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CHANGE IN PERCEPTION OF KARST FROM MORPHOLOGY TO MORPHO-HYDROLOGY: TURKISH EXPERIENCE IN COMPREHENSION OF KARST

SPREMEMBA V DOJEMANJU KRASA OD MORFOLOGIJE DO MORFO-HIDROLOGIJE: TURŠKA IZKUŠNJA V RAZUMEVANJU KRASA

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Abstract UDC: 551.44(560):001.4

Mehmet Ekmekci: Change in perception of karst from morphology to morpho-hydrology:Turkish experience in comprehension of karst

Since its establishment as a science in the end of 19th century, methods applied in the study of karst evolved from classification to a system approach providing prediction in x,v,z and t. Information collected to answer the question "what is it" followed by the questions "why and how" and "what if". The change in questions required collection of new information which in turn changed perception of karst by related scientists. An overall evaluation of the progress in karst studies postulates an evolutionary character. Four major stages can be defined with transitional limits to track the change in perception of karst in accordance with the progress in the applied methodology. After discussing the history of karst studies in Turkey, the author questions the reason why the track did not progress parallel to the general evolution of karst studies in the world. Considering the fact that change in perception has caused shifts in meaning of the concepts and terms of karst, it is proposed to define terms not only on the basis of form but the processes of formation and function.
Key Words: karst, methods, morphology, hydrology, terminology, Turkey.

Izvleček UDC: 551.44(560):001.4

Mehmet Ekmekci: Sprememba v dojemanju krasa od morfologije do morfo-hidrologije: turška izkušnja v razumevanju krasa

Od uveljavitve krasoslovja kot znanosti ob koncu 19. stoletja so se metode proučevanja krasa razvile od klasifikacije do sistemskega pristopa, ki omogoča napovedovanje v x, y, z in t. Zbiranju informacij, ki naj bi dale odgovor na vprašanje »kaj je to«, so sledila vprašanja »zakaj in kako« ter »kaj če«. Sprememba vprašanj je zahtevala zbiranje novih informacij, ki so spremenile način znanstvenega dojemanja krasa. Celotno vrednotenje razvoja v krasoslovnih študijah zahteva evolucijski pristop. Za sledenje sprememb v dojemanju krasa glede na razvoj uporabljane metodologije lahko definiramo štiri glavne stopnje s prehodnimi mejami. Po razpravi o zgodovini krasoslovnih študij v Turčiji se avtor sprašuje o vzrokih, zaradi katerih napredek ni bil vzporeden splošnemu razvoju krasoslovnih študij v svetu. Ob upoštevanju dejstva, da je sprememba v dojemanju povzročila premike v pomenu pojmov in izrazov o krasu, predlaga definicijo izrazov ne le glede na obliko, temveč na osnovi procesov nastajanja in funkcije.
Ključne besede: kras, metode, morfologija, hidrologija, terminologija, Turčija.

INTRODUCTION

With simplification and generalization it is possible to define four major stages that apply to human understanding of natural phenomena as summarized in Table 1. These stages may also be regarded as the steps of evolution of methods employed in scientific research. Therefore, it is not unrealistic to think that every branch of science is evolving through these stages to reach its ultimate target which is “to define the system and the interactions with its environment in both dimensions of space and time”. Based on this concept, it is possible to assess the state of a branch of science in its course of evolution by inspecting the method it applies to define the relevant natural phenomena.

The first stage that applies to understanding natural phenomena is “comparison”. When we first encounter a new phenomenon we try to understand it by comparing it with the “known”. This stage includes identification of similarities and differences. This was how “karstic features” were first described in late 1800s. Comparison provides an answer to question “what is it like ?”. However, man wants to know more also about the relations among parameters defining the phenomenon. Thence, he evolves his method of research from “comparing” to “relating” things, in the search of answers to new questions like “what is related to what?”, and “what accompanies what”. This second stage can be reached only after a great amount of information gathered (accumulated) during the first stage. These relations are therefore empirical and do not give an insight or an answer to the question like “why ?”, “what causes this?” or “what is this consequence of ?”..

