Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 353-360

DEFORESTATION IN THE SOUTH CHINA KARST AND ITS IMPACT ON STONE FOREST AQUIFERS

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ABSTRACT

G.K.W.: Environmental Changes, deforestation, aquifers
Geogr.K.W.: China, South China, Guangxi, Guizhou, Yunnan

Stone forest aquifers comprise an important class of shallow, unconfined karstic aquifers in the south China karst belt. They occur under flat areas such as floors of karst depressions, stream valleys, and karst plains. The frameworks for the aquifers are the undissolved carbonate spires and ribs in epikarst zones developed on carbonate strata. The ground water occurs within clastic sediments which infill the dissolution voids. The aquifers are thin, generally less than 100 meters thick, and are characterized by large lateral permeabilities and small storage.

The magnitude and duration of the seasonal recharge pulse that replenishes the stone forest aquifers have been severely impacted by massive post-1958 deforestation in the south China karst region. The loss of seasonal upland storage in the "green reservoir" has resulted in both a reduction in the volume of recharge to the lowland stone forest aquifers and a shortening of the seasonal recharge event. This response is compounded by increased ground water withdrawals as the people attempt to offset the declining supply.

INTRODUCTION

The purposes of this summary are to describe the hydrogeologic properties of stone forest aquifers which constitute an important class of thin, shallow, unconfined aquifers in the vast south China karst belt, Figure 1, and to qualitatively assess the impacts of deforestation on the stone forest aquifers. This article is an abridged version of Huntoon (1992a,b).

SETTING OF THE STONE FOREST AQUIFERS

Centered around the southern Chinese provinces of Yunnan and Guizhou, and the Guangxi Autonomous Region are 500,000 km^2 of the most spectacular tower karst landscapes in the World (Zhao 1988). A class of shallow aquifers, herein called stone

Figure 1. Location of Guangxi Autonomous Region and Guizhou and Yunnan provinces in south China.

forest aquifers, occurs in this terrain. These aquifers owe their existence to intense but shallow dissolution of the carbonate bedrock.

The stone forest aquifers occur under flat areas within the karst belt. They are most extensive under the inland plains found within a few hundred meters or so of sea level (Figure 2). However, as shown on Figure 3, they are also common at much higher elevations including occurrences along river valleys in the mountainous areas, under large and small karst depressions within the elevated areas, and even under flats along ground water divides.

EPIKARST AND EPIKARST AQUIFERS

Superimposed on the south China carbonate terrains, both hills and plains, is an epikarst (Figure 4) which is an intensely dissolved veneer consisting of an intricate network of intersecting roofless dissolution-widened fissures, cavities and tubes dissolved in the carbonate bedrock. The depths to the base of the epikarst zone are variable, usually being less than 100 m. As revealed in quarries and hand dug wells, the crevassed, highly dissolved upper part ranges from 10 to 30 m deep. Widely spaced dissolution-widened fractures extend another 30 to 70 m below the crevassed zone. Externally derived sediments, soils, karst breccias and residual clays infill the solution openings within the epikarst zone.

The term epikarst aquifer was first defined by Mangin (1975) to describe saturated zones within the intensely dissolved veneers found on carbonate stratigraphic sections. Since the introduction of the concept of an epikarst aquifer, the

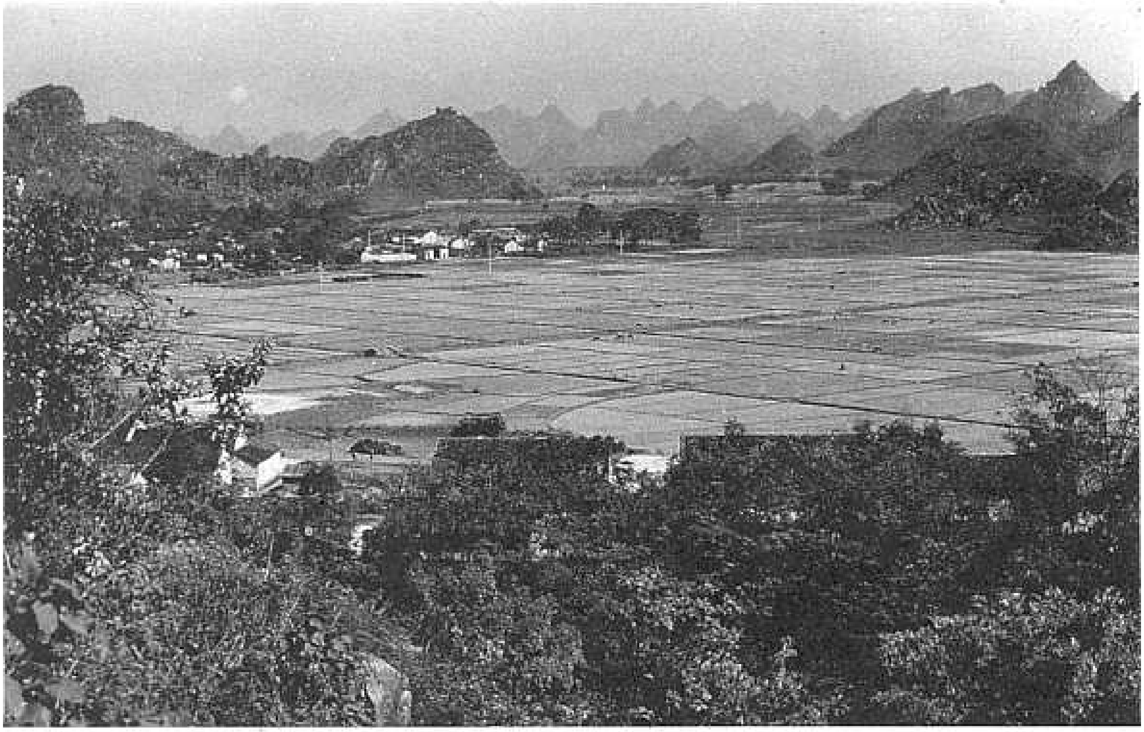

Figure 2. Carbonate peak clusters rising from a karst plain near Xiaopingyang, Guangxi Autonomous Region, China. A stone forest aquifer underlies the plain.

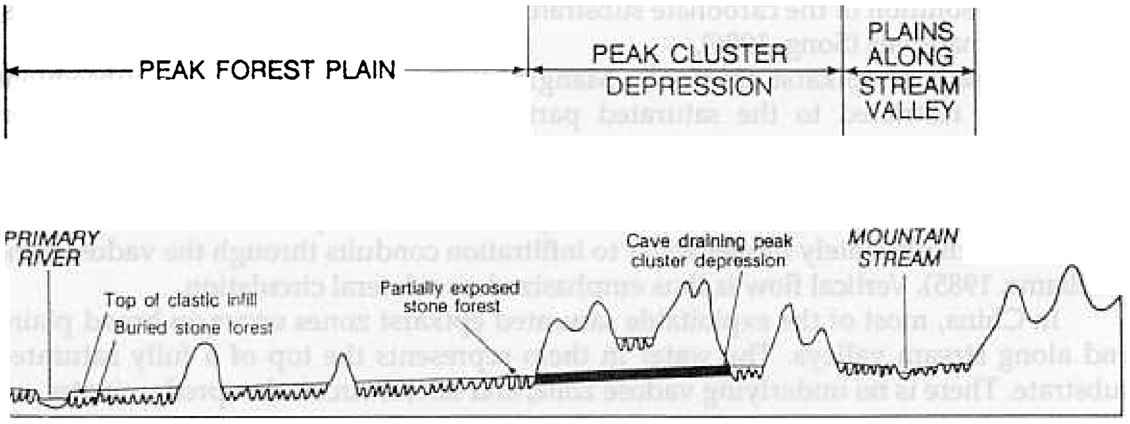

Figure 3. Schematic cross section, vertical scale greatly exaggerated, showing some typical settings for stone forest aquifers under flat areas within the south China karst. Epikarst occurs on all the carbonate surfaces; however, only the infilled epikarsts under the flat areas which host the stone forest aquifers are shown.

