

VIBEKAP, MỘT SỐ KẾT QUẢ VỀ HỢP TÁC ĐÀO TẠO VÀ NGHIÊN CỨU CỦA CÁC CÁN BỘ VIỆN NGHIÊN CỨU ĐỊA CHẤT VÀ KHOÁNG SẢN TẠI CÁC TRƯỜNG ĐẠI HỌC CỦA VƯƠNG QUỐC BỈ

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Dự án hợp tác nghiên cứu về các vùng karst giữa Việt Nam và Bỉ (VIBEKAP) được tài trợ bởi Hội đồng các trường đại học khối Hà Lan ngữ của Vương Quốc Bỉ (VLIR), là dự án được thực hiện trong giai đoạn 1998-2003, mà đối tác chính phía Việt Nam là Viện Nghiên cứu Địa chất và Khoáng sản (RIGMR) và các đối tác khác phía Bỉ là trường Đại học Tổng hợp Leuven (KUL), Cục Địa chất Bỉ, Trường Đại học Tổng hợp Tự do Bruxelles (VUB), Phòng kỹ thuật Thủy văn và Thủy lực (thuộc VUB). Mặc dù dự án VIBEKAP đã kết thúc năm 2003, nhưng việc cộng tác nghiên cứu và đào tạo vẫn tiếp tục phát triển thông qua các nghiên cứu sinh bậc tiến sĩ và dự án bảo tồn karst vùng Tây bắc Việt Nam (LLINC). Dự án VIBEKAP đã có nhiều kết quả nghiên cứu quan trọng, cũng như đã đào tạo được các chuyên gia nghiên cứu về karst. Dự án được thực hiện trên cả hai lĩnh vực: khoa học về Trái đất và xã hội, tập trung vào các vấn đề liên quan đến nước như lũ lụt, xói mòn, cung cấp nước... ở vùng karst Thuận Châu (Sơn La, tây bắc Việt Nam).

Những dự án của VLIR đã mở ra một cơ hội tuyệt vời cho các cán bộ khoa học của RIGMR khả năng được học tập và nghiên cứu tại Vương quốc Bỉ, bằng cách cấp học bổng bên ngoài dự án thông qua các tổ chức khác nhau. Đến nay, đã có 21 nghiên cứu viên nhận được học bổng để tham dự các khóa học nâng cao về địa chất (KUL), các chương trình đào tạo Thạc sĩ Khoa học về Tài nguyên Nước (IUPWARE, VUB-KUL), Tài nguyên Đất (PHYLARES, VUB-UG), và Quản lý Sinh thái Biển (ECOMAMA, VUB-UA). Thêm vào đó, Tiến sĩ Vũ Thanh Tâm đã bảo vệ thành công luận án tiến sĩ của mình năm 2003, và hiện nay có 4 nghiên cứu sinh khác đang thực hiện các luận án bậc tiến sĩ tại Phòng Kỹ thuật Thủy văn và Thủy lực của trường VUB.

Sự hợp tác thành công về đào tạo và nghiên cứu giữa RIGMR với các trường đại học tại Bỉ, mà trực tiếp là với phòng Kỹ thuật Thủy văn và Thủy lực, được thể hiện rõ ràng nhất thông qua các công trình khoa học của các cán bộ RIGMR trong thời gian học tập và nghiên cứu tại Bỉ. Bài báo này là sự tổng hợp các kết quả chính của những nghiên cứu nói trên trong một số lĩnh vực sau: thủy văn, địa chất thủy văn, viễn thám - hệ thống tin địa lý (GIS), thủy địa hoá và chất lượng nước, tai biến tự nhiên và cơ học đất, hệ sinh thái và quản lý môi trường biển.