We need to evolve from the stage of “empirical relations” to a new stage which provides us with “causative relations” in order to find the answer to the latter questions. At this third stage factors are related to parameters so that they give an explanation of the genesis and occurrence of the phenomenon. This type of relation allows us to make predictions about the changes in one parameter when a change occurs in another one. This prediction is also valid when changes occur otherwise. However, predictions are limited to some local point in space and a moment in time and they do not provide us with the knowledge of what happens if more than one factor is changes simultaneously.

We should find a way to evolve to a stage in order not only to define all factors and parameters that constitute the phenomenon but also to predict the changes in case of one or more than one of these factors or parameters being changed. This means that once we can define such a relationship, we have the knowledge how the system works and interacts with other systems at the same time. That is, predictions are not limited to certain points in space and time. It is clear that this is the ultimate target of all branches of science. This objective is achieved by exact mathematical expressions, generally based upon laws of conservation (e.g. energy-mass) which are expressed as partial differential equations for continua.

In this framework of evolution of methods of understanding natural phenomena, it would be interesting and informative to discover the stages of karst research starting from its comparative nature in late 1800's.

EVOLUTION OF KARST STUDIES

Having described four main phases of development in the methodology of understanding natural phenomena in its broadest sense it is possible to review the karst studies accordingly. Apparently evolution of a preceding phase into the next is not abrupt but transitional. Therefore it is more convenient to demonstrate the dynamic character of evolution instead of defining certain periods to characterize the phases. To achieve this, the author prefers to illustrate the evolution of karst studies by an imitation. Development of a drainage basin is used to depict also the contribution of different fields of science. As illustrated in Figure 1, two major branches contributed to comprehension of karst: physical geography and hydrology. Evolution of these two major branches into Karst Studies is proposed in accordance with the evolution of the scientific method employed.

Comparative Stage

In the course of geomorphology, karst studies may be assumed to begin with the recognition of some *peculiar* landscapes and morphological features. It is worthy of note that *peculiarity* is a term indicating the comparative method of study. The study in geomorphology included primarily the origin, development and evolution of surficial features. In the meantime, caving evolved into speleology and thereby it contributed to the science of geomorphology by adding subsurface morphological features. Geomorphology and speleology then were joined in a new area of study: *Karst Morphology*.

Hydrology of karst areas was recognized as a challenge by hydrologists. Because all fundamental assumptions became invalid as basic equations were based upon linearity, homogeneity and isotropy of the flow medium. Hydrological behavior of surface and subsurface water systems was difficult to understand without taking the geomorphological development into account due to the fact that interaction between surface and subsurface waters were controlled by morphology. In non-karstic areas, geomorphological development is sequential - that is development is at the surface and proceeds from higher to lower parts. Whereas, in karst, surface and subsurface morphological features develop simultaneously and the driving force is the energy gradient of the water. At this stage, morphology was combined with hydrology in order to better understand hydrology of karst. This combination is depicted with a dashed line in Figure 1.

Stage	Method	Information on Phenomenon	Prediction
1	Description-Comparison-Classification	What is it? What does it look like?	None
2	Empirical Relations-Permanent Accompany-Correlation	What is related to? What type of relation?	How ?
3	Causative Relations	Consequence of ? Cause of?	Instantaneous. Only in one dimension at each time. What if?
4	Mathematical Relations (Models based on laws of conservation)	Which variables and parameters do govern? What are the interactions?	What if? Possible for all parameters at all x,y,z and t

Table 1. Human understanding of natural phenomena.

