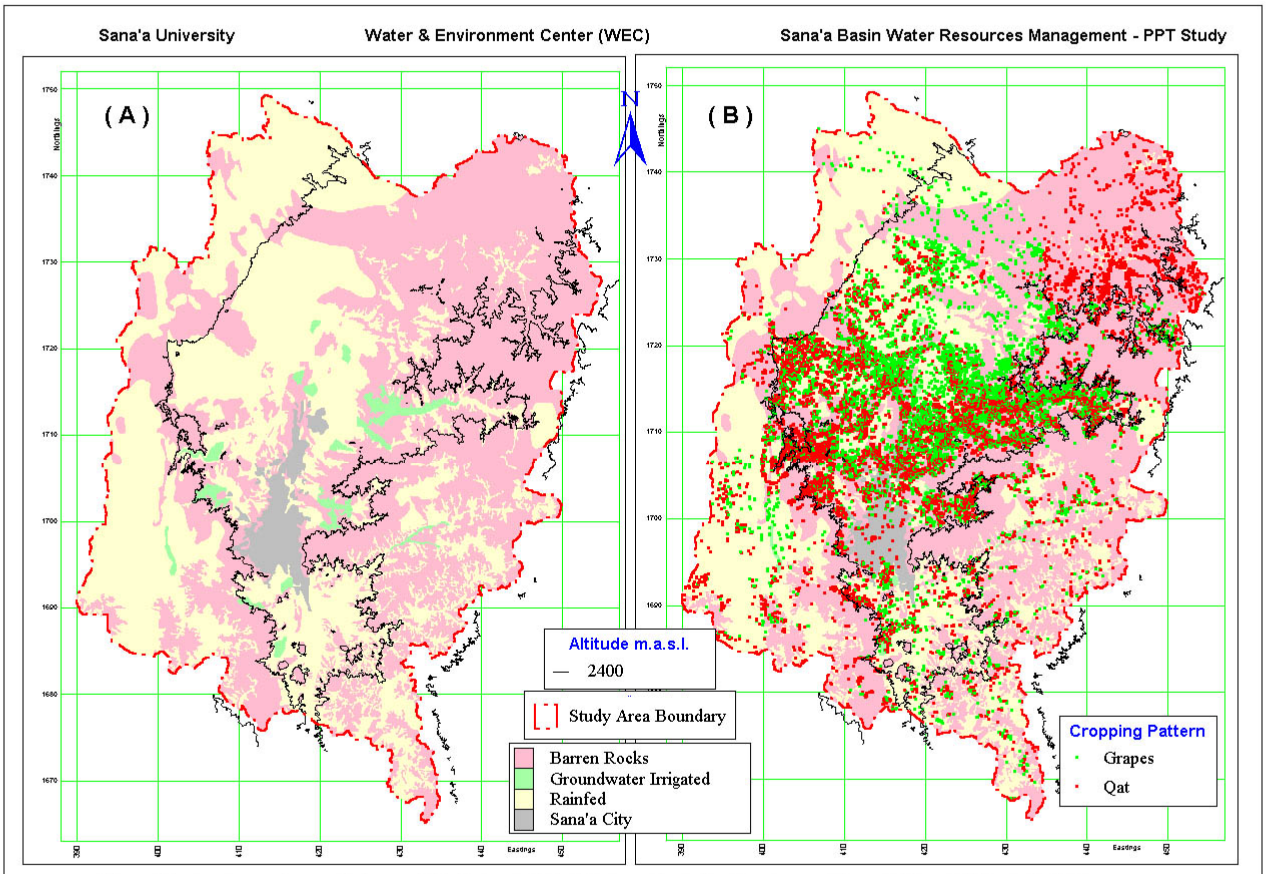

Figure 1.2 : Land use changes between 1984 (A) and 2000 (B). (modified after Mosgiprovodkhoz, 1986 and WEC - ITC, 2001)

Table 1.1: The main statistics on land availability

Region	Plateau			Terraced slopes (cultivable)	Non-terraced slopes and plain areas (cultivable)	Total area	Agricul. land	Cultivated area					% Irrigated			
	Cultivable		Pasture					Rainfed		Irrigated		Total				
	(km^2)												1984		2000	
		%						1984	2000	1984	2000		1*	2*	1*	2*
Region A	-		80.5	37.2	10.7	560.0	128.4	46.9	11.7	1.0	36.2	47.9	0.8	37.0	28.2	75.6
Region B	115.1	71.2	197.8	44.4	2.4	689.8	359.7	159.3	136.0	2.4	25.7	161.7	0.7	44.0	7.1	15.9
Region C	-		163.9	46.6	301.0	690.5	511.5	332.1	278.0	15.5	69.6	347.6	3.0	67.0	13.6	20.0
Region D	1.8		190.0	57.7	43.2	437.2	292.7	96.4	47.4	6.3	55.3	102.7	2.1	35.0	18.9	53.8
Region E	100.1	45.5	53.1	81.7	38.4	351.6	273.3	218.5	188.6	1.7	31.6	220.2	0.6	80.0	11.6	14.4
Region F	19.7		186.3	104.5	61.3	479.9	371.8	182.3	170.1	3.2	15.4	185.5	0.9	49.0	4.1	8.3
Total	236.7		871.6	372.1	457.0	3,209.0	1,937.4	1,035.5	831.8	30.1	233.8	1,065.6	8.1	312.0	83.5	188.0

1* : % of Agricultural Land

2* : % of Cultivable Land

3. Soils

3.1 Background

Since the early sixties, a series of studies have been conducted on the Sana'a Basin. These studies were mainly directed towards investigating and evaluating the water resources situation within the Basin and proposing means of development, especially with regard to the water supply of the metropolis area. All of these studies concluded that serious limitations to the water supply are largely originating from the extensive irrigation development. Nevertheless, it was only recently that attention has been given to studying agriculture land use changes and irrigation development in the Basin.

In assessing the present agriculture it is necessary to look at the past and generate information about characteristics of past use of land and water. This could be done by obtaining a temporal set of data from which a trend may be established. As more interest is generated in spatial and temporal extrapolation of localized agricultural activities, the need for standardized data become imperative. In the case of Sana'a Basin we faced the problem of varied standards as the only comprehensive detailed study on agricultural resources development was based on a different classification system than that used in other studies . Hence, it is rather difficult to use the reports comparatively because of the different basis of classification and characterization of soils in the Basin.

For effective agricultural planning, a knowledge of soil resources is indeed imperative. Failure in selecting suitable locations for development (e.g. agricultural, urban ….. etc.) is partially related to the lack of soil resources inventory. In Sana'a Basin, available soil information partially answers questions critical to the evaluation and management of soils. The objectives of this report were to : (i) identify soil categories occuring in each of the sub-catchment in Sana'a Basin according to existing soil information, (ii) review land use characteristics and cultural practices, and (iii) recommend proper management aspects for major soils in the Basin.

During the past three decades, several soil surveys were carried-out in the Sana'a Basin. Most of these surveys were conducted for areas of agricultural potential and were used by rural and agricultural development projects. For basin-wide characterization of soils and their limiting properties only two soil survey reports could be utilized; i.e., Mosgiprovodkhoz, 1986 and King et.al.,1983. The latter conducted a generalized soil survey (1:500 000) covering the western areas of Yemen, west of longitude 45^0 30' E; i.e, covering the territory of the former YAR. Soils were characterized, classified, and mapped according to the American Soil Taxonomy (USDA, 1975). On the other hand, the former report Mosgiprovodkhoz (1986) provided focused study on Sana'a Basin water resources (Mosgiprovodkhoz, 1986). A semi-detailed soil survey (1:50000) was conducted, with soil on properties of selected plots were studied at a map of (1: 100 000). Soils that mapped, characterized, classified and mapped according to the Russian Soil Classification System. Thus, these two studies could not be adequately correlated, due to differences: in technical language, in land coverage, and in management approaches.