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VIBEKAP, TRAINING AND RESEARCH RESULTS BY RIGMR STAFF AT BELGIAN UNIVERSITIES

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I. INTRODUCTION

The VLIR supported project, ‘**Rural development in the mountain karst area of NW Vietnam by sustainable water and land management and social learning: study of its conditions and facilitation**’ between the main Vietnamese partner, the Research Institute of Geology and Mineral Resources (RIGMR) and several Belgian partners from the Katholieke Universiteit Leuven (KUL, promotor), Vrije Universiteit Brussel (VUB) and Belgian Geological Survey, took place between 1998-2003 and is better known as the Vietnamese-Belgian Karst Project (VIBEKAP). Although, VIBEKAP officially ended in 2003, it still continues by way of research from PhD students and the follow-up, also VLIR supported, LLINC project ‘**Improving multi-stakeholder collaboration for conservation of the Pu Luong - Cuc Phuong limestone landscape, NW Vietnam**’. VIBEKAP generated many interesting results, as well as built up a much needed karst expertise. The project was multidisciplinary, with geo-scientific and social components, focusing on water related problems (flooding, water supply, erosion, etc.) in the karst area of Thuan Chau and Son La (N.W. Vietnam).

These VLIR projects opened a wonderful chance for capacity of the RIGMR staff to study in Belgium by way of additional scholarships of different organizations. Up to now, 21 staff-members obtained a scholarship to study Geology (Katholieke Universiteit Leuven) or some MSc programs in Water Resources Engineering (IUPWARE, Vrije Universiteit Brussel - Katholieke Universiteit Leuven), Physical Land Resources (PHYLARES, Vrije Universiteit Brussel - Universiteit Gent), and Ecological Marine Management (ECOMAMA, Vrije Universiteit Brussel - Universiteit Antwerpen) (*Table 1*). Additionally, Dr. Vu Thanh Tam successfully defended his PhD thesis in 2003 and four RIGMR staff members have started their PhD researches in Belgium at the Department of Hydrology and Hydraulic Engineering (VUB).

The success of the training and research cooperation between RIGMR and Belgian universities, particularly the Department of Hydrology and Hydraulic Engineering, can be best observed by the results of the research work executed by RIGMR staffs while studying in Belgium. In the remaining of this paper, we summarize most important results so far in the research domains: hydrology, hydrogeology, remote sensing and GIS, geochemistry and water quality, natural hazard and soil mechanics, ecosystem and environmental marine management.

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**Table 1. Staff of the Research Institute of Geology and Mineral Resources
trained at Belgian Universities**