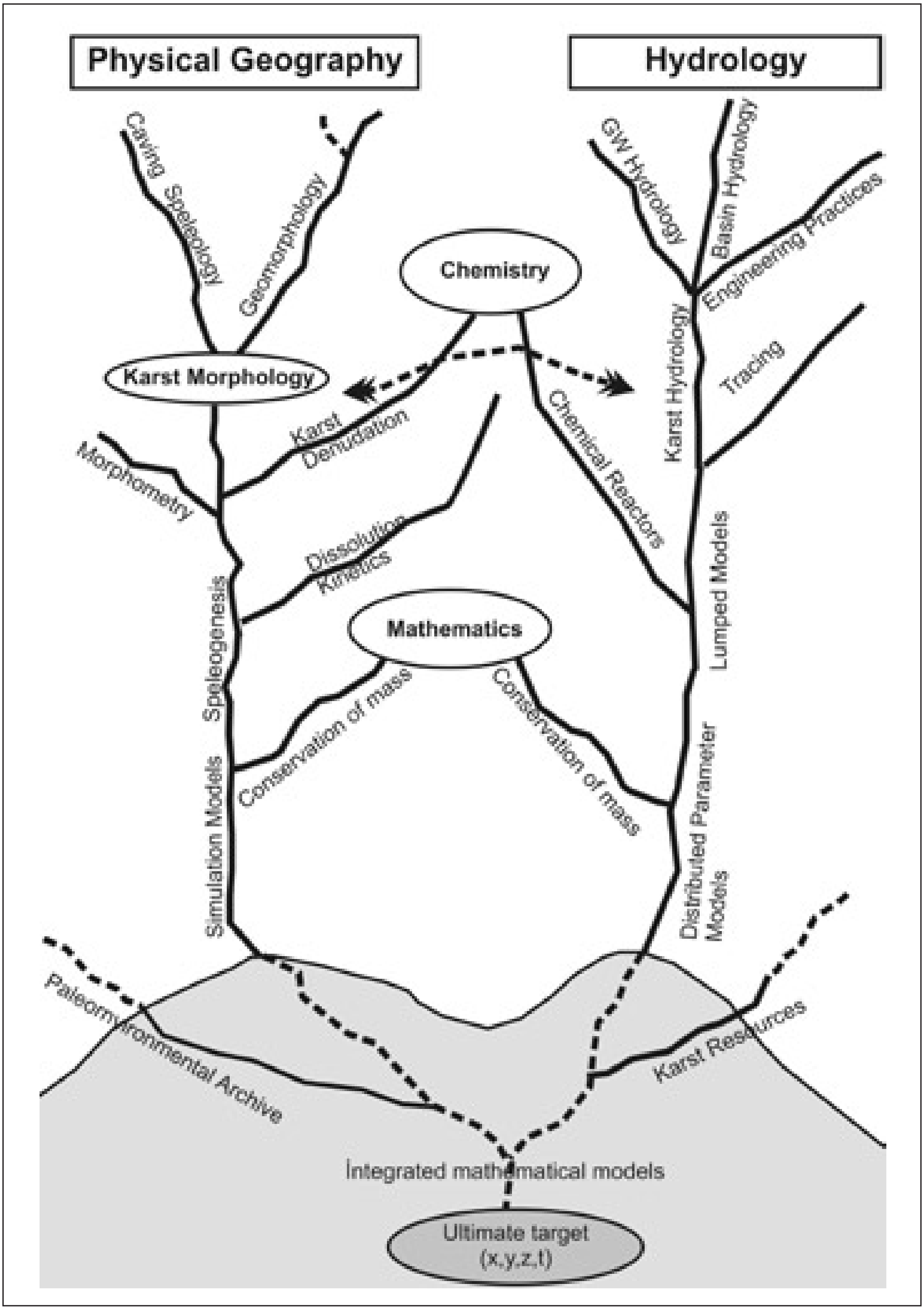

Figure 1: Illustration of evolution of karst studies.

During this stage, karst was defined mainly by its peculiar morphology. Following detailed definition of these special features different areas with these features were compared according to their dimensions, geographical distribution, type of geologic framework that they form. All information obtained from comparison led to classification of karst according to different bases.