In this paper, a thorough review of both studies will be undertaken for soil resources' data to be compiled and presented; with an attempt to relate them to each other. In addition, soil management aspects will be generalized from both studies and other related literature.

3.2 An Overview of Soil Genesis

3.2.1 Soil forming factors

Soil results from the factors of soil formation : (i) climate, (ii) topography, (iii) vegetation, (iv) parent material, and (v) time. Each soil is a product of the first four factors working together over long periods of time (fifth factor). The contribution of any one factor, depends upon the others, and any one factor, may be dominant, depending upon the location. In the Sana'a Basin, it is thought that the governing factors of the soil cover formation are climate and topography (Mosgiprovodkhoz, 1986). A brief discussion of each of the soil forming factor follows.

3.2.1.1 Climate

The climate of Sana'a Basin ranges from arid to semi-arid due mainly to the differences in elevation and topography. The dominant climatic factors in soil formations are precipitation and temperature. Each of these factors exhibits marked variations with changes in elevation and slop aspects.

3.2.1.2 Topography

The Sana'a Basin contains many distinctly different land forms which provide different environmental landscapes for the formation of soils. There are four major physiographic units in the Basin : (i) Plateau, (ii) Terraced slopes, (iii) wadi bottom, and (iv) highland plain. The topography of the study area has : (i) introduced high intensity of accumulation erosion processes resulting in a thick layer of loose continental Quaternary deposits, and (ii) attenuated appreciably the effect of parent and underlying bed rocks on the soil formation. It should be noted, however, that the natural topography of most developed land holdings have been modified considerably.

3.2.1.3 Vegetation

Vegetation influences soil formation mainly through the addition of organic matter from leaves, stems and roots. The vegetation in Sana'a Basin is poorly developed herbaceous and shrub-arboreal vegetation, the kind and intensity closely associated with climate and topography. The amount and seasonal distribution of precipitation has a direct effect on the vegetation.

3.2.1.4 Parent material

All soil materials initially came from rock. It is therefore important to know about the different kinds of rocks and the material weathered from them to get an understanding of the soils that formed. Geologically, the Sana'a Basin is composed of Precambrian, Jurassic, Cretaceous, Tertiary and Quaternary rocks (Mosgiprovodkhoz, 1986). They identified most common rocks/ materials that served as a source of parent material for soils in the Basin are : Quaternary loose deposits (24%), sandstone (5%), limestone (12%), Tertiary basalts (40%) and Quaternary basalts (19%).

3.2.1.5 Time

Time is essential in making a soil, whether a few years or centuries. Examples of soil profile differences due to the age may be helpful in understanding the role of time in soil formation. *Entisols*, such as *Ustic Torrifluvents,* are generally located adjacent to present wadi bottoms and on fans and lack distinct horizons, however changes are occurring. If the soil remains in place for a long enough period of time without being disturbed, well defined layers (horizons) will result. In the Sana'a Basin, the time factor is probably best expressed in the highland plateau. Examples of soils which have the strongest soil profile development are *Typic Haplustolls* and *Thpic Calciorthids.*

3.2.2 Soil formation processes

According to King et al. (1983), the genesis of the soils in Yemen is influenced primarily by six natural processes and two man-induced processes. These processes result in the accumulation of soil parent material and in the formation of the soil itself. Accumulation of soil parent material results from aeolian deposition, fluvial sedimentation, colluvial deposition, or combination of these three processes. The formation of the soil is accomplished by low levels of soil leaching and low level of accumulation of organic matters. Parent material is also formed by man-induced processes through terracing and irrigation. Soil formation processes are the leaching of soil parent material by irrigation and the accumulation of organic matter by cropping.

Fluvial sedimentation, both along wadis and on intermountain plains, is particularly active along wadi flood plains and accounts for the layering and thin-bedding of many wadi soils of flood plains. In general, alluvium materials become finer towards the lower reaches of the wadi or the flood plains. In the plain lacustrine deposits are observed, which suggest a previous wetter climate and/or restricted drainage. Large areas of soils in such intermountain plains also appear to have deep cap of recent wind and water deposited materials. Colluvial deposite in the Yemen volcanic zone are distinct from the aeolian and alluvial deposits. They occur as moderately sloping pediments at the base of steep volcanic walls or mountain sides. Commonly, soil parent material in the country accumulates as a result of any sequence or combination of these processes; in alternating layers of colluvium, alluvium, and loess materials.
Natural processes that act on parent material are soil leaching and organic matter accumulation. As a result of intermittent and low level of soil leaching, carbonates and other salts are not advanced and soil mineralogy is characterized by a young stage. Similarly, due to arid and semi-arid conditions of the country, there is little accumulation of organic matter in soil horizons.

Man affects soil formation by terracing and irrigation. Terraces retain and collect parent material along mountain slopes, and soil is able to form on these accumulations. Long periods of irrigation and water control have also affected the deposition of soil parent material.

3.3 Brief Description of Soils

3.3.1 Sana'a basin land resources

Administratively, Sana'a Basin falls within parts of 10 districts : Bani Hushaish, Khawlan, Bani Mattar, Bani Bahlul, Arhab, Hamdan, Sanhan, Eyal Seraih, Bani Harith, and Nehm. Only Bani Hushaish falls entirely withinthe Basin. These districts belong to two governorates (Sana'a and Amran) and the City of Sana'a. As delimited by Mosgiprovodkhoz, (1986), the

Basin covers an area of 3205 sq. km, of which 3139 sq. km. They surveyed for soil classification and prepared a soil map (1:200 000).

The Basin area was divided by Mosgiprovodkhoz (1986) into six natural and agricultural regions, according to spatial changes of climate, altitude and soils. The salient features of these six agro-ecological regions are given in Table (2.1).

Table (2.1): Salient features of Sana'a Basin's agroecological regions compiled from Mosgiprovodkhoz (1986).

Features	*Agro-ecological Regions*					
	A	B	C	D	E	F
Total Area, km^2	560	689.8	690.5	437.2	351.6	479.9
Rainfed Area, ha	4690	15930	25850	9640	21850	18230
Irrig. Area, ha	100	240	1550	630	170	320
Active Crop., ha	4790	16170	27250	10270	22020	18550
Inactive Cropland	-	-	7510	-	-	-
Avrg. Elevation, m	2110	2320	2270	2510	2660	2540
Mean annual P, mm	193	242	242	242	324	284
Penman's PET, mm	2150	2010	2030	1940	1850	1890
Km = P / PET	0.09	0.12	0.12	0.12	0.18	0.15

3.3.2 Soils Classified According to the American System

King et al. (1983) produced a generalized soils map (1:500 000) covering an area approximately one fourth of the land area of the Republic of Yemen (ROY), utilizing satellite remote sensing besides field investigation. They identified the predominant soils and mapped them at the association of soil subgroups level according to the USDA-CS Soil Taxonomy (USDA, 1975). That soil survey work, the first to map such a extent of the country, reported the presence of 6 *soil orders,* 12 *sub orders,* 22 *great groups,* 39 *subgroups* and 71 *soil families.* An easy-reference tabulation of these taxonomic units along with their areal extent was compiled by Bamatraf (1991).