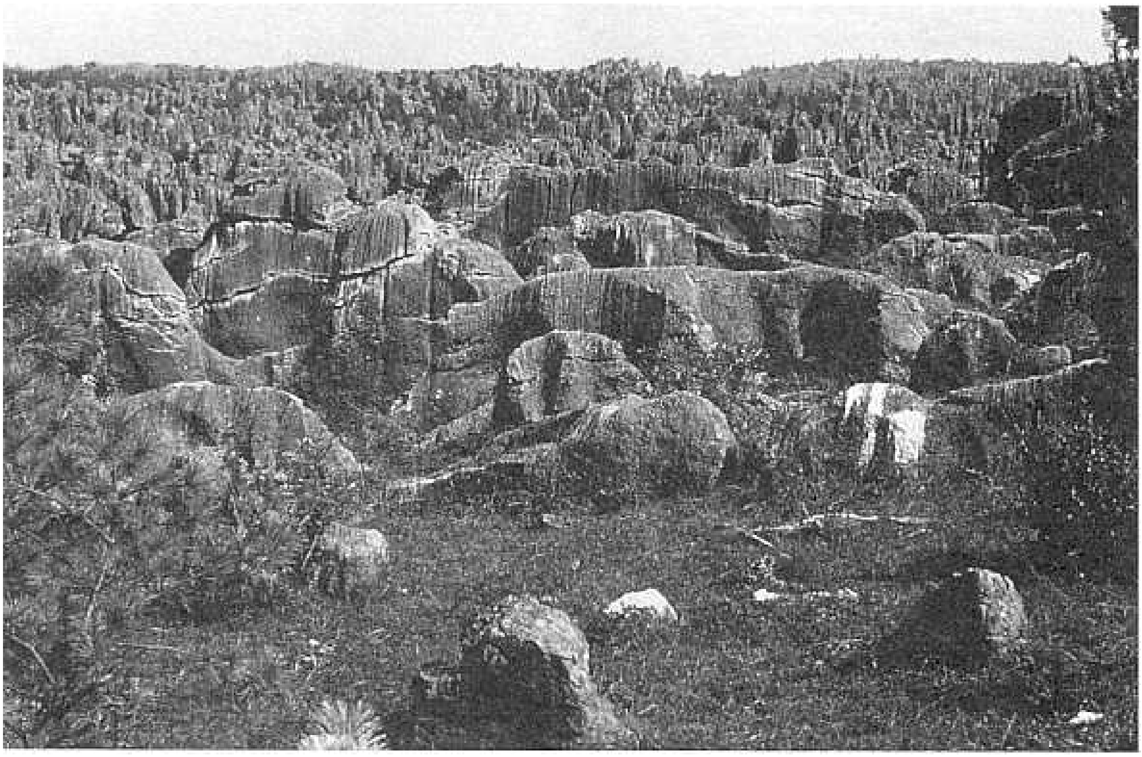

Figure 4. The famous Kunming Stone Forest 110 km from Kunming, Yunnan Province, China. This type of bedrock surface when infilled with clastic sediments serves as the framework for stone forest aquifers.

word epikarst has been widely adopted as a noun to denote the morphology of the highly dissolved veneer itself. This usage is employed here. The epikarst zone owes its origin to dissolution of the carbonate substrate beneath a mantle of soils, residual clays, and clastic materials (Song, 1986).

The usage of epikarst aquifer by Mangin (1975), as well as by most subsequent workers, is restricted to the saturated parts of dissolution veneers occurring on elevated outcrops which are separated from underlying areally extensive aquifers by a vadose zone. Although there are important lateral circulation components within the elevated epikarst aquifers, they are conceptulized as compartmentalized collector systems which ultimately funnel water to infiltration conduits through the vadose zone (Williams, 1985). Vertical flow is thus emphasized over lateral circulation.

In China, most of the exploitable saturated epikarst zones occur on broad plains and along stream valleys. The water in them represents the top of a fully saturated substrate. There is no underlying vadose zone, and lateral circulation predominates.

STONE FOREST AQUIFERS

Storage within stone forest aquifers occurs in dissolution voids in the carbonates and in intergranular porosity within the infilling sediments. Permeability through the aquifers results from (1) interconnected dissolution cavities within the carbonate bedrock, (2) partings between the carbonates and infilling sediments, and (3) intergranular permeability within the infilling sediments. The permeabilities of the dissolution cavities and partings are often extremely large, whereas the intergranular

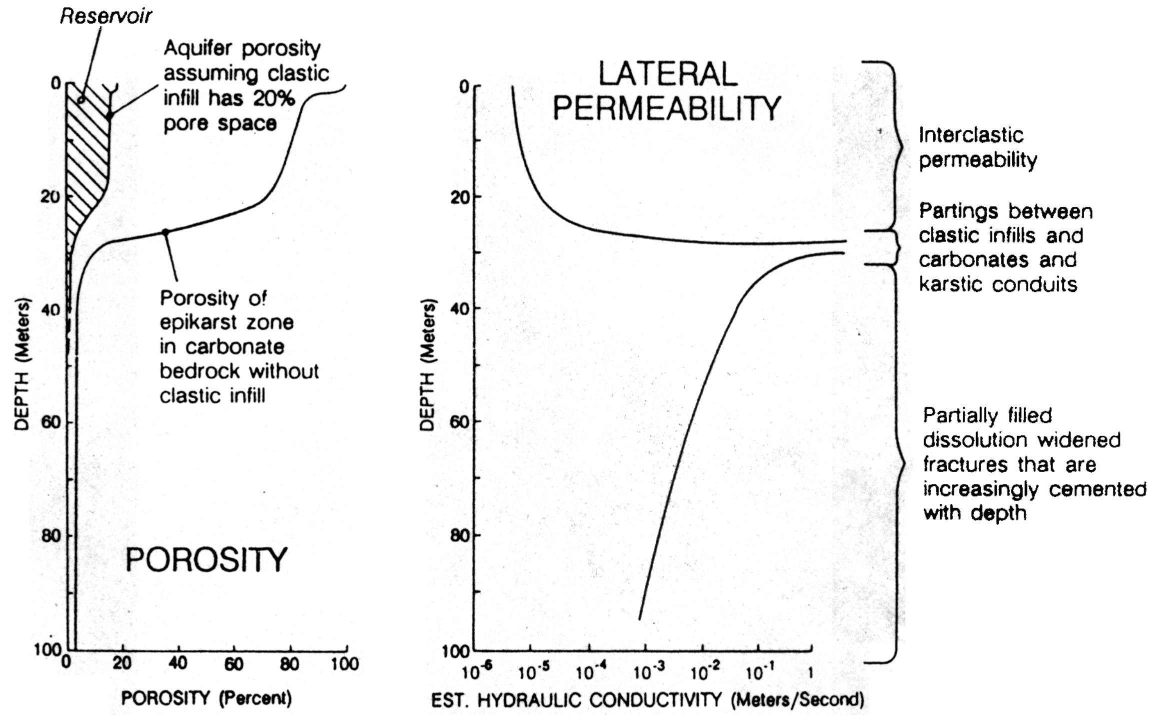

Figure 5. Idealized porosity and permeability distributions in a typical stone forest aquifer based on observations from hand dug wells and quarry walls in the vicinity of Xiaopingyang and Laibin, Guangxi Autonomous Region, China.

permeabilities of the arkoses and clays are very small.

Figure 4 summarizes the porosity and permeability distributions in a typical stone forest aquifer. The fact that the stone pillars have virtually no porosity combined with the fact that the clastic infills have porosities of about 10 to 20 percent implies that the porosity of a stone forest aquifer is considerably less than that of a corresponding volume of clastic rocks. As Figure 5 shows, the reservoir capacities of the stone forest aquifers are severely limited by the thinness of the epikarst zone.

HYDRAULIC RESPONSE TO SEASONAL RAINFALL

Most of the south China karst belt lies in the humid subtropical monsoon climatic zone. In a typical year, 70 to 75 percent of the 1 to 2 m of precipitation falls during the monsoon season from April to August. This produces flooding on the karst plains and in karst depressions. The stone forest aquifers become fully recharged to the point that water levels lie at or above the ground surface. The water levels fall rapidly with cessation of the monsoon rains. Early on, the water exits the karst plains both as surface runoff and lateral discharge through the stone forest aquifers.

As the dry season progresses, increasingly greater percentages of the total discharge from the plains circulate out through the stone forest aquifers. By October or November, water levels have fallen below the land surface to depths that commonly exceed 1/2 meter or more, even in lowlands. By December, the bulk of the annual precipitation has flowed out of the region through the aquifer and the region is starting to show signs of drought.

Figure 6. Contrast between deforested karst hills and a surviving vegetated hillside behind a small village in the area south of Wuxuan, Guangxi Autonomous Region, China.

QUALITATIVE IMPACTS OF DEFORESTATION

The deforestation of south China took place in three phases beginning with the Great Leap Forward campaign in 1958. Chairman Mao Zedong's objective in instituting the Great Leap Forward was to build a modern infrastructure in China, an effort that required steel and cement in huge quantities. The south China forests fueled this effort. This first major assault on the forests began immediately and was particularly effective. The trees were cut and converted into charcoal. In many places in south China, as shown on Figure 6, thick subtropical forests were cut to the last tree on the tops of the most remote karst hills. Once this phase was completed, cutters returned to the forests and uprooted the stumps by hand which, in turn, were converted into charcoal. The vastness of this program is unknown to me. However, the forests were virtually eliminated, save only for a few special forest preserves, for as far as one could see from Guizhou and Yunnan provinces, and the Guangxi Autonomous Region, which I visited in south China in 1988 and 1990.

The magnitude of the deforestation is revealed not by grand statistics, but rather by the following account related to me by Chen Yao Yuan. Linxu Commune was the center of steel smelting near Mashan, Guangxi Autonomous Region. Tens of thousands of people were divided into many companies to mine, transport ore, fell trees, make charcoal, smelt steel and process timber. Many blast furnaces were built and their fires burned very brightly. In 1958, about 3,000 people were employed to cut trees, each responsible for supplying a kiln load of wood per day -approximately 1 m^3. Every day 3,000 m^3 of wood were burned. The nearby karst hills were stripped bare.

Deforestation followed in two more phases. Extensive cutting took place during the Cultural Revolution between 1966 and 1976 when uninhibited by governmental restrictions, peasants cut extensively. The last serious deforestation phase occurred in the period following the decollectivization of the agricultural communes in 1979. As the peasants dispersed into the countryside, they reentered the forests to harvest the remaining trees in order to build new dwellings.

The ensuing impact on ground water supplies was the loss of what, in retrospect, the Chinese call their green reservoir. The amplitude of the flood-drought cycle has been exacerbated. This impact is compounded locally by climatic changes attending the loss of temperature and humidity moderation once provided by the forests giving rise to drier, hotter dry seasons. Desertification has begun in some of the drier areas.