On the hydrology side, the response of karst springs and groundwater level in wells to precipitation, extension of recharge areas beyond the topographical divide and connections of springs and wells with swallow holes, sinking streams etc. were in the centre of research. Karstic springs were compared and later classified according to their discharges where variation was the key parameter in classification of springs.

Empirical Stage

The comparative stage provided a good collection of information on individual cases as well as a good knowledge on different types of karst. Comparison required extensive measurement which lead to morphometry where statistical analyses became essential. Upon this accumulation of information, research was oriented to relate different factors that are specific to karst. Relations were established on the basis of correlations between various parameters. Where good correlations obtained, regression equations were transformed to empirical relations. Equations suggested for karst denudation are good examples of empirical relations (Ford and Williams, 1989). The exponential equation relating karstification with depth is another example (Milanović, 1980). Research on hydrology, in the meantime, involved tracing techniques to understand better the relations between input, storage and output characteristics of karst aquifers.

Studies performed during this stage provided an insight of the nature of karst and karst processes although the question “why ?” was not answered. This required introduction of some methods and techniques borrowed from particularly chemistry.

Causative Stage

Application of dissolution/precipitation kinetics was a major step in understanding the causative relations in karst. Karst, at this stage is studied in terms of karstification processes. This was the stage where studies on speleogenesis found a systematic basis. Relations established at this stage provided answers to the question of “why ?” in particularly the hydrogeological processes governing karstification. Models were produced for chemical speciation and computation of saturation indices. Similarly, chemistry was among the major sciences that researchers utilized in studying karst hydrology. The idea and mathematics of chemical reactors were adapted to karst hydrology, simulating the karst aquifer to a chemical reactor with specific character of inputs, outputs and mixing. This was achieved to a great extent with the help of tracing techniques in addition to hydrochemical data. The use of isotopes should be regarded as a major step in this progress. The output was lumped models simulating the hydrologic response of karst aquifers.

Although lumped models simulate the response of an output to input, it is not possible to have simulations of hydraulic heads, groundwater fluxes, groundwater flow direction, destination and velocity. However, management requires all these parameters to be simulated in x,y,z and t. That is how karst studies evolved into the modeling stage.

Modelling Stage

The demand for models stems for two major reasons: to get an insight on how the system works (informative) and to predict the response of the system against any change (predictive) in x,y,z and t. This sort of model principally requires an exact mathematical expression simulating the natural phenomenon. Such mathematical expressions are usually based on laws of conservation (mass, energy, momentum, etc.). This is the stage that dominantly represents the present.

The progress in explanation of dissolution/precipitation kinetics of carbonates accelerated the studies related to speleogenesis and cave development. Research oriented to modelling karstification in general and cave development in particular. Models developed for cave development in many cases included a theory of speleogenesis, at least implicitly. Ford (2003) emphasizes the importance of the modeling stage in his paper where he gives the perspectives in karst hydrogeology and cavern genesis.

On the hydrology side, after development of mixing cell models, distributed parameter models replaced the lumped models as new information on the geometry of the karst medium is expanded.