| No | Name | Study | Programme | Scholarship | Time period |
|----|----------------------------|-----------------|------------|-------------|-------------|
| 1 | Mr. Vu Thanh Tam | MSc | IUPWARE | ABOS | 1994-1996 |
| 2 | Mr. Tran Trong Thang | Training course | Geology | KUL | 1998-1999 |
| 3 | Ms. Vu Thi Minh Nguyet | MSc | IUPWARE | VUBAROS | 1998-2000 |
| 4 | Mr. Trinh Hai Son | MSc | ECOMAMA | VUBAROS | 1998-2000 |
| 5 | Mr. Quach Duc Tin | MSc | IUPWARE | VUBAROS | 1999-2001 |
| 6 | Mr. Le Quoc Hung | MSc | IUPWARE | VLIR | 1999-2001 |
| 7 | Mr. Nguyen Quoc Dinh | MSc | PHYLARES | VUBAROS | 1999-2001 |
| 8 | Mr. Nguyen Dai Trung | MSc | PHYLARES | VLIR | 1999-2001 |
| 9 | Mr. Ho Huu Hieu | MSc | ECOMAMA | VLIR | 1999-2001 |
| 10 | Mr. Do Van Thang | Training course | Geology | KUL | 1999-2000 |
| 11 | Ms. Nguyen Thanh Huong | MSc | IUPWARE | VUBAROS | 2000-2002 |
| 12 | Mr. Nguyen Thanh Long | MSc | PHYLARES | VUBAROS | 2000-2002 |
| 13 | Mr. Phan Duc Le | MSc | PHYLARES | VUBAROS | 2000-2002 |
| 14 | Ms. Nguyen Thi Hai Van | MSc | ECOMAMA | VUBAROS | 2000-2002 |
| 15 | Mr. Nguyen Duy Binh | MSc | PHYLARES | VUBAROS | 2001-2003 |
| 16 | Ms. Nguyen My Linh | MSc | PHYLARES | VLIR | 2001-2003 |
| 17 | Ms. Nguyen Thi Minh Phuong | MSc | ECOMAMA | VLIR | 2001-2003 |
| 18 | Mr. Nguyen Xuan Nam | Training course | IUPWARE | VLIR | 2002-2003 |
| 19 | Ms. Tran Minh Thien | MSc | PHYLARES | VLIR | 2002-2004 |
| 20 | Mr. Nguyen Tam | MSc | PHYLARES | VUBAROS | 2002-2004 |
| 21 | Mr. Vu Thanh Tam | PhD | HYDR - VUB | VIBEKAP | 1999-2003 |
| 22 | Ms. Vu Thi Minh Nguyet | PhD | HYDR - VUB | BTC | 2002-2006 |
| 23 | Mr. Le Quoc Hung | PhD | HYDR - VUB | VN 322 | 2002-2006 |
| 24 | Mr. Nguyen Thanh Long | PhD | HYDR-VUB | BTC | 2003-2007 |
| 25 | Mr. Nguyen Dai Trung | PhD | GENT | BTC | 2004-2008 |
| 26 | Mr. Le Nguyen Hoang | Master | PHYLARES | VLIR | 2004-2006 |

1. Hydrology

Huong (2002) and Liu et al. (2004) applied the WetSpa model to evaluate flood processes in karstic areas. The major obstacles to modeling flood processes in karstic areas are a lack of understanding and model representations of the distinctive features and processes associated with runoff generation in those regions and a lack of field data. In this study, a distributed flood modeling approach, WetSpa, was performed by modifying model representations of some of the predominant features and processes of the karstic Suoi Muoi catchment with

complex-terrain and mixed land use in the northwest Vietnam. The model was calibrated based on 15 months of hourly hydro-meteorological data, topography, land use and soil types in GIS format, and used to continuously simulate both baseflow and fast-responding overland, conduit and channel flows during stormflow periods. Considerable variability in simulation accuracy was found among storm events and within the catchment. The simulation results showed that the model represents reasonably well stormflows generated by rainfall events in the study catchment, and the potential of using distributed flood simulation for estimating future flood conditions under changing land use conditions. It is argued therefore that the WetSpa approach is suitable for application in karstic areas under human and natural pressure [17, 20].

2. Hydrogeology

Nguyet (2000) and Nguyet et al. (2004^a) showed the first tracer tests that were ever carried out in the karstic northwest of Vietnam and performed within the framework of the Vietnamese-Belgian Karst Project (1998-2002). Common salt, fluorescent dyes uranine (fluorescein) and sulforhodamine B were used as tracers. The experimental results have proven the existence of flow paths between injection points and springs in Suoi Muoi and Nam La catchments. Tracer recovery rates are determined and vary from 29 to 96%; the estimated flow velocities vary from 72 to 288 m/h [22, 23].

Time series analyses is used by **Tam et al. (2004^a)** to characterize the transient flow regimes of the Nam La cavern conduit, northwest Vietnam. The conduit transforms the input signal to an output signal, and the degree of transformation provides information on the nature of the flow system. The input for the analysis is net precipitation and the flow hydrograph at the cave entrance, while the output series is the flow hydrograph at the resurgence. Cross-correlation and cross-spectrum analysis are used to investigate the stationarity and linearity of the input-output transformation of the system, resulting in hydrodynamic properties such as system memory, response time, and mean delay between input and output. It is shown that during high flow periods, the flow in the conduit is pressurized. Consequently, the linear input - output assumption holds only for low flows. To highlight the hydrodynamics of the cavern conduit for the high flow periods, wavelet spectrum and wavelet cross-spectrum analyses are applied [32].