The impact on the stone forest aquifers is directly attributable to loss of ground water storage in the formerly forested hills. Small springs on the flanks of the hills which were once perennial are now ephermeral. Surface flows, essential for late dry season irrigation and recharge, are now characterized by early and rapid recessions. These diminished releases of water from the green reservoir decrease dry season recharge to the stone forest aquifers which, in turn, is manifested as reduced discharges from springs and greater water level declines. Consequently, dry wells and dry karst windows have become more common as the dry season progresses. At the same time, the local population is attempting to develop more ground water to mitigate the losses.

Reforestation efforts have been undertaken. These included aerial reseeding in the early 1960s. Reforestation programs have met with some success, although two trends thwart regrowth. First, the area is experiencing a population explosion, and second, this population relies on plants for fuel. Everyday, without exaggeration, armies of peasants climb into the hills to cut brush and weeds to fuel domestic stoves and various cottage industries such as brick or lime kiln operations. The result is continuous cutting at a rate that appears to exceed steady-state regrowth in many areas. Where before a small forest area would produce relatively good quality fuel on a reasonably steady basis, now several hills must be scavanged to produce poor quality fuel having an equivalent BTU content.

The primary attribute of the ideal tree used in reforestation is that it grows rapidly. It is considered a great species if it can resprout if chopped off at ground level. Chen Yao Yuan provided the following list of species that are in common use: (1) Melia azedarach Linn, (2) Rader machera sinica (Hance) Hemsl, (3) Toona sinensis (A. Juss) Roem, and (4) Zenia insignis Chun. The Chinese foresters and hydrologists are continually seeking alternative species which they can test on karst soils.

SUMMARY

Stone forest aquifers have very large lateral permeabilities and very small storage capacities. Consequently they usually have poor development potential. Their extreme importance in the region results from the fact that they underlie most of the cultivated lowlands floored by carbonate rocks in south China.

The primary shortcoming of these aquifers is their poor ability to retain in storage the plentiful waters recharged during the April to August monsoon season. Within two to three months into the ensuing dry season, much of the water in the aquifers has drained out of the region owing to large lateral permeabilities.

The poor storage characteristics of the stone forest aquifers have been exacerbated since 1958 by massive deforestation in the upland areas. The "green reservoir" formerly retained large volumes of water in the uplands which was released to the down-gradient stone forest aquifers during the dry season, thus partially mitigating water level declines. Now this hydraulic moderation is greatly diminished. The result is a water supply crisis that has become more severe during the past few decades as a result of three mutually coupled trends. (1) The surface water flood- drought cycle has worsened through the cumulative hydraulic and climatic impacts attending deforestation. (2) Development pressure has increased on the stone forest aquifers as the surface water resources have become less reliable. (3) A population explosion in the karst belt has placed increasing demands on the total water supply and at the same time the people's requirements for wood fuels have contributed to a serious lack of progress on reforestation.

ACKNOWLEDGMENT

Financial support for this research was provided by the Institute of Karst Geology, Geological Academy Sinica, Guilin; Institute of Mountain Resources, Guizhou; and Comprehensive Technical Development Center for Mountains of Guangxi, Nanning, Peoples Republic of China. Ru Jin Wen of the Institute of Karst Geology coordinated the logistics of my research in China.

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Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 361-369

HYDROGEOCHEMICAL PATTERNS AND MATHEMATICAL CORRELATIONS IN KARST AT THE EXAMPLES OF CUBA

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ABSTRACT

G.K.W.: environmental changes, geochemistry, hydrochemistry monitoring techniques.
R.K.W.: Cuba, Pinar del Rio, Sierra del Rosario.

Physico chemical behaviour and changes in karst environmental using hydrogeochemical patterns and mathematical relationships between ionic concentration and electric conductivity of the waters from different regions of Cuba have been studied.

INTRODUCTION

The chemical composition acquisition in natural waters is controlled by a complex process in which participate physico chemical, geologic, hydrologic, climatic and environmental factors. In some places or regions with certain homogeneity, many of these factors are constant and the relative chemical composition of the water undergoes little changes, in spite of the absolute chemical composition change in a greater range. These variations are controlled by the lithology and the precipitation regime .

In this paper, the hydrogeochemical patterns of some karst and non karstic waters from Cuba, as well as the mathematical correlations between ionic contents and electric conductivity of the waters, are presented. Anthropogenic on karst are also discussed in terms of variations in mineralization, hydrogeochemical patterns and mathematical relationship in the long run.

MATERIALS AND METHODS

The water samples were systematically collected and analysed "in situ" using the Markowicz and Pulina methods (1972). The hydrochemical data were processed by SAPHIQ and SAMA computer programs - automatic systems for hydrochemical data processing and water quality monitoring (Alvarez et al, 1990) - available in TURBO PASCAL. By means of these systems, the original data were analysed and depurated on the basis of the errors between the theoretical and measured electric conductivity as well as the analysis of the ionic ratios in correspondence with the local lithology. Also, mathematical relationships were obtained with these systems between ionic contents and electric conductivity using a polynomial model from one to five degrees, which pass through the axis crossing point.

Many scientist have not found good correlation coefficients between ionic concentration and electric conductivity. Only significant fittings were reported for the mineralization (Bakalowicz, 1974), total ion concentration (Ford and Williams, 1989), the major macroconstituents of the waters (Drake and Ford, 1974) and other physico chemical parameters (Langmuir, 1971; Bray, 1977; Herman and White, 1984). As criterion of good mathematical agreement we use in this paper the similarity index SI defined by

$$SI = \frac{\sum_{i=0}^{n} R1\ R2}{2}$$

where:

Rl: Relation between the ionic concentration obtained by chemical analysis and modelling;

R2: Relation between each ion and the total sum of ions.

Further control of chemical composition of waters can be made by means of the corresponding mathematical equations and the measurement "in situ" of electric conductivity. The theory which support the use of referred computer programs has been recently reported (Fagundo, 1990).

The hydrogeochemical patterns are represented in this paper by means of the diagrams proposed by Stiff (1951) and the stecheometric relations $Na^+ + K^+ : Ca^{2+} : Mg^{2+} : Cl^- : HC0_3^- : S0_4^{2-}$, where the sum of ions and cations are both equal to 10 meq/L.

RESULTS AND DISCUSSION

In order to study the physico chemical behaviour of the karst waters, its hydrogeochemical patterns and changes developed by the effect of natural and anthropogenic factors, two typical Cuban karst areas were chosen: San Marcos river basin in Sierra del Rosario and the developed karst in southern plain, both in Pinar del Rio province, representatives of mountain and coastal plain tropical karst, respectively.

San Marcos river basin

This region is characterized by the tectonic and lithologic features (Pszczolkowski et al., 1987). Different types of rocks as sedimentary-effusive, ultrabasic and limestones from Paleogene to Cretaceous and also Quaternary sediment covers occur.

The lithology and the water flow conditions are the major factors that determine the chemical composition of the waters and the hydrogeochemical patterns. We can distinguish the following water types: sodium calcium hydrocarbonate for waters from the sedimentary-effusive rocks, magnesium hydrocarbonate for the waters which originate in the ultrabasic massif, and calcium hydrocarbonate for that waters which flow in the karst areas (at the source, caves, exsurgences and springs from the

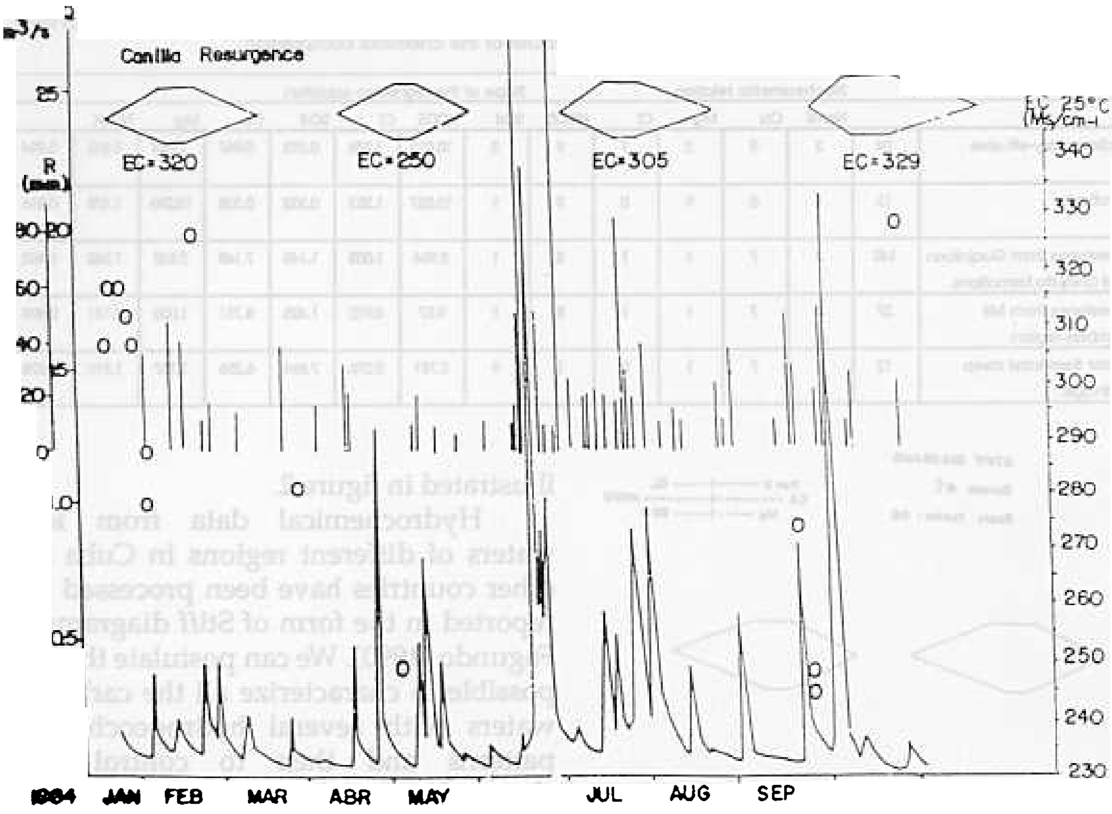

Fig. 1 - Variation of the water level, debit, mineralization (in terms of electric conductivity) and chemical composition at Canilla exsurgence during the 1984-1985 hydrological year as a consequence of the rain regime.

saturation zone). Finally, there are waters of calcium sulphate type from the karst deep drainage (deep phreatic zone).