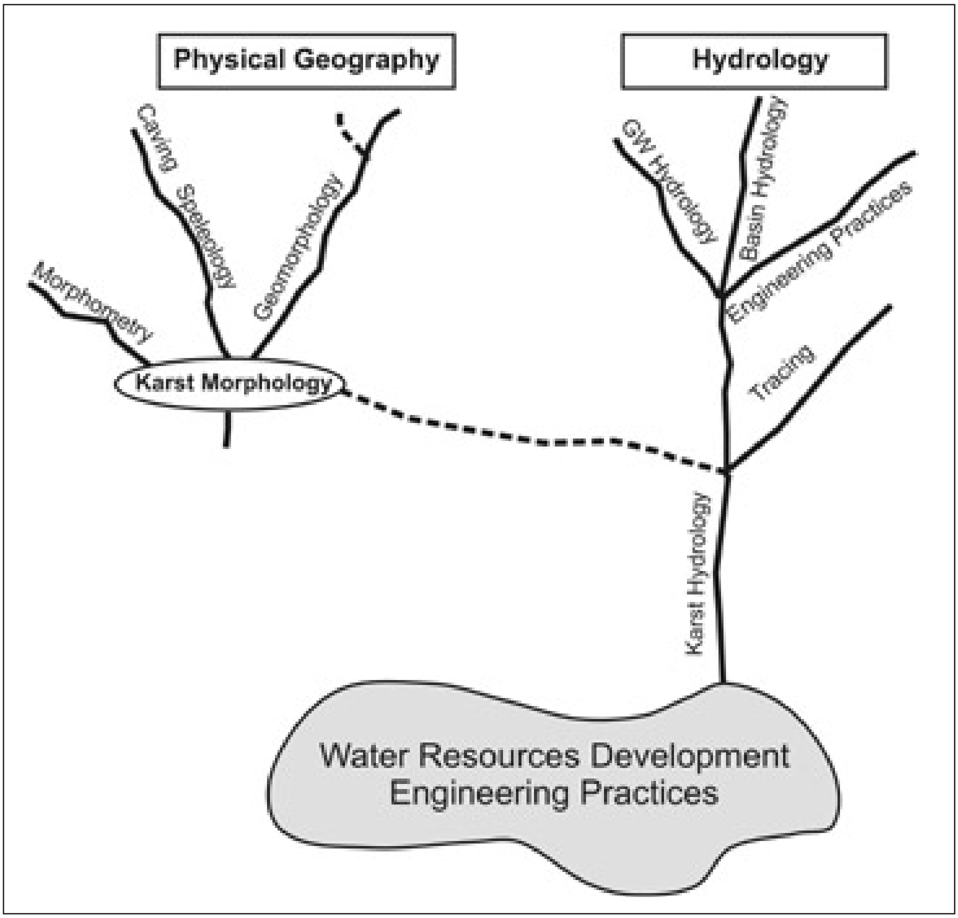

Figure 2: Capture of morphology by hydrology for the sake of water resources development.

Today, the need for the knowledge of flow direction, destination and velocity as well as hydraulic head distribution, groundwater fluxes and spring discharges leads the research toward development of distributed parameter models similar to those presently used for groundwater flow in non-karstic media. A detailed review can be found in Quinlan et. al. (1996) and Scanlon et. al. (2003).

What is Next?

From what has been achieved so far, it is not difficult to make a guess on what will be achieved in the future. Today, development of mathematical models for cave development/speleogenesis and groundwater flow and solute transport progress separately. But it is not surprising to expect an integration of these two separate branches in one holistic mathematical model that will provide simulation of the whole system with dynamic geometries and boundary conditions. This seems to be the ultimate target for karst research to be reached in the future.

As depicted in Figure 1, studies on karst resources other than water and research on the use of karst media for paleoenvironmental reconstruction will most likely contribute to the integrated approach to modeling of karst systems.

RELATION BETWEEN PERCEPTION OF KARST AND KARST TERMINOLOGY

It is reasonable to expect a change in perception of karst along the course of progress of this specific branch of science. Shift in the meaning of terms and concepts can be hence regarded as an expected consequence.

At the comparison stage it is normal to use the terms on the basis of morphology, that is ***"form"***. Therefore, the major difference between distinct features is the shape and dimensions. This type of definition of terms was represented by mainly karst geomorphologists, because perception of karst by geomorphologists was based almost entirely on *"form"*.

However, evolving into the empirical and causative stages, definitions included the processes governing the occurrence. This obviously caused a slight change in concepts to reflect the ***"formation"*** beside the *"form"*. By this way, definitions were also based on the type and nature of *formation of the forms*.