3.3.2.1 Identification and spatial distribution

A zoomed-up map (1:250 000), digitally projected on the Sana'a Basin's location map, was produced from the original generalized soil map, and attached with its legend to this report figure 2.1. From this enlarged digital map and using the original map legend, it was possible to identify soils at the association of soil subgroups level, to spatially distribute, and to estimate the areal extent of the Sana'a Basin soils. Accordingly, the presence of 5 *soil orders,* 9 *suborders,* 14 *great groups,* 23 *subgroups* and 38 *soil families* is reported in Table (2.3) and legend attached to figure 2.1. It is evident from this generalized soil mapping that the soils of Sana'a Basin are very diverse, as shown by the relatively large number of taxonomic units in this proportionally small area of land; (Sana'a Basin represents about 2.5% of the mapped area of YAR, and less than 1% of the ROY's land area). This diversity may, unfortunately, indicate the complexity of soil management in the Sana'a Basin; and that soil resources may be vulnerable to many degradation processes, due to natural and man – induced factors. Many hazards are, thus, anticipated to affect areas of recent agricultural development, especially when poor management levels were applied. Farmers of old Yemen "Arabia Felix" must have comprehended this naturally occurring soil diversity in the retrospective regions.

Figure 2.1: Soil map (American classification simplified after Kimg et. Al.,1983).

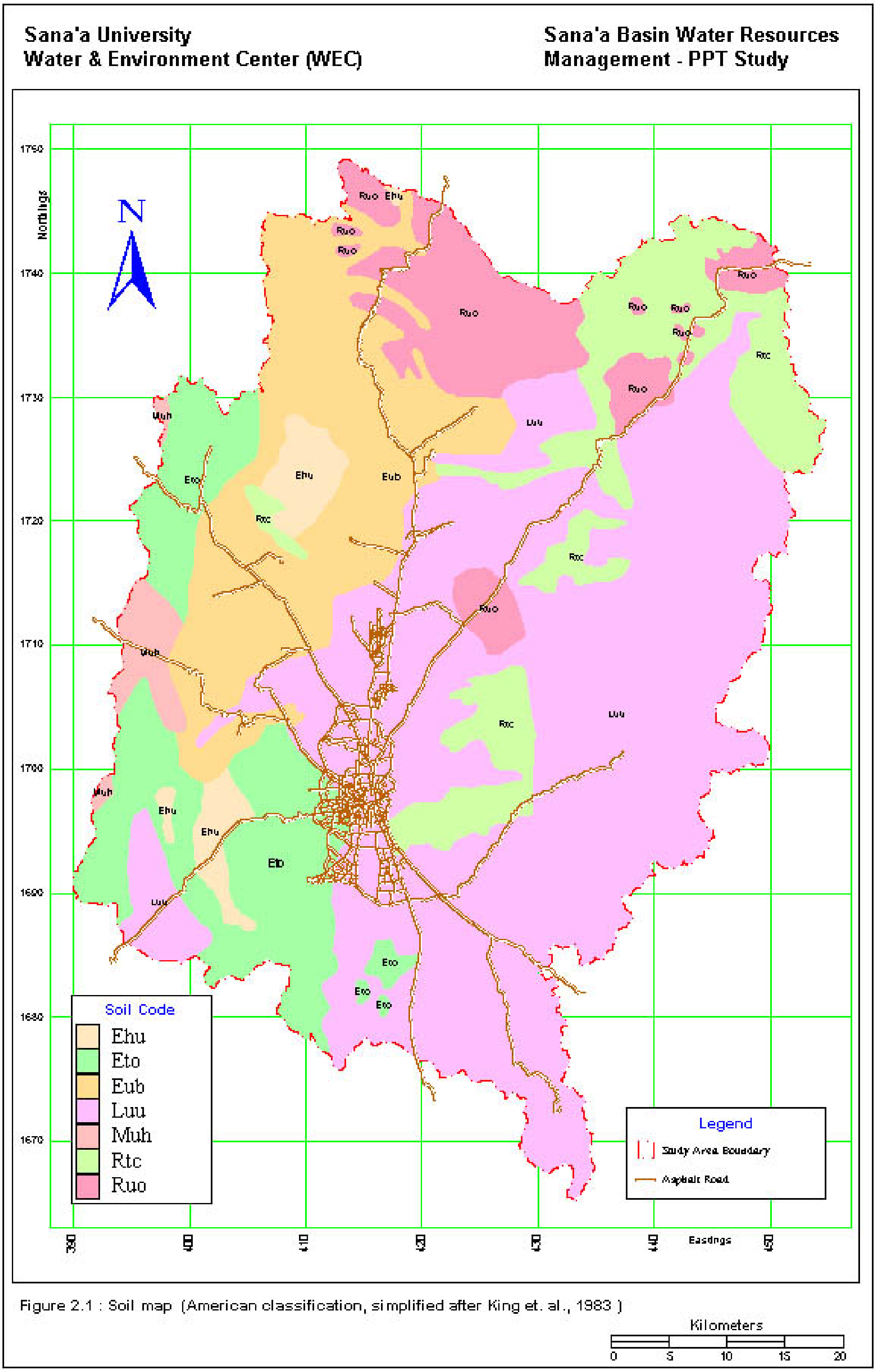

Figure 2.1 : Soil map (American classification, simplified after King et. al., 1983)

Table (2.2): Taxonomic units of soils in the Sana'a Basin and their relative importance

Order	***Sub-order***	***Great group***	***Soil subgroups***	***%***	***Rank***
Inceptisols	Tropepts	Ustropept	1.Entic Ustropepts	9.46	3
			2.Typic Ustropepts	28.38	1
Entisols	Aquents	Fluvaquent	Typic Fluvaquents	0.26	13
	Fluvents	Torrifluvent	2.Typic Torrifluvents	0.55	12
		Tropofluvent	3.Typic Tropofluvents	0.64	11
		Ustifluvents	4.Typic Ustifluvents	18.46	2
	Orthents	Torriorthents	5.Lithic Torriorthents	1.73	7
			6.Typic Torriorthents	3.97	5
			7.Ustic Torriorthents	1.62	8
		Ustorthent	8.Lithic Ustorthents	0.64	11
			9.Typic Ustorthents	5.72	4
Aridisols	Argids	Haplargids	1. Typic Haplargids	0.26	13
	Orhtids	Calciorthids	2 Typic Calciorthid	0.81	9
			3 Ustollic Calciorthid	2.37	6
		Aamborthids	4 Typic Camborthid	0.26	13
			5 Ustollic Camborthid	2.37	6
		Salorthids	6 Aquollic Salorthids	0.26	13
Mollisols	Udolls	Argiudolls	1 Typic Argiduoll	0.64	11
	Ustolls	Haplustolls	2 Aridic Haplustolls	0.16	14
			3 Entic Haplustolls	0.64	11
			4 Typic Haplustolls	0.08	15
			5 Vertic Haplustols	0.80	10
				0.64	11
Alfisols	Ustalfs	Natrustalfs	1 Typic Natrustalf	0.64	11
Rocks			Rock Outcrops	14.45	-
			Basalt flow	4.86	-
Total				***100.00***	**-**

Source : Compiled from Yemeni soil map (King et al, 1983), and the author's constructed soil digitally

Figure 2.2: Soil map (simplified after Mosgiprovodkhoz)