These waters change the absolute chemical composition as a consequence of the rain regime, but practically do not undergo changes in its relative chemical composition as we can see in the figure 1 for one hydrological year. The ion stecheometric relations are the same for each sample. Similar behaviour in other systematic sampling points in other regions was observed.

The hydrogeochemical patterns of the waters from San Marcos basin in terms of the corresponding stecheometric relations appear in table 1.

Linear equations were obtained when concentration in each ion and electric conductivity data were fitted. The slops of the corresponding regression equations are also listed in table 1. The magnitude of the slops are functions of the ionic concentrations of the waters and the local lithology. Three hydrogeochemical patterns characterize all karst waters of the basin and there are other two for the non karstic waters.

The mean similarity index between real and theoretical values of the chemical composition is also expressed for each type of water in table 1, and the corresponding chemical composition obtained for an example by analysis and modelling are

Table 1 - Hydrogeochemical patterns as a function of stecheometric relations.
Slopes of the linear relationship between ionic concentration and electric conductivity of the water from San Marco River basin, and the similarity index (SI) between real and modelling values of the chemical composition

Geological environment	N	Stecheometric relation						Slope of the regression equation						SI
		Na+K	Ca	Mg	Cl	HCO3	SO4	HCO3	Cl	SO4	Ca	Mg	Na+K	
Sedimentary-effusive	34	3	5	2	1	9	0	10.013	1.276	0.393	5.947	1.933	3.802	0.894
Ultrabasic.	13	1	0	9	0	9	1	10.537	1.253	0.332	0.338	10.296	1.478	0.898
Limestones from Guajaibon and Chiquita formations.	140	2	7	1	1	8	1	8.994	1.003	1.148	7.148	7.832	1.242	0.883
Limestones from Mil Cumbres region.	27	2	7	1	1	8	1	9.57	0.912	1.405	8.751	1.005	2.131	0.893
Water from karst deep drainage.	12	2	7	1	0	1	9	0.781	0.276	7.866	6.256	1.157	1.510	0.978

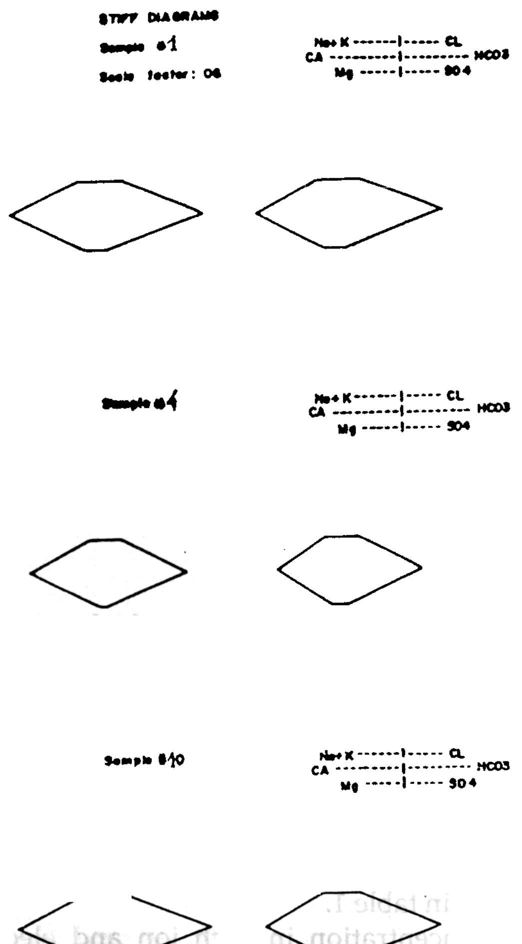

Fig. 2 - Chemical composition of the Canilla resurgence determined during the period 1984-1989 by means of field chemical analysis (on the left) and modelling (on the right).

illustrated in figure 2.

Hydrochemical data from karst waters of different regions in Cuba and other countries have been processed and reported in the form of Stiff diagrams by Fagundo (1990). We can postulate that it is possible to characterize all the carbonate waters with several hydrogeochemical patterns and then to control their chemical composition with a few set of mathematical relationships between ionic concentration and electric conductivity (see figure 3).

Pinar del Rio southern coastal karstic plain

In the southern part of Pinar del Rio province there are a great karst massif constituted by Miocene limestones, partially dolomitized and occasionally covered by Quaternary sediments. In this area, a reach aquifer occurs whose recharge zone is in the premountains region at the North, and it is freely discharged to the sea at the South. The waters in the aquifers are of calcium hydrocarbonate type in the zone non affected by the seawater mixing. Toward the coast some hydrochemical facies occur as the result of the mixing between fresh and marine waters. They are stratified along the vertical profile of each well and a horizontal profile across the aquifers (Arellano and Fagundo, 1985). The hydrogeochemical patterns for these waters are illustrated in figure 4.

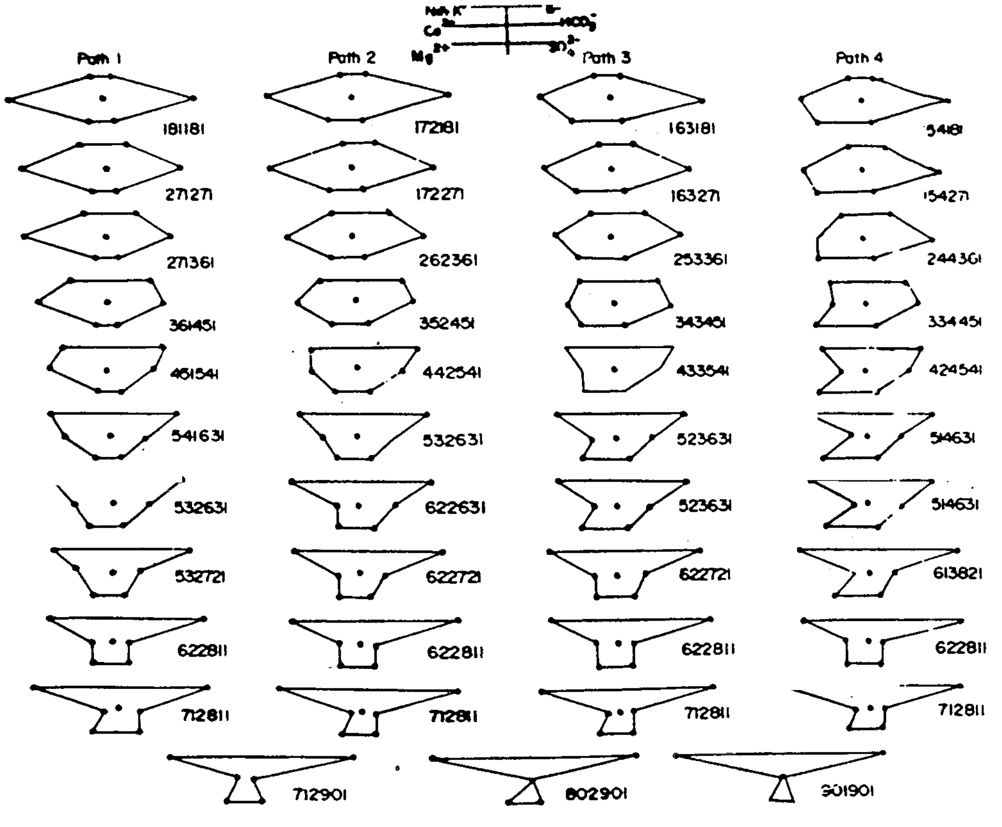

Fig. 3 - Some hydrogeochemical patterns characteristic for karst waters from different Cuban regions and other countries.

There are also different modes of water chemical evolution in this region, which depend on the dolomitization degree of the sampling site inside the aquifer. In such conditions different contents of magnesium for same seawater mixing level exist. We have observed at least, four chemical evolution paths for the waters of these regions as well as for other coastal karst aquifers in Cuba (see figure 5).

We have occasionally observed changes in the original hydrogeochemical patterns in a some sampling points (well) in the long run. Generally, it is due to a decrease in the rain regime and/or an increase in the aquifer overexploitation. In this case, the mineralization and NaCl salinity showed a progressive increase during the observational period (see figure 6). The additional quantity of foreign ions as Na+, K+ and Cl in hydrocarbonate water increase calcite and dolomite solubility and considerable quantity of carbonate rock can be solved from the aquifer (Picknett et al., 1976).