Tam et al. (2001, 2005) presented the results of an investigation of underground conduits, which connect the swallow holes and the resurgence of a blind river in the tropical, highly karstified limestone Nam La catchment in the NW of Vietnam. The Nam La River disappears underground in several swallow holes near the outlet of the catchment. In the rainy season this results in flooding upstream of the sinkholes. A multi-thematic study of the possible connections between the swallow holes and the resurgence was carried out to investigate the geological structure, tectonics, cave structure analysis and discharge time series. The existence of the underground conduits is also tested and proven by tracer experiments [29, 36].

Hung (2001) suggested that lineament density map could be used to predict the cave development in fractured limestone [7]. **Tam et al. (2005)** predict the location of the underground conduits based on a lineament analysis. A remote sensing derived lineament-length density map is used to track routes from the swallow holes to the resurgence, having shortest

length but highest lineament density. This results in a plan-view prediction of underground conduits that matches with the cave and fault development. The functioning of the conduits is further explained by analysing flooding records of a nearby doline, which turns out to act as a temporary storage reservoir mitigating flooding of the catchment outlet area [36].

Tam et al. (2003, 2004^d) presented an application of the double-porosity concept and the Cooper-Jacob straight-line approximation in an interpretation and analysis of recovery tests in fractured and karstified limestone in NW Vietnam. Based on the occurrence of two parallel straight lines in semi-log plots of drawdown vs. pumping time and residual drawdown vs. recovery time, a method was developed to calculate hydraulic properties of the fractures and the matrix blocks. Early-time drawdown is related to a water release from fracture storage while late time drawdown as a consequence of a release from both fractures and matrix blocks. Both media share a conductive property of the fractures. The drawdowns of early- and late times are described by the well-known Theis well flow equation, and under appropriate conditions can be approximated by the Cooper-Jacob approximation, resulting respectively two parallel straight lines. Relevant equations are derived for residual drawdown on the basis of the principle of superposition, which facilitate a curve matching method to calculate principal aquifer characteristics, such as recovery transmissivity and storativity [31, 35].

Speleothems are precipitated from seepage waters from the overlying surface. They contain high-resolution palaeo-environmental information, by a number of properties such as oxygen and carbon stable isotope ratios etc., which may be used to investigate aspects of environmental change. Son La karstic area is one of most suitable areas to investigate and obtain a reconstruction of the climatic events in Vietnam. **Tam (2004)** studied, a stalagmite from Ta Chinh Cave, Tua Chua, Son La, Vietnam. It provided a discontinuous stable isotope record from 132230 + 1100 to 35060 + 200 y BP with the lower part belonging to the last interglacial period meanwhile the upper part corresponds to a glacial period. Oxygen isotope analysis indicates that the high amount of rainfall not only occurs in the interglacial also in the glacial. Carbon isotope analysis indicated the presence of an active vegetation cover dominant by C3 plants [28].

3. Remote sensing and GIS

a. Lineament analysis

Hung (2001) and Hung et al. (2002, 2003^b, 2004^a) set up an effective methodology to map and analyse lineaments for (hydro) geological research. The Lineament Analysis Software (LAS), which was developed by the Department of Remote Sensing and Geomatics of RIGMR since 1996, is providing a powerful tool for lineament study and analysis. Lineaments are explored by statistical descriptors, which are used to remove most of non-geological lineaments. By using LAS, the quality of the lineament map is increased considerably such that it better serves geological structure studies. The application of lineaments is further increased by defining lineament indices and lineament density maps. Three common indices (length of lineaments, number of lineaments and number of intersections of lineaments) and two transformed indices (average of the lineaments length, ratio between number of intersections of

lineaments and the number of lineaments) are used not only for creating the lineament map but also for classifying lineaments. LAS interfaces with GIS for user friendly post-processing of lineaments [7, 8, 11, 12].

b. Groundwater in fractured rock

For a karstified limestone area in NW Vietnam the relationship between the distribution of lineaments and borehole specific capacity is determined by **Long (2002)**, **Hung et al. (2003^a)**, **Tam (2003)** and **Tam et al. (2004^b)**, resulting in the conclusion that not only the borehole geomorphological - hydrogeological position but also the lineament distribution influences the specific capacity [21, 10, 30, 33].