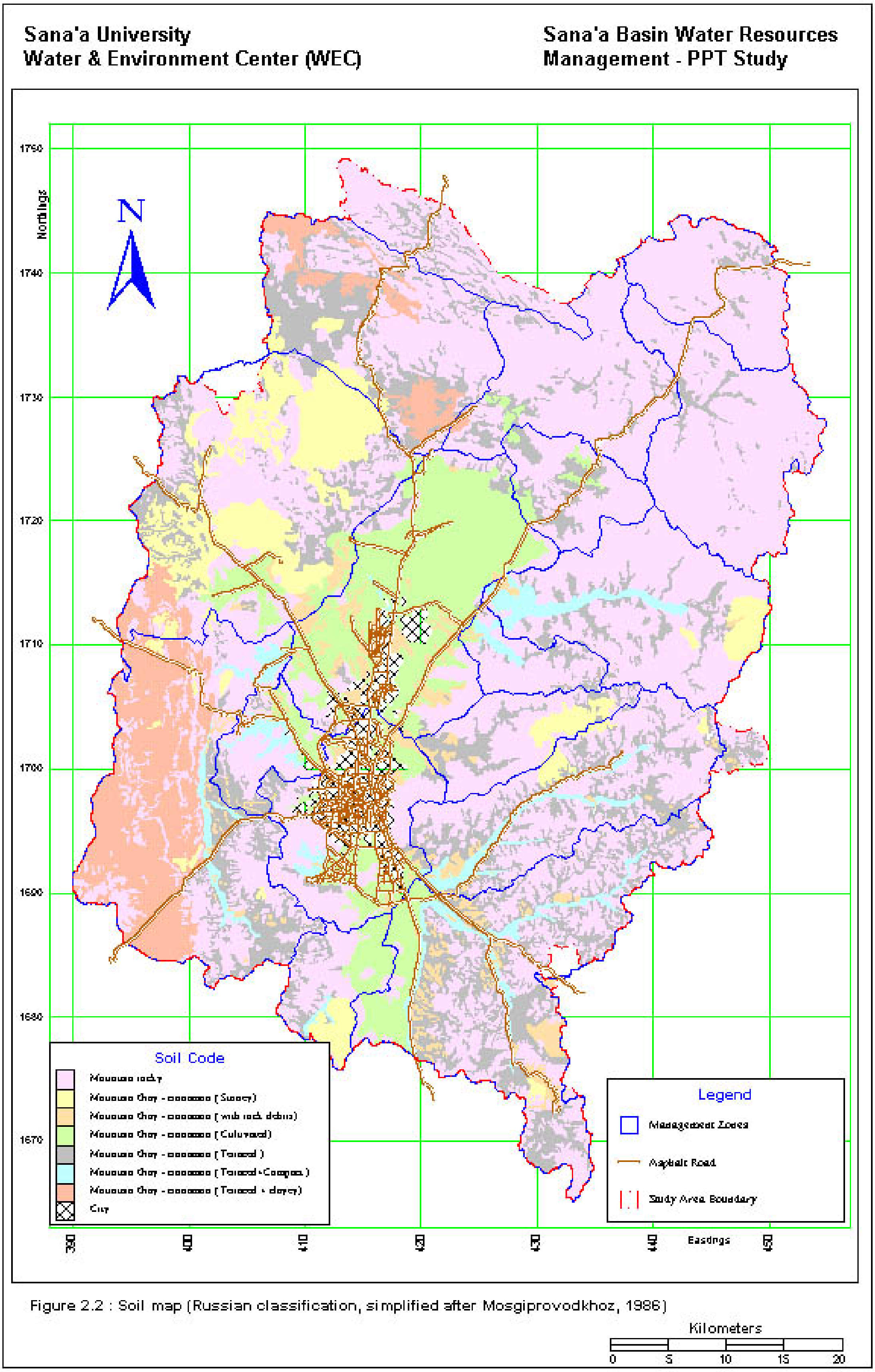

Figure 2.2 : Soil map (Russian classification, simplified after Mosgiprovodkhoz, 1986)

Major soil subgroups/families

Soil information in Tables 2.2 and 2.3 reveals that approximately (37.8%) of the Basin's area is predominantly *Inceptisols,* that is, the embryonic soils with few diagnostic features. They are immature soils having profile features more weakly expressed than mature soils and retaining close resemblances to the parent material (Buol et al., 1980). *Inceptisols* are featured by their highly resistant parent material, extreme landscape positions (e.g. steep lands ….etc), and geomorphic surfaces so young as to limit soil development. These soils occupy most of the area of sub catchments D, F, C and A, respectively. *Tropepts,* the only recognized suborder in Yemen, are the *Inceptisols* of iso- temperature regimes. One great group found in the Basin is the *Ustropepts*, which have >50% base saturation and ustic soil moisture regime. *Typic Ustropepts* and *Entic Ustropepts* area the recognized subgroups of these soils, represented in three families with fine silty to fine loamy texture, mixed minerology and isothermic soil temperature regime.

Entisols, the recently formed soils (33.6 %) , occupying most of the area of sub catchments B and E, and south most parts of C; where the city of Sana'a is located. They include soils of such slight and recent development of epipedon or simple man-made horizons have formed. Their setting is of first importance in introducing factors limiting soil horizon development, such as being in wetlands (*Aquents* : permanently or seasonally wet), alluvial lands (*Fluvents* : loamy and clayey with irregular organic matter with depth), and higher-lying rocky lands (*Orthents* : loamy and clayey with regular organic matter content with depth). *Entisols* present engineering problems in many regions. Erosion by water wind, and mass wasting is important in steep and hilly to mountainous areas, where runoff or infiltration is rapid. Flooding and deposition must be reckoned within lower reaches lands, particularly in river (wadi) floodplains, such as the Sana'a City. Rangelands in sub-humid, semi-arid and arid regions cover vast areas of soils of this order. *Entisols* formed by active cumulization of fertile soil material are highly prized in traditional agriculture because of their ability to grow crops without fertilization. Predominant great groups in the Basin are *Ustifluvents* , *Ustorthents* (both with ustic soil moisture regime), *Torriorthents* (with torric soil moisture regime), and to lesser extent *Tropofluvents* (iso soil temperature regime) and *Fluvaquents* (irregular decrease in carbon content with depth). "*Typic*" subgroups of these great groups are dominant, with few "*Lithic*" and "*Ustic*" subgroups. Some 22 soil families were recognized under this order, showing a wide range of textural classes (from skeletal sandy to fine silty textures) and of soil temperature regimes (from isomesic to isohyperthermic); with mixed minerology..

At a decreasing areal extent *Mollisols* (grassland soils of steppe and prairies) *Aridisols* (soils of arid regions) and *Alfisols* (high base status forest soils) are present, but showing more diversity at most of the taxonomic units. Spatially, they are distributed at all sub-catchments of the Basin. *Rock outcrops* and *Basalt Flow* are mostly found in association with *Entisols* of the A, B and E sub-catchments.