In this type of water the corresponding fitting of the ion contents and electric conductivity data is more significant for the second degree than linear equations if all the data are processed. Better results can be obtained processing the data corresponding to each hydrogeochemical pattern (see table 2). In this case,

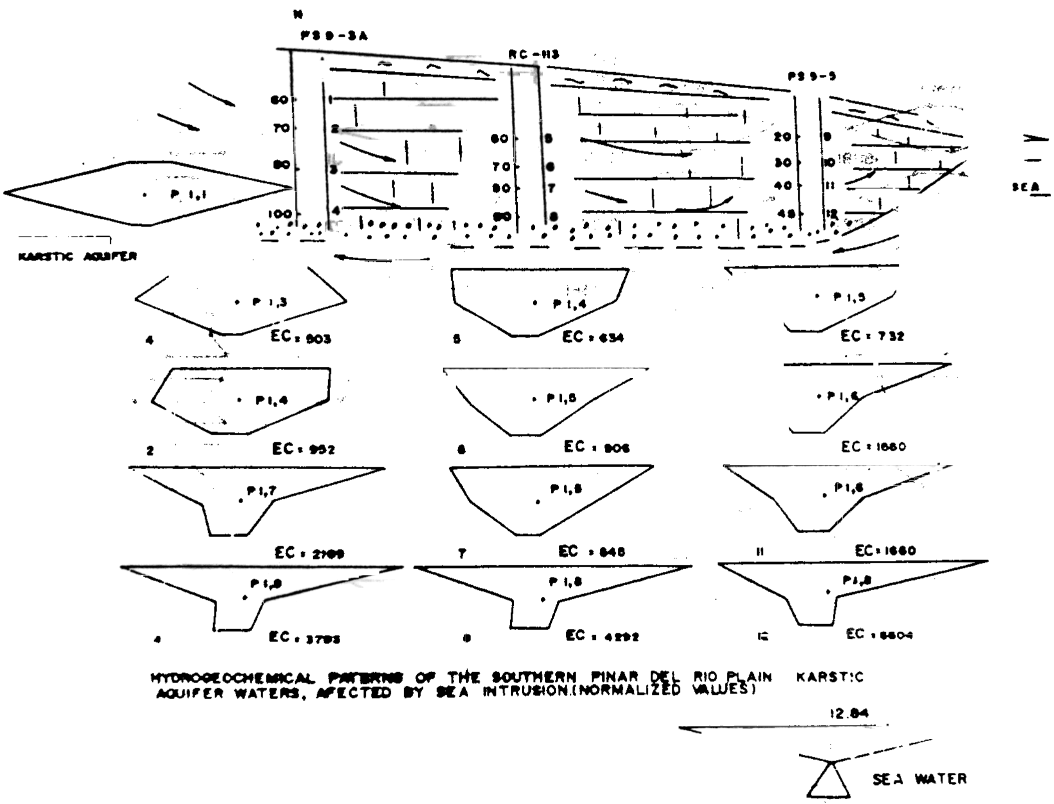

Fig. 4 - Hydrogeochemical patterns of waters from wells along vertical and horizontal profiles at the coastal aquifer karst of the Pinar del Rio southern plain.

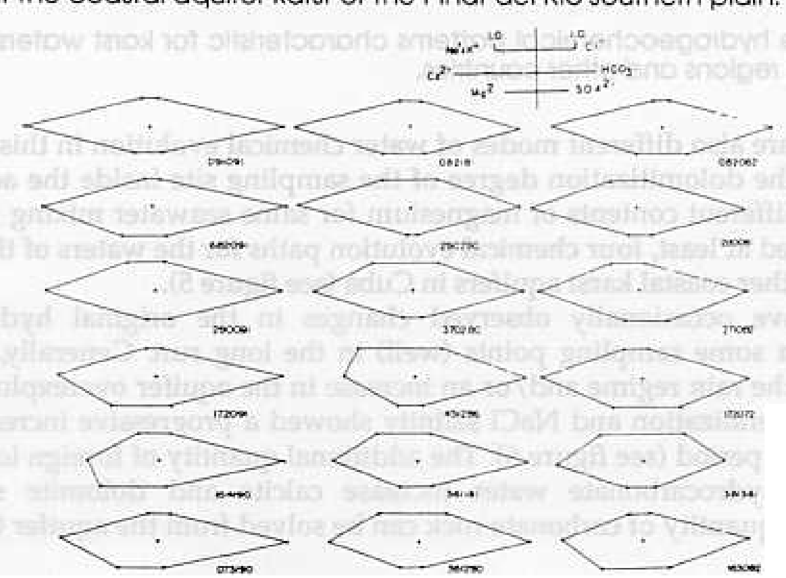

Fig. 5 - Hydrogeochemical patterns and evolution path of waters depending on the dolomitization degree at the coastal aquifer karst of the Pinar del Rio southern plain.

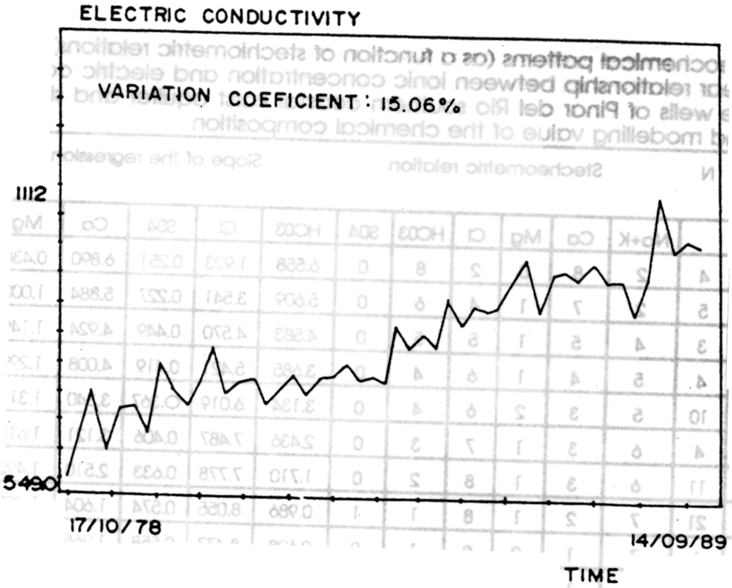

Fig. 6 - Changes in the mineralization (and salinity) during the period 1978-1988 at an observational sampling point from the coastal aquifer karst of the Pinar del Rio southern plain.

mathematical equations are of linear type. Using these expressions and the electric conductivity measurement in field by means of a conductimeter connected to a 100 m probe it is possible to control the chemical composition and salinity of the waters, but we need to take into account the range in which each sampling point reflects the different hydrogeochemical pattern (see table 3).

CONCLUSIONS

The lithology and the water flow conditions determine the hydrogeochemical patterns, characterized by a given stecheometric relation. In the case of tropical karst and non karstic waters there is, generally, one hydrogeochemical pattern in the same sampling point, where many of the factors remain constants. In case of underground waters there are less changes of the relative chemical composition than in the first surface waters. A discrete number of hydrogeochemical patterns can characterize all the waters running through the limestones.

More variability can be distinguish in coastal karst aquifers encroached by seawaters, where waters in the aquifer are stratified along vertical and horizontal profiles. In such cases, different chemical facies in a same well occur.

The human activity can change the natural hydrogeochemical patterns in the karst as a consequence of the wastewaters input the chemical treatment in the agriculture and the aquifer overexploitation. In coastal karst areas, the latter increases significantly the water salinity and the karstic processes.

In all the cases, empirical mathematical relationships were found between ionic chemical composition and the electric conductivity of the waters. In one of the controlling factors of the chemical composition acquisition is dominant, as for instance

Table 2 - Hydrogeochemical patterns (as a function of stechiometric relations).
Slopes of the linear relationship between ionic concentration and electric conductivity of the water from some wells of Pinar del Rio southern coastal karst aquifer and similarity index (SI) between real and modelling value of the chemical composition

Hydrogeo-chemical pattern	N	Stecheometric relation						Slope of the regression equation						SI
		Na+K	Ca	Mg	Cl	HC03	S04	HC03	Cl	S04	Ca	Mg	Na+K	
HP1	4	2	8	0	2	8	0	6.558	1.923	0.251	6.890	0.438	1.404	0.932
HP2	5	2	7	1	4	6	0	5.609	3.541	0.227	5.884	1.000	2.493	0.923
HP3	3	4	5	1	5	5	0	4.583	4.570	0.449	4.924	1.149	3.529	0.958
HP4	4	5	4	1	6	4	0	3.685	5.421	0.419	4.008	1.299	4.218	0.945
HP5	10	5	3	2	6	4	0	3.134	6.019	O.367	3.340	1.311	4.869	0.898
HP6	4	6	3	1	7	3	0	2.436	7.487	0.406	3.121	1.618	5.590	0.936
HP7	11	6	3	1	8	2	0	1.710	7.778	0.633	2.510	1.492	6.119	0.919
HP8	21	7	2	1	8	1	1	0.986	8.055	0.574	1.604	1.400	6.611	0.931
HP9	6	7	1	2	9	1	0	0.628	8.477	0.558	1.265	1.700	6.698	0.941
HP10	7	8	1	1	9		1	0.282	8.913	0.665	0.844	1.449	7.567	0.944

Table 3 - Electric conductivity ranges in which each well from part of the Pinar del Rio coastal Karst aquifer to reflex the different hydrogeochemical patterns.