On the other hand, for karst hydrologists, ***"function"*** of karstic features *(forms)* is more important due to their perception of karst as a system of extensive interactions between the surface and the subsurface. The hydrologic *"function"* of the form is more crucial for hydrologists in defining the terms.

Apparently, perception of karst by karstologists is now based more than ever on the morpho-hydrological approach in the sense of integrated modeling of the whole domain with solid, liquid and gas phases. This kind of perception requires a terminology to define the concepts on the basis of ***form, formation*** and ***function***. A ***form*** of specific ***formation*** may ***function*** in different ways under different conditions. In this case definition of this specific ***form*** should be different for different types of functioning: e.g. estavella and ponor. A karstic feature may be defined as a ***paleo-form*** when it looses its function.

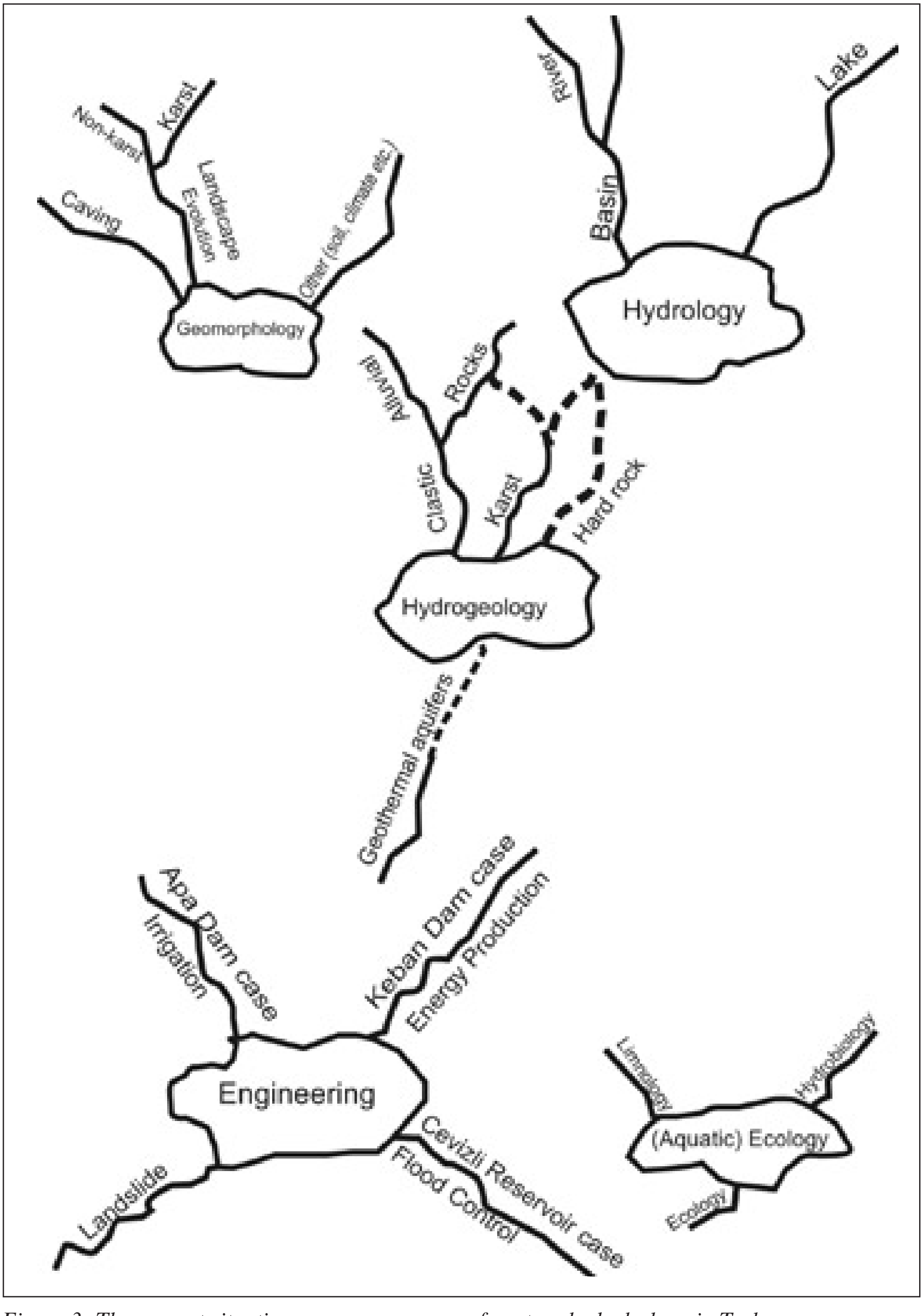

Figure 3: The present situation as a consequence of capture by hydrology in Turkey.

TURKISH EXPERIENCE IN COMPREHENSION OF KARST

With reference to the two main branches, namely karst morphology and karst hydrology that form "karstology" in the integrated sense as depicted in Figure 1, what happens if ***capture*** takes place before mature conjunction? The Turkish experience exhibits an example to what if *morphology* is captured by *hydrology*.

Historical

Although the term karst or some words on peculiar forms on carbonates has been mentioned in some travel notes and short papers by some geographers like Tietze (1885), Penck (1918), Philippson (1918), Chaput (1936), Louis (1937) and Lahn (1940), the paper on the karst of Turkey published by Alagöz in 1943 is regarded as the first systematic research on the karst phenomenon in Turkey (Ekmekci, 2001). Actually, the paper authored by ***Ervin Lahn*** in 1940 should be regarded as the first paper focused on the problem of karst although he emphasized the water potential and its availability for agricultural use in the area. His paper is on karst phenomena in the Konya region where formation of *obruks* (cenotes) still continues.

"In April 1928, I visited the *Tarn* canyon and the *Dargilan* cave in Central Massif, France. Later, in October of 1931, I traveled through the *Karst Land*, located to the east of *Trieste*. The terrific canyons, vertical caves, temporarily flooded karst plains that I saw then made me feel a great desire to see and identify the karst landscape of my country."