Table (2.3): Major Soil Subgroups and Familes in Sana'a Basin

Sub groups	*Soil Families*
Typic Ustropepts Entic Ustropepts	Isothermic Fine Silty, Mixed, Isothermic; Fine Loamy, Mixed, Isothermic
Typic Ustifluvents Typic Torriorthents Typic Ustorthents	Coarse Loamy, Mixed, Isothermic; Fine Loamy, Mixed, Isothermic; Coarse Loamy, Mixed, Isohyperthermic; Fine Loamy, Mixed, Isohyperthermic; Coarse Loamy, Mixed, Calcareous, Hyperthermic. Sandy Skeletal, Mixed, Calcareous, Hyperthermic; Coarse Loamy, Mixed, Hyperthermic; Coarse Loamy, Mixed, Hyperthermic; Coarse Loamy, Mixed, Isomesic; Sandy Skeletal, Mixed, Isohyperthermic; Coarse Loamy, Mixed, Calcareous, Isohyperthermic; Fine Loamy, Mixed, Isohyperthermic; Coarse Loamy, Mixed, Isohyperthermic. Sandy Skeletal, Mixed, Isothermic; Coarse Loamy, Isothermic; Fine Silty, Mixed, Isothermic; Coarse Loamy, Mixed, Calcareous, Isomesic; Fine Loamy, Mixed, Isothermic.
Ustollic Calciorthids Ustollic Camborthids	Fine Loamy, Mixed, Isothermic Coarse Loamy, Mixed, Isothermic

3.3.3 Soils classified according to the Russian system

Soils of the Basin were classified according to the Soviet system as *Mountains Gray Cinnamon* underdeveloped soil *type* of the *Light* and *Ordinary sub-types.* The rest of the area is a *Mountain Embryonic Rock Outcrop type.* In the Soviet (Russian) system, the category of soil *type* is commonly used for broad regional comparisons and generalizations. It nearly corresponds to the levels of *soil order* and *sub-order* categories of the United States Soil Taxonomy (Buol et al., 1980). The available soil map of the Basin figure 2.2 is simplified after Mosgiprovodkhoz, 1986.

3.3.3.1 Identification and spatial distribution

As reported by Mosgiprovodkhoz (1986), the World soil map of 1981 compiled by Soviet soil scientists at a scale of 1:100 000 000, the Sana'a Basin area belongs to tropical and subequatorial zones. The Basin's soils are those of mountainous regions including "mountain cinnamonic and gray cinnamonic of xerophyte forests and shrub steppe". Therefore, the Russian team classified the Basin soils as *Mountain Gray Cinnamon*, according to Soviet standards, taking into account the prevailing natural conditions and the amount of precipitation. These soils used to be grouped with *Chestnut* soils, which are notably different in properties than *Gray-Cinnamon*. Both soils *types* are formed under conditions of alternatively humid climates, but the latter characterizes a little drier conditions with small amounts of annual precipitation.

The *Gray-Cinnamon* soil are regard as a transition soil *type* between *Cinnamonic* soil and *Gray* soils as the name indicates. They contain less humus than *Cinnamonic* ones. The Basin's soils belong to two soil *types* : *Mountain Embryonic* soils *type* which are bedrock outcrops, and *Mountain Gray- Cinnamon (MG-C)* soil *type* . The latter *type* divides into two *subtypes* : *Ordinary* and *Light,* and then into a number of lower level taxa. The classification of identified soils in the Basin along with their spatial distribution (areal extent) are presented in table (2.4). The soil *subtype* category is composed of taxa within the *types* differening qualitatively in expression of one of the soil-forming processes and/or intensity with which they reflect the main pedogenic process of the *type* (Buol et al., 1980). Proceeding downward through lower levels, there are the *Genera*, *Species* and *Varieties* taxa. The Mosgiprovodkhoz (1986) reported only on soil *Varieties*, which differentiate according to soil texture at a lower level of generalization than used at the level of the *Genera.*

3.3.3.2 Major soil subtypes/varieties

The predominant soil *subtype* is the *light MG-C* soil, extending over 57.3% of the Basin's area; about half of which (28.8%) is classified as carbonate under-mature soils *variety* with fine earth thickness of not more than 30 cm. The rest of this soil *subtype* comprises seven *varieties,* indicating a broad variability in soil properties of the Basin. Next to this *subtype* is the *Mountain Embryonic* (bedrock outcrops) occupying about 36.8% of the Basin's area. Together, this *type* and the under mature (shallow) soils *variety* of the *light MG-C* extend over about two thirds of the Sana'a Basin surface. The *Ordinary Mountain Gray-Cinnamon subtype* found to occupy only 5.9% of the area. A brief description of the main features for the major soil *subtypes*/ *varieties* is presented below, based on summarization from Mosgiprovodkhoz (1986).

The *Mountain Embryonic* soils pertain to mountain summits, to steep mountain stopes and cliffs, and to rolling plains. They relate to rock outcrops of the Tertiary and Quaternary Basalts, Sandstones and Limestones. Generally, they are barren of any grass vegetation, with some occasionally observed developing lichens. Vegetation may occur when the rough surfaces of these rocks catch at least few centimeters of soil cover. These soils usually occur in combination with the *MG-C Light Carbonate under-mature* soils, and sometimes with *shallow medium-deep and deep MG-C* terraced soil variety.

The *MG-C light carbonate under-mature* soils are found on gentle and sometimes on steep slopes as well as on the levelled-off limestones. They occur either separately or together with the Mountain Embryonic soils, but rarely with other types of soils. They are covered with sparsely growing vegetation, used as pastures for sheep and goats. Characteristic to this soil variety is shallow depth to bedrock (< 30 cm), stoniness, low humus content, and calcareousness.

Table (2.4): Sana'a Basin Soil Classification and Areal Extent

Taxon (Soviet)			Index	Area	
Type	***Sub Type***	***Variety***		***Km²***	***%***
Mountain Embryonic (bedrock outcrops)	-		1	1149	36.8
Mountain Gray-Cinnamon	Light	Under-mature carbonate eroded, with stone, fine rock debris, sandy loam, light and medium loam.	2	896.5	28.8
		Carbonate slightly eroded sporadically slightly solonetz, slightly saline with stone, fine rock debris, sandy loam and light loam.	3	83	2.7
		Carbonate slightly eroded, cultivated predominantly slightly solonetz, sporadically slightly saline, light and medium loam, rarely sandy loam.	4	241	7.7
		Irrigated carbonate slightly eroded cultivated, solonetz sporadically slightly saline; light and medium loam.	4ir	25	0.8
		Carbonate terraced, light and medium loam, rarely sandy loam.	5	437.5	14.0
		Irrigated carbonate terraced, predominantly solonetz sporadically slightly saline, loam and medium loam, rarely sandy loam	5ir	10	0.3
		Carbonate terraced solonetz with signs of compactness, medium and heavy loam.	6	58	1.9
		Irrigated carbonate terraced solonetz, predominantly saline with signs of compactness, medium loam, rarely heavy loam and light loam.	6ir	35	1.1
				1806	57.3
Mountain Gray-Cinnamon	Ordinary	Carbonate terraced sporadically slightly solonetz, slightly saline, signs of compactness, light and medium loam, rarely heavy loam and clayey.	7	179	5.7
		Irrigated carbonate terraced sporadically slightly solonetzic saline , with signs of compactness, light and medium loam	7ir	5	0.2
				184	5.9
Total				3139	100

Sources : Mosgiprovodkhoz, 1986

The MG-C light carbonate cultivated: soils are widespread in the Basin covering 241 sq.km (7.73%). They occur in the Sana'a plain elevated from 2100m to 2350m and in a large inter-mountain depression in the center of the Basin. These soils are subjected to wind erosion; hence, framers protect fields with banking-up and low grains in furrows. Varieties with light and medium loam are most spread occurring from the surface to a depth of 0.6-0.8cm; however, they rarely occur throughout the profile. Generally, the relevant soils do not yield without irrigation. But irrigated soils are limited spreading in the basin covering 25sq.km (0.85%). They occur only in the Sana'a basin plain and in an intermountain depression of considerable extension occupying the most northwester side of this plain. Almost all crop varieties can be grown in these soils. Irrigated-soils varieties do not differ significantly from those non-irrigated ones, mainly in a poorer structure and in deep setting of plant roots.