Well	Deep	HP1	HP2	HP3	HP4	HP5	HP6	HP7	HP8	HP9	HP10
P2	60-100	300-399	400-585	590-689	690-969	970-1219	1220-1879	1820-3779	3780-4691	4700-6000	>6000
P4	60-90				300-794	800-1279	1280-1799	1800-2449	2450-5159	5160-7000	>7000
P5	20-50					500-999	1000-1699	1700-1839	1840-4249	4250-7709	>7710
P1	70-100	400-529	530-649	650-779	780-950						
P6	60-90					200-359	360-449	450-1699	1700-4000		
P3	30-40				600-999	1000-1699	1700-2299	2300-2899	2900-4399	4400-8299	>8300
P7	40-70							500-949	950-4129	4130-7399	>7400

the lithology, the most accurate equations are of the linear type but if more than one of these factors play the major role in the mode of chemical composition acquisition we can found that non linear equation are the better when all the data are processed and linear equations are the best when the corresponding data of each hydrogeochemical pattern are separately processed. By means of these equations and field measurements of electric conductivity it is possible to control the water quality in terms of chemical composition, mineralization and salinity.

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Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 371-376

TOPOCLIMATIC FACTORS OF AIR POLLUTION IN KARST

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ABSTRACT:

G.K.W. air pollutants, topoclimate changes, urban pollution
Geogr. K. W.: Yugoslavia, Montenegro, Dragova luka, Niksicko polje

Air is physical space with a characteristic gas-structure and ingredient that made life possible for the majority of living things on Earth. For this reason it is important that the quality of the air is high enough to support life.

Bearing in mind the fact, that air is a composition of gases,with different chemical compositions, specific weight densities and mobility, it is certain that the physical condition of earth's surface will cause change in the ordinary structure of the atmosphere. The morphology of the ground creates a specific kind of climate, a topoclimate, which has a big influence on the concentration of pollutes, as a result we can speak about the inter-relationship of ground-morphology, climate and air pollution. Karst is characterized by a heterogeneous and jagged surface morphology, which creates a mosaic topoclimate.

I. Mosaic topoclimate at karst as result of jagged karst morphology

By topoclimate we imply the kind of microclimate, which is a product of the influence of a topographic surface and which shows itself as a deviation from the normal climatic parameters of a place.

This deviation could manifest itself in a positive or negative variation in temperature humidity velocity, intensity and direction of wind, and in the quantity of precipitation (rain).

We made measurements on Montenegrian karst (the holokarst surrounding Nik`isko polje, and high mountain karst on Durmitor), and on the shallow karst (merokarst) surrounding Belgrade. We measured the temperature and humidity of the air and the ground, the velocity and direction of the wind, and the the depth of the snow cover. We paid special attention to concave (doline) forms and convex (hum or hill) forms.

The measurements were made over some time in order to eliminate the time factor from the experiment. By this method we were able to concentrate on the special components of microclimatic parameters. We used automatic meteorological measuring instruments with processors in order to avoid the influence of human presence on the microclimate. The presence of people can change the temperature, making it higher in winter and lower in summer, it can increase the humidity slightly and can influence wind direction and velocity. We attempted to select dolines and hums with no woody or brush vegetation and with an even grass cover. Because of the small variations we used a very precise instrument which could be read to the second decimal, in other word exacted +/-0,01%.

THE RESULTS OF MEASURING

1. Merokarst surrounding Belgrade

Measuring in a doline in village Sremlica, south of Belgrade (dimensions of doline: length 28 m, breadth 19,5 m, depth -7,5 m):

- measuring date: 17 July 1990; 12 February 1991
- meteorological parameters of place (Beograd):

July, 12 h: temp.: 32.1 °C; humidity 56%; wind velocity 3.2 m/s
cloudy 0%.
Febr., 13 h: temp. 1.8 °C; humidity 79%; wind velocity 2.6 m/s
cloudy 20%; high of snow-cover 18 cm.

2. Holokarst of Montenegro (Niksicko polje)

a) Measuring in doline in village Dragova luka, near Niksic (dimensions of doline: length 64 m; breadth 51 m; depth 24.5 m):

- meas. date: 2 August 1984 at 12 h and 4 February 1985 (12 h);
- meteorolog. parameters place Niksic: air temperature 31.6 °C; air humidity 48%; wind velocity 1.8 m/s (August); and air temp. -0.2°C; humidity 92%; wind velocity 3.6 m/s (February);

b) Measuring of hum Ridjanska glavica (west of Niksic):

- dimension in hum: length 56 m; breadth 48 m; height 26 m;
- meas. date: 3 August 1984 at 12 h; 5 February 1985 at 12 h;
- meteorological parameter place: air temperature 31.4 °C; air humidity 47%; wind velocity 2.1 m/s (August); and temper. -0.3 °C; humidity 88%; wind velocity 1.2 m/s (February)

As can be seen from the above list and draft number l the pollominy phenomenon by dolines are:

Tab. 1 Variable of measured meteorological parameters in doline in village Sremlica, 12th July at 12h

meteor parameters	locations							
	1	2	3	4	4	6	7	8
temperature in °C	34,0	34,6	31,0	27,2	28,1	26,1	30,4	27,3
humidity of air %	52	60	56	64	53	68	55	69
soil humidity %	11	32	14	34	12	36	16	42
wind velocity, m/s	3,2	1,2	3,0	1,6	3,0	1,3	3,4	1,4
13 th February at 13 h								
temperature in °C	2,8	4,6	1,7	0,8	1,8	1,1	1,9	0,8
air humidity in %	70	82	78	81	86	92	80	90
soil humidity in %	35	48	38	50	36	54	37	57
wind velocity, m/s	2,6	1,3	2,4	1,4	2,4	1,0	2,3	1,1
high snow in cm	0,0	0,5	21,0	35,0	30,5	46,0	15,5	6,0

Table 2 Variable of measured meteorological parameters in doline, and on hum near Niksic (Montenegro)

a) Measuring in doline in village Dragova luka

meteor parameters	1	2	3	4	5	6	7	8
	locations							
measuring in August								
air temperat. °C	38,1	39,2	31,3	29,0	28,3	23,1	31,3	26,1
air humidity %	40	38	48	54	48	68	50	70
soill humidity %	9	18	10	21	17	31	19	29
wind velocity m/s	2,1	1,1	2,0	1,0	2,0	1,2	2,1	1,4
mesuring in February								
air temperat. °C	-5,6	-6,2	-0,2	+0,1	+1,2	+3,2	-0,1	-0,3
air humidity %	86	92	86	92	88	96	87	96
soil humidity %	30	45	34	47	38	56	36	56
wind velocity m/s	3,4	1,6	2,8	1,1	3,2	1,8	2,6	1,0

b) Measuring into hum in village Ridjani ner Niksic

measuring in August								
air temperat. °C	29,1	28,1	31,2	31,3	34,1	35,1	29,8	27,9
air humidity %	38	35	37	34	40	36	41	40
soil humidity %	17	6	15	6	10	3	16	6
wind velocity m/s	2,2	2,8	2,0	3,0	1,9	2,2	1,8	2,9
measuring in February								
air temperat. °C	-3,8	-3,4	-2,1	-0,1	+0,2	+0,4	-0,8	-3,2
air humidity %	92	84	88	80	80	78	90	88
soil humidity %	42	31	41	30	38	30	40	32
wind velocity m/s	0,8	1,4	0,9	1,6	1,0	1,9	0,9	1,7

- the air temperatures are lower at the bottom than on the edge (inversion);

- the air temperatures are lower on the north slope than on south (result of exposition);

- bigger differences in air temperature are observable between the northern and southern exposition, the bottom and the top (exposition coefficient of difference is about O.40 and topological difference coefficient is about 0.25);

- the different soil-temperatures were measured, but those were smaller than air-temperature (this results from thermal inertia);

- the topological difference in the soil-temperature reduced with depth; at a depth greater than 1.8 m no topological difference were registrated;

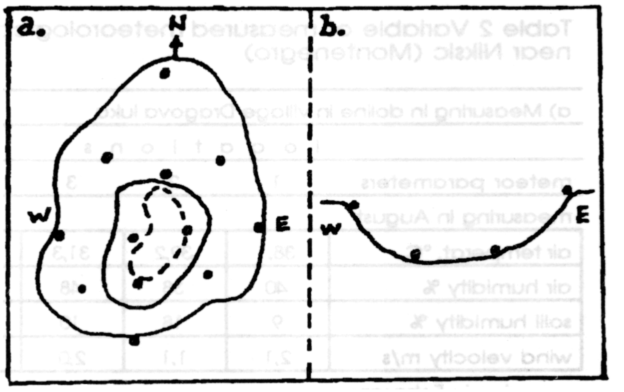
- deviation from this norm is possible only if there is a cavern not far below the surface (such influence we found in Lusci polje in West Bosnia, but it is a separate problem for another work);

- there are only slight differences in air humidity between location in dolines, because the measurement were made in the afternoon; those differences were noticeable only in the morning, but we haven't presented them now because of reciprocal parallel and elimination of time-factor;