The above lines are extracted from the paper written directly on karst phenomenon in Turkey by **Cemal Alagöz** in 1943. From his paper, we understand that he had read Cvijic's book Das Karstphänomen published in 1893. Apparently, this first paper on karst (Alagöz) seems to be an output of an impressive travel rather than definition of a geopmorphological problem. For sure, this never undervalues Alagöz's contribution but it gives a clue on the perception of the phenomenon at the beginning. This type of perception required only description of the landscape and special features of karst areas in different regions of Turkey. Unfortunately, morphometric measurements and analyses were not included in the method of describing the forms even until recently. As a consequence, the karst studies by geomorphologists remained at the comparison stage and did not evolve into the empirical stage.

These studies were followed by methodic research by various researchers (e.g. ***S. Erinç, B. Darkot, A. Ardel, M. Ardos, I. Yalçınlar, T. Aygen, , M. Başar, M. Bener, N. Güldalı***) from early 1950s to early 1970s. From 1970s karst morphology became a special topic for research not only at universities but also in governmental organizations responsible for development of natural resources. Among these, ***Aygen*** focused on speleology and did a lot of explorations in Turkish caves. He established and chaired the Cave Research Association in Turkey in 1959.

On the other hand, the history of hydrological studies in karst areas may be started in 1970 when ***D. J. Burdon*** came for a mission as a UN-FAO consultant upon invitation by the General Directorate of Sate Hydraulic Works (DSI). In late 1960s Turkey was suffering from the lack of adequate knowledge and expertise to overcome problems related to water resources development. In his mission reports of 1970 and 1972 Burdon called attention to the water resources potential in karst areas of Turkey with a special emphasis on the problems related to karst, particularly in coastal aquifers. He has based his definition of karst almost entirely on hydrogeology, giving very little role to morphology. Following the recommendations of Burdon, DSI requested expertise from the UNDP, particularly on problems related development of submarine springs, saline costal springs, locating positive wells in carbonate areas, etc. W.C. Dimock, completed a mission in 1973 as a UNDP consultant. Dimock also emphasized the water resources potential of the karst medium rather than its nature and related processes. Missions executed by Jasminko Karanjac (1974-1977), Boris Mijatović (1976), Vujica Yevjević (1977-1984) and Petar Milanović (1979, 1984-1990) played a key role in setting up a comprehension of karst based almost entirely on hydrology-hydrogeology, minimizing the importance of the knowledge of the nature of karst and karstification processes.