The MG-C light carbonate terraced: soils cover 437.5 sq.km (14.03%), pertaining to artificially terraced slopes of wadi valleys and other slops, and to bottoms of small wadies. They vary widely in the lithological structure, humus content and other agrochemical indices. AC or AD is the profile class of these soils with several humus content occurring on the parent rock (C)grain and forage crops, namely barely, wheat and durra. These non-irrigated soils are similar to those irrigated soils that cover 10 sq. km (0.32%). Irrigated soils occur among the non-irrigated soils. They differ in deeper setting plant root systems (> 80cm) only.

The MG-C ordinary carbonate terraced : soils cover 179 sq.km (5.74%) in Sana'a Basin They occur widely on the high mountain plateau in the southwester side of the Basin elevated from 2700m to 3100m. They pertain to artificially terraced slopes: from 2-4 to 10 and occasionally more, which is the most favorable zone for dry agriculture. In humid and medium humid years, these soils yield medium harvests of grains without irrigation; however, it is not possible to gather harvest for moisture deficit in dry years. Irrigated soils occur among these non-irrigated soils, occupying 500 ha (0.16%) only. They pertain to the drilled holes, which are not very numerous in the basin, and are taken up by vegetables, fruit trees and grass.

3.3.4 Remarks on findings

From the above information on the identified soils, according to available soil surveys using the American (King et al., 1983) and the Russian (Mosgiprovodkhoz, 1986) systems, could not be easily correlated nor even be compared/contrasted . It is, however, beyond the scope of this report to correlate results; but soil survey results remain to be further correlated. Differences in reported results on areal extent of the Rock Outcrops in the Basin, puts a question mark on these results; thus necessitates further investigation, even using remotely-sensed data, at larger scale.

Further investigations should be standardized terms of choosing soil classification system (Al-Eryani et al., 1992). Probable systems are the US Soil Taxonomy (USDA,1975) or the FAO/UNESCO soil classification system (FAO, 1993). The later was developed to prepare a universal worldwide correlation of soil units; whereas, the first suits more national conditions. Appropriate mapping scale should be utilized according to the aim of the investigation. In the case of Sana'a Basin, semi-detailed soil maps should be undertaken at scales of 1:20 000 or 1: 50 000, recognizing soil types according to the US system. These kind of soil surveys are much useful in soil management studies and they can be easily become "user-friendly soil maps". But for community identification of Soil and Water Conservation as a priority, an issue-focused participatory rural appraisals are undertaken. During this, "*Participatory soil maps"* of the village are drawn, and the maps are used to discuss resource problems, identify seriously degraded areas and determine the range of techniques that might be used. Participatory soil maps are those maps, constructed with full participation of users; they usually show user's perception of their soil resources. After all they (the users) are the ones who will implement field works of soil management.

4. Towards Integrated Management of Water Resources: Agro-Ecology Considerations

Integrated management of the water resources available in the Basin cannot be achieved without considering land use, which, in turn, is largely detemined, by the prevailing agro-ecological conditions. Such conditions are mainly related to the following several natural and /or human-induced factors:

- Climatological conditions and hydrological regime.
- Soil properties and spatial distribution.
- Natural physiography and agricultural land availability.
- Land use potential and cropping patterns.

Since the prevailing critical shortage in water resources is resulting mainly from serious overdraft of groundwater for irrigation, any agro ecological considerations to be proposed should aim at limiting future expansion in pump irrigated areas. The object of this chapter is therefore to:

1. analyze the interaction of the above factors,
2. assess the situations developing from such interactions,

3. delineate different zones of groundwater exploitation for irrigation purposes, and
4. identity the most probable area for future expansion.

4.1 Hydro-Climatological Considerations

Three different indices are considered to represent limitations to agricultural productivity due mainly to natural conditions related to the prevailing climate and hydrological regime: rainfall, evapotranspiration and atmospheric moistening. To assess the current situation in the Basin, an isohyetal map was first prepared using the most recent data available on rainfall (1991 – 1997). The evapotranspiration and moistening patterns, as given in the Russian study, were then superimposed on the isohyetal map (figure 3.1). Conventional index of annual atmospheric moistening (k_m) was calculated by dividing rainfall (P) by potential evapotranspiration (ET_0), using mean annual values. The ranges of this index used for determining the moistening pattern across the Basin has been modified after Mosgiprovkhor (1986) as follows:

$K_m \leq 0.10$ = extremely dry conditions
$0.010 < k_m < 0.14$ = very dry condition
$0.14 < k_m < 0.22$ = dry
$k_m \geq 0.22$ = semi-dry

4.2 Physiographic Considerations

Delineation of natural zones with similar mesoclimatic conditions has been performed on the basis of 200 m contour line intervals. The geomorphological features dominant in each region was then identified by using a recent map prepared from remote sensing–satellite images (WEC-ITC, 2001). Additional features identified through aerial photography and field observations were obtained from the Russian study. Delineation of the different landforms and topographic zones, indicating the more suitable ones for agricultural practice, was performed by superimposing the three types of information on a single map (figure 3.2).

Figure 3.1: Moisture, Evapotranspiration and Rainfall distribution.

Figure 3.2Main physiographic features.