- the differences in soil humidity are visible; on the south exposition at a depth of 5 cm the soil is on the whole 20 % drier than on the north exposition;

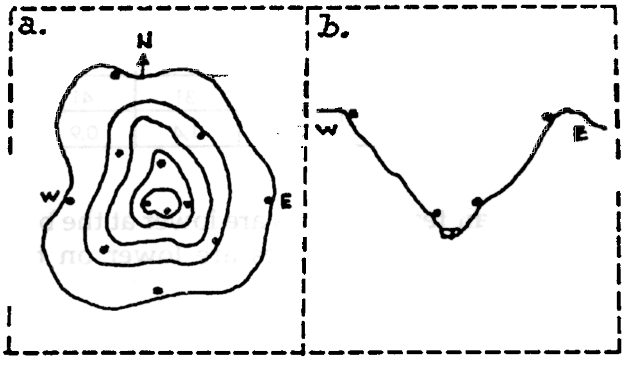
- the topological differences in the coefficient of humidity of the soil are reduced;

Fig.I. Location of measuring point in doline in Sremcica Village (a: plan; b: profile contour interval is 5 m)



- because of the change in terrain configuration the wind direction changes; this change in direction is different depending on the location of the measuring point;
- the changes of wind direction refer to deviations from the basic-horizontal direction;
- modification in the wind-velocity is also registrated on the frontal (blow-side) and the increase on the opposite side, wind-velocities are lower at the bottom than on the edge of doline;
- the depth of snow-cover is different on some parts of the doline depending on the exposition, but also on the position in relation to the dominant north-west wind direction.

Fig.2. Location of measuring point in doline in village Dragova Luka near Niksic (a: plan, b: profile; contour interval: 5 m)



Topological differences by some meteorological factors on the hums (hills) are:
- air temperatures are lower at the north expositions on the whole by 2.8 °C than on the south;
- those differences are less in relation to the east and west side, although differences were also noticed between them (the west exposition having lower temperatures than the east); this is the result of late sunning.

Differences in temperature were registrated between the top and bottom. At the south exposition the highest temperatures (those are the highest air-temperatures on the whole hum) were measured on a little bit above the middle part of the south exposition. When temperatures are lower than at the bottom of the south side (this is the result of moist air at the bottom of the north-west exposition of hum.

Pollutants with a specific weight lower than the air gas-mixture concentrate

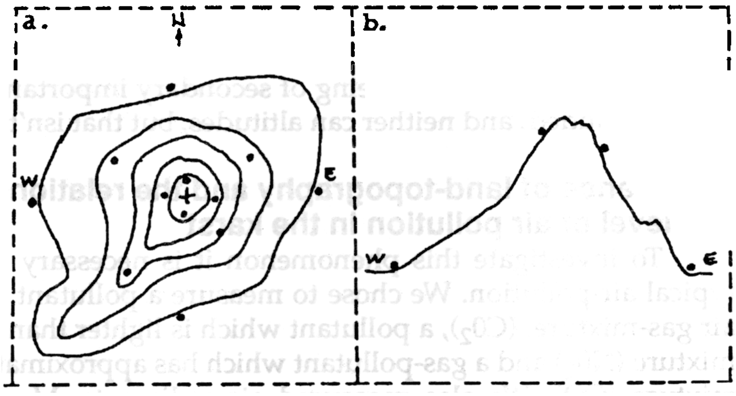


Fig.3. Location of the measuring point in hum Ridjanske glavice near Niksic (Montenegro)

Table 3. Measuring results of the air pollution level

a) doline

	l o c a t o n s							
	1	2	3	4	5	6	7	8
SO2	-	-	-	-	-	-	-	-
NO2	121	134	123	137	118	136	118	142
CO	8	12	10	14	11	18	10	15
aerosols	80	115	82	118	90	121	88	119

b) hum (hill)

SO2	-	-	-	-	-	-	-	-
NO2	150	123	147	120	135	112	148	125
CO	17	12	14	11	11	10	14	11
aerosols	124	110	92	88	118	90	93	84

where the air is warmer and drier. The deposition of air sediments depends more on the direction and velocity of the wind, and less on the temperature and humidity. The biggest quantity of air sediment was found where the wind velocity is lowest, that is the leeward part near the top and on the blow-side near the bottom. The smallest quantity was measured on the hill-sides.

Soil humidity at the depth of 5 cm was different. At the top of the hum and on the south exposition it was lower than on the north exposition and at the bottom of the hum. The highest soil humidity was measured at the bottom of the northwest side of the hum. The position of the locality in relation to the direction of the wind on this day influenced the soil humidity. The part onto which the wind was blowing were drier than the leeward.

The highest wind velocities were measured on the hum side and the smallest at the bottom of the hill, from the windward side. The changes in wind direction are the results of the ground-morphology and they are in accordance with the ground topography. The change of the wind direction also brings about a change in the power and velocity of the wind.

Analysing the results and the factors it could be concluded that the convex form (hum) and concave forms (dolines, uvalas and karstic poljes) have an effect on the value of the meteorological parameters. The resulting mosaic is in the main the result of the topographic factors and the ecological factors have less influence.

The affirmation is that microclimates on the karst are predominantly topoclimates, ecoclimates being of secondary importance. Climate zoning-factors can not be excluded, and neither can altitudes, but that isn't the object of this research.

2. Influence of land-topography and the relationship between topoclimate and level of air pollution in the karst

To investigate this phenomenon it is necessary to measure the levels of some typical air-pollution. We chose to measure a pollutant which is heavier than ordinary air gas-mixture, ($C0_2$), a pollutant which is lighter than the ordinary weight of air gas-mixture ($N0_2$) and a gas-pollutant which has approximately the same weight as air-gas-mixture (CO). We also measured air sediments. Measurements were made on the northwest rim of Niksisko polje in a doline not far from a bloomery, where there is daily pollution, and on the top of a hum where there is a meteorological station on the outskirts of Niksic town, where there is constant urban air-pollution. Measurements were made at the time of maximum pollution in winter (February). The dimensions of doline are: length 75 m; breadth 62 m; and depth 38 m. Dimension of hum are: diameter 68 m, high 21 m.

As it can be seen from a comparison of indicators the topoclimatic parameters influence the concentrations of particular pollutants in the karst. Pollutants with a specific weight are bound by their density to the locality colder and more moist air at the bottom of the north-west exposition of hum.

These indicators help urban planners to fix optimum land destination. In areas where greater pollution is to be expected with toxic pollutants we didn't plan recreation, faculties homes, health and school buildings. With this knowledge we can fix the locations for forest protection zones, and locate industry. The conclusion is that it isn't desirable to build industrial and other polluting capacities in karst depressions, because they create a "pollution pocket", and the polluted air takes a long time to disperse because of the reduced wind-influence.

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Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 377-382

TOWN AND LAND USE PLANNING IN KARST POLJES

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ABSTRACT

G. K.W.: agrochemistry, pollution, ecosystem, karst environment.
Geogr.. K. W.: Yugoslavia, Bosnia, Croatia, Montenegro, Slovenia, Cetinje.

Karst is a specific landscape with numberless limiting factors connected with human life, economy and other activities. Land use planning is reflective human activity, which has the intention to trend and to rule with direction and menagement of development in the way particularly expanse could give the optimum of land use.

The urban planning engages settlement with purpose of the settlement itself, it is particular functions of part of settlement, to determinate for optimum living there and for the best functions of particular parts of it.

The goal of planning is harmonize the possibilities of the natural environment with the human needs, of the people who lives there. It is well-known that karst is very poor expense. There are many limiting factors, there are not materials and resources, so life is very hard. Taking everything into consideration land use and urban planning in karst conditions is very difficult.

INTRODUCTION

Every planner, working on karst has to bear in mind the following limitation:

1. Water-shortage in the most part of this territory

2. Seasonal water surplus in some parts of the karst, that causes floods, and has to be taken into account in planing

3. Shortage of mineral raw materials and other mineral resources which makes economic planning difficult.

4. The big unevenness of the terrain, makes the limitations for planing traffic, so that infrastructure segment is more complicated .

5. The temperature inversions in karst depression and accumulation of leaden air pollutants brings to enlarged pollution so that each planning of industry and suppling with heat, involves all these consequences.

6. Very sensitive ecosystem due to thin pedological cover so that every antropogenic intervention is risky and demands sensitive planning.

7. A very small quantity of fruitful soil made impossible intensive agriculture on a large scale and results in agrarian over population and problems of local food supply.

8. Because difficult climatic conditions, forest ecosystems are very unstable, so

that any human intervention could have catastrophic effects on forests and the forest economy.

9. The scattered settlement pattern with considerable distances between houses makes difficult for supply of electro-energy, water and drainage, PTT services and other utilities.

I. PLANNING PREDISPOSITION AND CHARACTERISTICS OF KARST POLJES

In order to plan effectively for land use and urban development we have to bear in mind many factors. The most important of these is to determine living and working conditions, cultural and recreation needs. That is why we talk about affirmative and destimulative factors of planning. Both of them exist on karst poljes.

a) Affirmative factors of urban planning

A karst polje is oasis of life in the karst-desert. It is different from the surrounding karst because of life better possibilities - these are:

1. The bottom of a polje is level and it is therefore easier for town-building; apartment buildings etc. can be built closer together and traffic is easier.

2. There is a greater abundance of of productive land in a polje and as a result there are many settlements.

3. In a polje there is often flowing water and there are wells; the general water problem in karst is therefore less acute.