Failures Due To Capture By Hydrology

The above mentioned eminent researchers had the mission to bring urgent solutions to water problems and train Turkish engineers in this aspect of karst. Research towards understanding the phenomenon was not included in their mission also because of limited time and funds. No geomorphologist or speleologist attended the activities supervised by these consultants. The trained group was composed of engineers and geologists who were assigned to find water and put it into service. In addition, at that time, geologists and engineers did not regarded water as a "natural resource" but a "natural product". A product is consumed, but resource is developed and managed. Development and management of a resource requires description the whole system in terms of inputs, outputs and interactions with the surrounding environment. Whereas, when a product is consumed, we search for a new one. *"I have it..No matter where it comes from"* was a typical phrase reflecting the perception of an engineer or a geologist As a result, karst was regarded mainly as a specific medium having significant water resources potential to be utilized disregarding its specifities.

This was how the karst research was captured by engineers and hydrologists for the sake of water resources development (Figure 2). As a result, a great amount of unrelated information was accumulated by different, non-coordinated disciplines that could not be utilized to propose conceptual models of the natural phenomenon and the processes. This caused in most cases repetition of experiences which means no significant progress was made. Illustrating this fact by again the imitation of drainage basin, we have in Turkey separated small lakes instead of a continuous evolution to an integrated ultimate target (Figure 3). Each discipline tried to make advances by itself disregarding the connections with others. Moreover, information accumulated at each small lake cannot be used efficiently by any of these disciplines.

It is not unrealistic to think that as a consequence of this sort of perception of the problem, Turkey experienced dramatic failures in developing its karst water resources and had to rediscover the importance of hydrogeological processes controlling karstification and their effect on hydrological behavior of the karst system. Aygen's work in 1966-1967 can be regarded as one of the landmarks in this aspect. He performed an intensive speleological-karstological study on the hydrogeological feasibility of the Oymapinar Damsite and its reservoir area with a team composed of Turkish and foreigner researchers. The demand for this study came after several failures in dam constructions in karst areas. The most dramatic failure was in the Keban Dam case which required million tons of cement grouting to provide water tightness at the dam site and the reservoir area.

In other cases, engineers several other dams and reservoirs (e.g. Cevizli reservoir, Apa Dam and May Dam), constructed without taking the nature of karst into consideration, failed to impound water or to function in accordance with the project.

REFLECTIONS ON TERMINOLOGY

As for the karst terminology in Turkey, there is still a great debate between hydrologists and geomorphologists. Hydrologists generally have a tendency to ignore the importance of definition of terms. Instead they seek for an answer to how the features affect the hydrological behavior of the system. Therefore, they do not care about misusage of the terms. On the contrary, geomorphologists tend to focus only on the form, even ignoring the processes controlling formation of the form as well as the function of the form. May the solution be a terminology correspondently evolving with the evolving method? A term defined at the comparison stage may not have the same meaning as a definition made at a causative stage.

Karst studies when not captured by one of the related disciplines seem to reach towards an ultimate target which integrates all in one system. The system is to be defined mathematically in x,y,z and t. Based on this postulation, definition of terms considering the form-formation and function together seems to unify the related disciplines avoiding inflation of terms.

Dedication

This paper is dedicated to the memory of Dr. Temucin AYGEN, the founder of scientific vision to caves and caving in Turkey.

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