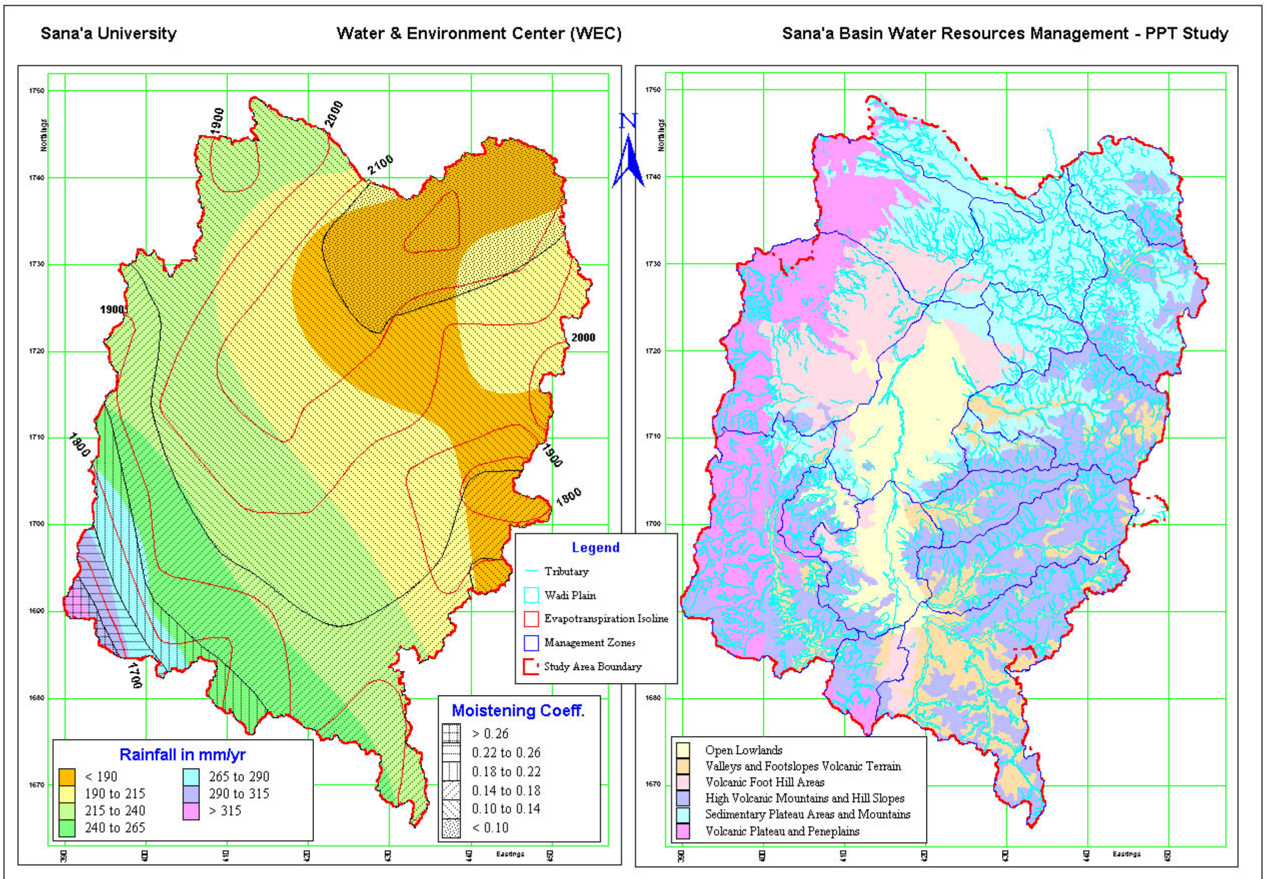

Figure 3.1 : Moisture, evapotranspiration and rainfall distribution

Figure 3.2 : Main physiographic features

4.3 Land-use Considerations

Irrigated land areas across the Basin sharply expanded from an estimated 7500 ha in 1984 (Mosgip., 1986, Vol. 3: Soils and Vol. 4: Land Reclamation) to 23380 ha in 2000 (WEC-ITC,2001). However, field observations suggest not all of these lands are pump-irrigated considering the following field observations:

- The average farm size is very small with the total area of 82 % of land holdings not exceeding 5 ha.
- Cropping patterns are particularly determined by the growing local market for economic cash crops (mainly qat, grapes and fruit to a less extent) such that more and more of such crops are now grown in traditionally spate-irrigated or even rain-fed areas.
- The significant difference in monthly water use (see below) during the dry season (October - January) and wet season (February – September) implies that a signification part of this water comes from rain and /or runoff. It also confirms the farmers claim to continue groundwater extraction during the rainy season (see Vol. 4, Socio-Economics) which in turn implies the occurrence of regularly irrigated areas ***(stable farm lands)*** and irregularly irrigated ones ***(unstable farm lands).***

Monthly water use (in Mm^3) during zone as calculated from ET$_o$ Values (Source: WEC ITC, 2000)

J	F	M	A	M	J	J	A	S	O	N	D	Total
5.1	6.2	6.5	6.6	7.2	7.5	7.3	7.2	6.7	5.9	4.9	4.9	75.1

- During field visits within the course of the present study uncultivated (dry) plots were found side-by-side or within short distances from cultivated plots with qat (sometimes with grapes) in the same farm. Farmers explanation, particularly those who buy water (see Vol. 4, Socio-Econ.) was that the dry plots are cultivated only when there is enough rain water and/or runoff (once every 2 years or more) while the application of groundwater is restricted to the cash crop plots during the non-rainy season.

From the above, it can be seen that there are two types of irrigated areas: regularly irrigated and irregularly irrigated. These two types of irrigated lands can be denoted as ***stable*** and ***unstable*** farms, respectively. The respective areas of these two types of farmlands in 1984 are given in different volumes of the Russian study, though not stated explicitly. The current situation can be deduced from the WEC-ITC study by assuming that the unstable farms are essentially represented by the "mixed cereals and others" irrigated areas as defined in the study. This gives a total of 3000 ha and 19700 ha for regularly irrigated (stable) farmlands during 1984 and 2000 respectively). The negative impact of such a vast expansion in this agricultural practice is not limited to rapid depletion of the groundwater, as it also constitutes a potential risk to land degradation. The latter is due mainly to the widespread traditional water application method (basin flooding), which is likely to affect soil fertility and reduce land productivity. Based on the evaluation of such a practice, the Russian proposed a "coefficient of regularly irrigated lands, I" as a relation between irrigation ratio in any particular region to the ratio w.r.t. the entire basin.. Adopting such an approach, the situation across the Basin has been updated as shown in table 3.1.

Table 3.1: Comparison of Irrigation Area and Coefficient of Regularly – Irrigated – Lands in 1984 (A) and 2000 (B)

A

Agriculture Region	*A*				*B*		*C*			*D*		*E*		*F*		*Basin*
Management Zone	7	8	13	16	3	4	1	2	10	6	9	5	11	12	15	
(1) Irrigated area (km^2)	1.00				2.40		15.1			6.3		1.7		3.2		29.7
(2) Region area (km2)	560.0				689.8		690.5			437.2		351.6		479.9		3209
(3) Ix 1 x 10^3	1.8				3.5		21.8			14.4		4.8		6.7		9.2
(4) I	0.2				0.4		2.4			1.6		0.5		0.7		
(5) Irrigated area (%)	3.4				8.1		50.8			21.2		5.7		10.8		100

B

Agriculture Region	*A*				*B*		*C*			*D*			*E*		*F*		*Basin*
Management Zone	7	8	13	16	3	4	1	2	10	6	9	14	5	11	12	15	
(1) Irrigated area (km2) **zone**	16.71	1.40	9.31	3.23	6.07	15.23	48.41	8.51	2.31	11.39	33.39	7.16	6.17	16.55	6.42	4.58	
Region	30.65				21.3		59.23			51.94			22.72		11		196.84
(2) Region area (km2) **zone**	341.4	111.6	209.6	81.1	241.9	243.4	305.5	175.5	72.6	51.2	227.0	90	62.2	366	361	218	
Region	743.7				485.3		553.6			367.8			428.6		579.1		3158.1
(3) Ix * 10^3	41.21				43.89		106.99			141.22			53.01		18.99		62.33
(4) I	0.66				0.70		1.72			2.27			0.85		0.30		
(5) Irrigated area (%)	15.57				10.82		30.09			26.39			11.54		5.59		100

4.4 Soils Considerations

4.4.1 Soil limitations

Specific limitations for soils of the Sana'a Basin is very difficult to assess due to differences in soil survey techniques, and in land classification and evaluation systems. For better perception of the general trends of limiting soil properties , the proposed list of potentially limiting soil properties as identified by King et al., (1983) and Mosgiprovodkhoz (1986), will be presented and manipulated. These properties are listed in Table (3.2).

Table (3.2): Limiting soil properties in Sana'a Basin as identified by two different investigators

Group of Soil Properties	*Limiting Soil Properties*	
	King et al., 1983	***Mosgiprovodkhz, 1986***
Soil Climate	. Soil moisture regime . Soil temperature regime	NI
Physical Properties	. Water retention (holding) . Soil depth . Drainage	. Texture of top 1 m . Stoniness . Thickness . Structure
Chemical properties	. Calcareousness . Salinity . Shrinking and Swelling . Gypsiferousness	. Salinity of Alkalinity
Erodibility	. Flooding . Wind blowing . Steepness	. Erodibility
Traficability	. Traficability	NI

NI = not identified as a limiting property

Soil information in Table (3.2) indicate that King et al., (1983) have presented a rather comprehensive list of limiting properties; hence their list will be used for further evaluation. It should be mentioned, however, that King et al., (1983) have not ranked these properties in order of importance; they characterized soil subgroups limitations in a rather descriptive manner. Therefore, in order to approximate the relative importance of limiting soil properties, the number and percent of the 23 soil subgroups with limiting properties are given in Table (3.3).