4. In some poljes there are exploitable deposits of lignite that could improve economic situation.

5. The base of a karst polje consists of soft sediments so it is easier to build an underground infrastructure (plumbing, sewerage system, telephone network), than on the neighbouring karst.

6. Planning in karst poljes is more softly, and building streets, parks, centres for sport and recreation, too.

7. Communal organization (streets cleaning trash collecting, buildings and parks maintenance) is simple on karst polje.

8. The important planners job is planning agrarian production in a polje to supply the town with all necessary products.

b) Destimulative factors of urban planing on karst polje

Despite of these advantages over the surrounding karst locality a polje is not the best place to build a settlement. Building a settlement implies some industrial activity, services, car-garages, and operation-servicing. These have a very negative effect on the quality of life and in karst-conditions it is more characteristic.

The quality of the life in karst polje rapidly worsens because of pollution. Polje is a concave depression in relation to the surrounding locality, pollutants from industry, thermo-electrical power generation, traffic, individual heating, and agrarian production accumulate at the bottom of the polje. There is no possibility of good ventilation, so smog typical of an inversion locality develops, creating a green house effect. As the temperature rises air circulates in the polje, carrying dust and other air sediments to a certain high (forming a blanket) which alters the attributes of microclimate. It is very important to take care about the location of industrial and energetic pollutes. And planners have to decide if it is necessary to build them in poljes at all.

If the settlement is planed and built in a polje it is necessary to ensure sufficient quantity of water. Water is necessary for drinking and also for the function of economy, cleaning the streets, cleaning cars, for domestic consummation, for watering gardens and for cattle. Often there is no enough water in the polje or in the surrounding area, and it has to be brought from elsewhere offsetting the hydrological balance of the polje. We must consider the problems associated with waste-water from industry and urban areas falls through if the ponor into the karst-underground, it is rarely cleaned naturally and flows long distance, reaching wells unpurified.

Waste-water from industry is full of acids, alkalines, decomposed salt, and heavy metals from servicing-activities. From the streets it carries naphtha derivates, oil, phenols and suspensions. From the domestic waste water there are organic substances, fat, pathogenic microorganisms, detergents etc.

The capacity of the recipient area to utilize extra water is limited by nature of underground drainage in karst which relies siphon and filtration through blocks, and entrails. The amount of suspended alluvium can block the elbows of siphons, and by the presence of compact (plastic, alu-foils etc.).

Fats and resins being lighter than water, stay at the top of the water table and with plastic and other folio cover in the gravel closing the capillary network, and other passages.

A narrow pedological stratum is situated at the bottom of a polje. It is very sensitive to the usage of chemical products because it has little capacity to accept new substances. Agrochemical products can however concentrate in the ground. The soil also absorbs artificial fertilizer, and special phosphate when change its chemical structure. If we take into consideration frequent flooding in poljes, we can see that pesticides and artificial fertilizers enter underground waters and pollute them.

The problem of communal and industrial refuse must be emphasized. The karst ecosystem is very sensitive to strange materials. Modern ecology couldn't accept trash depositing. As a solution carbonate base is very porous, and underground water is quickly polluted with organic substances, microorganismes and pathogenic bacterias.

If we build cities, traffic lines or long-distance overlines then the landscape will be destroyed. A lot of time is necessary in order to heal these "scars" on the face of karst areas.

Land shortage is also a problem in karst poljes. Towns need enough space to develop. Modern planning is based on functional zoning with relatively large protected industrial and recreation zones. But it is very hard to find such an example. In the karst, here more than anywhere, conflict is apparent between the land use needs for building and agricultural production. That is why some parts of towns are situated on the rims of poljes. Such works make infra- structural and superstructural elements more expensive.

2. PRINCIPLES AND METHODS OF REGIONAL AND URBAN PLANNING ON KARST AREA

Considering that the town is the functional, productional and cultural centre of the polje, and sometimes the centre of a larger area it is necessary to consider the polje a whole. An urban plan for a town or a village is not enough, we need regional (land use) plan for the whole polje.

We can differentiate between general and detailed urban planning. The General Plan aims at common determinations, functions, main infrastructures, and other usage of surfaces. The Detailled Plan is working out the usage of each area and structure. Our work is only about general urban planning because detailled planning is the theme of a separate work. Since the karst polje is functional encirclement and gravitational city sphere then we have to carry out a urbocentric politic of land use planning, most often of a monocentral type and sometimes of a bipolar type. Each land use plan has to explain the concept of regional development, function of zones in the polje and the environmental problems of the whole polje.

A united legally verified methodology for designing land use and Urban Plans on dominantly karst relief territory does not exist in Yugoslavia. Despite this fact some main principles of land use planning for such areas have been established during up to date practice in planning for towns and wider regional territory on the coast and in the background zones.

A couple of projects have been realised or are being served as a basis for the above mentioned standardisation. These projects are: the Regional Plan for southern, middle, and northern part of Adriatic Coast, the Regional Plans made by certain municipal communities, the Environmental Program for Mediterranean, Action Plan, the Regional Plans for Republics of Slovenija, Croatia and Bosnia, the International UNDP Project (YUG/79/104) for Regional and Urban Planning in Montenegro.

Naturally, beside these regional plans a whole series of urban studies and plans have been made which cover almost all the important economic centres located in regions with dominant karst relief.

Starting from the existing legal condition, theory and practise of planning, a methodological framework of these plans has been made in the shape of a dialectical triangle, the point of which are: Planning aims (thesis); Spatial and economical possibilities (antithesis) and Plan (synthesis).

The process of making these plans was realised in a few connected phases:

- 1. Collecting, processing and using documentation material (maps, remote sensing images, statistical series, measurements, reports and other relevant data sets (INDOC BASE);
- 2. Analitical-research work on partial sector studies and problems (ANALYSES AND ESTIMATION OF PRESENT STATE);
- 3. Basing problems and defining aims and recommendations for further development (PLANNING CONCEPTION);
- 4.Making the chosen kinds of land development and its institutional and professional verification (DESIGNING PLAN);
- 5. Making the final planning document based on suggestions and remarks from the previous phases (FINAL REPORT).

The connection between long and shorter plans and the consideration of a region as a whole and in particular form the methodological basis for planning and the arrangement of land use on karst terrain. Longterm aspects of the plans provide the basic strategic framework and the shorter aspects guarantee a harmonious realisation of the chosen priorities.

Some of the plans and programs of the latest generation lay stress on ecological protection backed by economical support and the plans themselves gained the additional character of preinvestment documents.

Numerous karst problems which could not have been solved without extra financial investments aimed at surpassing the limiting thresholds of development are

MATRIX OF CORRELATIVE RELATIONS	INDUSTRY ON THE COSTAL ZONE	INDUSTRY ON THE KARST BACKGROUND	TOURISM	TRANSPORTATION	TERMINALS	FACILITIES	RECREATION	HOUSING	WATER SUPPLY	LANDSCAPE PROTECTION	TRAFFIC CONNECTIVITY	ENERGY SUPPLY	
INDUSTRY ON THE COASTAL ZONES	X	3	3	4	3-4	3	3	3	4	3	4	4	-
INDUSTRY ON THE KARST BACKGROUND	3	X	3	4	3	3	3	3	4	3	4	4	0
TOURISM	1	1-3	X	1-3	1	3-4	4	3	4	3	4	4	0
TRASPORTATION	3	3	3	X	3-3,5	2-3	3	3	4	3	4	4	-
TERMINALS	3	3	3	4	X	3	3	3	4	3	4	4	-
FACILITIES	1	1	3-4	2	2	X	3-4	4	4	3	4	4	0
RECREATION	1	1	3-4	1	1	3-4	X	3	4	3	4	4	0
HOUSING	1	1-3	3	4	1	4	4	X	4	3	4	4	0
WATER SUPPLY	3	3	3	3	3	4	3	4	X	3	0	4	0
LANDSCAPE PROTECTION	1	1	2	1	1	2	3	2	3	X	3	3	0
TRAFFIC CONNECTIVITY	3	3	3	4	3	3	3	3	0	3	X	0	-
ENERGY SUPPLY	3	3	3	3	3	4	3	4	3	3		X	0

Fig.I. Matrix of correlative relations between different land uses on the karst area.

LEGEND: 1 Eliminated; 2 Unbearable; 3 Endurable; 4 Indispensable; O Without influence
- Sensitive

EXPLANATION:

1 Eliminated:another land use can not exist neighbourhood;

2 Unbearable: other land use can exist but they are in collision (estimation 2);

3 Endurable: another land use can exist but it is indifferent to one that already exists (estimation 3);

4 Indispensable: demands presence two land uses because input functions (estimation 4)

thus overcome. The input-output table on the limitation created common attitudes as to the location of certain contents and activities on the karst terrain (fig. 1).

CONCLUSION

The karst environment is very vulnerable ecologically so it is very important to keep in mind the ecological aspect of urban and land use planning of cities in karst poljes.

Because they are depressions they have a predisposition to grow air pollution. In planning one has to exclude every activity that could increase air pollution. It is necessary to reduce the use of all means of transportation which pollute the environment and change suppling of thermal energy to electricity and natural gas.

Drinking waters have to be controlled because we aren't sure from which side they come from. For ecological, sanitary and health reasons make a great importance about trash depositing. Karst environment can't annul all negative consequences so agrochemical products have to be reduced in the smallest way.

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