Table (3.3) Relative importance of soil limitations of soil subgroups in Sana'a Basin

Limiting Soil Property	*Soil Subgroups (*)*																							*Affected*	
	Inceptsols		*Entissols*									*Aridisols*						*Mollisolls*					*Alfisols*		
	1	2	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	1	2	3	4	5	1	No.	%
Moisture (**)	○	○	▲	■		○	■	■	○	○	○	■	■	○	■	○			○	○	○	○	○	21	91
Temperature	●		●	●	●	●	●	●		●	●	●	●					●		●				13	57
Water Retention				●		●	●	●		●	●		●		●			●		●		●		11	48
Depth							●			●														2	9
Drainage			●														●							2	9
Calcareouness	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	22	96
Salinity																	●							1	4
Shrink & swell																						●	●	2	9
Gepsiferons																								0	0
Flooding			●		●	●																		3	13
Wind Blessing																								0	0
Steepness	●	●							●	●					●			●		●				7	30
Trafficability	●	●		●		●	●	●		●	●				●			●		●				11	48

Source: Compiled from King et al. 1983

(*) Numbers under each soil order corresponds to soil groups numbering in table (3.2)

(**) Aridic Moisture regime (■), Ustic moisture regime (O), Aquic moisture regime (▲), Dots (●). Elsewhere are indicative of adverse effect of soil properties on soil subgroups.

Evidently, calcareousness related to nutrient deficiency could be considered the most serious soil limiting factor, it affects 96% of soils in the Basin. Next to calcareousness, soil moisture regime in the Basin seems to be a limiting property. Most of the adverse effect of this property is related to the *Ustic* moisture regime, which may occessionally need supplemented irrigation. *Aridic* moisture regime necessitates the need for full irrigation. Conversely, soils with *aquic* moisture regime are very wet soils and need drainage. On the other hand, about one half of the mapped soil subgroups have restriction due to lower water-holding retention capacity. Likewise, the vulnerability of soils to erosion ranks third, by which about 43% the soil subgroups are affected. Trafficability, as related to inaccessibility of machinery and impediment of mechanical cultivation due to mountainous locations, affects about one half of all identified soil subgroups. As for the combined effect of restricted drainage and salinity it appears only in 13% of the soils. Other soil limitations are minor.

4.4.2 Managing specific soil properties

Looking back to Table (3.2), only seven soil subgroups can be pointed out to be the major soils of Sana'a Basin. These subgroups are : *Typic Ustropepts, Entic Ustropepts, Typic Ustifluvents, Typic Ustorthents, Typic Torriorthents, Ustollic Calciorthids,* and *Ustollic Camborthids,* occupying more than 70% of the Basin, and along with the Rock Outcrops/ Basalt Flow they represent more than 90% of the Basin's surface. Three common soil limiting properties for these subgroups are soil moisture regime, calcareousness and trafficability. To a lesser extent, soil temperature regime and water retention (holding) capacity adversely affect about half the major soils. Management aspects of these specific soil properties will be briefly presented in the following discussions based on limited quotation from different sources.

Soil Moisture Regime (SMR): only one (udic) of the four recognized SMRi (*aridic* or *torric, ustic, udic* and *aquire*) does not introduce soil limitations. The remaining three need to be managed according to the prevailing moisture condition. The *arodic* (dry) SMR necessitates irrigation, the ustic may need supplemental irrigation, while the *aquic* SMR requires proper drainage management.

Calcareousness : indicates higher concentrations of calcium carbonates (lime). This problems needs to be addressed on a site-specific manner. Effective lime is the portion of Ca CO_3 concentration that introduces severe deficiencies in plant micro nutrients (e.g. Fe, Mn, … etc). Proper management of fertilizers containing these micro nutrients is a must to alleviate the adverse effect of increasing soil $CaCO_3$ content. Adding chelat forms and foliar application of these nutrients are among the solutions to this problem. "Man-induced" calcareousness, such as applying chemical fertilizer with alkaline base, need to be well aware of as it accentuates the problem.

Trafficability : occurs as a result of several reasons; among which are presence of coarse fragments, steepness and terracing. An appropriate technology needs to be followed to cure the problem of impeding machinery movement in cultivated fields.

Soil Temperature Regime (STR) : of the three common STR in Yemen (i.e., iso-; mesic, thermic and hyperthermic); the mesic (and iso-mesic) STR may introduce frost hazard to crops. The other two STR's resemble hot climates that certain crops may not tolerate. In each of these situation, crop selection and other temperature conditioning are needed to overcome hazards due to STR.

Water Retention (Holding) Capacity : a soil property that is closely associated with soil texture. Coarser or very fine texture can impose restriction upon soils to provide the required water storage to meet crop water requirements. Soil conditioners, natural (manure) and artificial (some biodegradable hydrocarbons), can be used safely to correct lower water-holding capacities of coarse-textured soils. Fine-textured soils need to be treated in a manner to allow higher proportion of crop-available water content.

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Soil Map Legend (King et al., 1983)

Predominant Soil Order	Soil Assoc.'s map Symbol	Soil Taxa (USA)			% of Asso-ciaton
		Sub-group	Phase	Dominant Soil Temp. Regime	
Inceptisols	Iuu	Typic Ustropepts	M,t	it	60
		Entic Ustropepts	F	it	20
		Typic Ustifluvents	F	it	10
		Ustollic Camborthids	F	it	5
		Ustollic Calciorthids	F	it	5
Entisols	Ehu Eto	Typic Ustorthents	M,t	it, iht, im	30
		Lithic Ustorthents	M	it, iht, im	5
		Typic Torriorthents	M	it, iht, im	5
		Lithic Torriorthents	M	it, iht, im	5
		Typic Ustifluvents	M	it, iht, im	5
		(Typic)Tropofluvents	M	it, iht, im	5
		Typic Natrustalfs	M	it, iht, im	5
		Entic Haplustolls	M	it, im	5
		Typic Agriudolls	M	Im	5
		Rock Outcrop	M	it, iht, im	30
Ustic Torri-orthents	Eub	Typic Ustifluvents	U	it	50
		Torriorthents	R	it	10
		Typic Ustorthents	T	it	10
		Basalt Flow	u,rl	it	30
Mollisols	Muh	Vertic Haplustolls	F	it	50
		Aridic Haplustolls	F	it	10
		Typic Haplustolls	F	it	5
		Typic Ustifluvents	F	it	30
		Typic Torriorthents	f	it	5
Rockoutcrop	Rtc	Typic Torriorthents	F	it	25
		Lithic Torriorthents	F	it	10
		Typic Torriorthents	F	it	5
		Typic Ustifluvents	F	it	5
		Typic Calciorthids	F	it	5
		Rock Outcrop		it	50
Entisols	Ehu	Typic Torriorthents	U	It, iht, ht	20%
		Typic Ustifluvents	u,t	It	20%
		Typic Ustorthents	u	It	10%
		Typic Fluvaquents	f	Iht	10%
		Typic Haplargids	u	It, iht, ht	10%
		Typic Calciorthids	u	Iht,	10%
		Typic Camborthids	m	It	10%
		Aquollic Salorthids	f	it	10%
Rock Out-crops	Ruo	Typic Ustifluvent	F	it	40%
		Rock Outcrops	Sp	it	60%