Tam et al. (2004^b) indicated that no significant spatial well yield patterns are evident in this highly fractured-karstified region. The supposition is that lineaments caused by geo-tectonic activities affect the local variability in borehole specific capacity. Sixteen pumping tests in conjunction with a comprehensive lineament analysis are used to prove the relationship. The boreholes and lineaments are classified into two groups according to their similarity in geomorphological - hydrogeological features. Lineaments tend to be less detectable in discharge areas (lowland wide-flat valleys) in contrast to the high density in recharge areas (highland narrow-mountainous ravines). In addition, the presence of a stream network in the former can act as a recharge source to the underlain karstic groundwater system. Consequently, boreholes that are in the discharge areas with a lower density of lineaments often produce high yield. For recharge areas with high density of lineaments, a good correlation is found between lineament density and borehole specific capacity [33].

c. Cave development

Hung et al. (2002, 2004^c, 2004^d) showed that integration of remotely sensed imagery with ground surveys is a promising method in cave development studies. A methodology was set up in which a variety of remote sensing and GIS techniques support cave analysis in the tropical karst area of the Suoimuoi catchment, NW Vietnam. In order to extract the maximum information from different remotely sensed data, the hue invariant IHS transformation was applied to integrate Landsat multispectral channels with the high resolution Landsat 7 ETM panchromatic channel. The resulting fused image was used, after enhancement, to visually and digitally extract lineaments. Aerial photos evaluated the extracted lineaments. Based on lineament density indices a fracture zone favorable for cave development is defined. The distance between caves and faults was investigated as well as the correspondence between the cave occurrence and the fracture zone [8, 14, 15].

Dinh (2001), **Dinh et al. (2004)** and **Tam et al. (2004^e)** constructed and analyzed a cave 3D database and concluded that the cave development in Son La is depending on the major trends of tectonic activity in this region [4, 5, 34].

d. Environmental monitoring

One of the most effective tools for environmental studies in mountainous areas, especially tropical karst mountainous areas, is remote sensing and GIS. Remote sensing and GIS technologies are scientifically established tools, but are not yet routinely used in environmental

analysis, monitoring and impact analysis. Remote sensing and GIS supported environmental analyses consist of methods for image transformation, image fusion, lineament extraction, time series, and change detection analysis (**Hung and Batelaan, 2003**) [9]. Based on the characteristics of lineaments, which are captured from the satellite images, the geological structure of a karst area in NW-Vietnam is studied in detail.

Time series and change detection analysis is applied for studying land cover changes. The groundwater recharge and discharge zones are defined by the technique of image transformation. It is shown that for a tropical mountainous karst area, containing an important National Park, environmental information can be obtained by way of application of remote sensing and GIS analysis. The extracted wetness, groundwater conditions, geological structure and land cover changes are essential information layers, necessary for future and improved management and protection of the National Park (**Hung and Batelaan, 2003**) [9].

Based on Landsat images of 1973, 1992 and 2000, with the additional information from aerial photos, natural forest, bare soil, arable land and open water are clearly recognized in Suoi Muoi catchment. The unsupervised classification (density slicing) method is used to define the main land cover types. From 1973 to 2000, the forest area reduced with more than 50%. The forest area is totally converted to arable land and bare soil. The area of open water increased partly due to a better recognition of open water areas in the increased non-forested areas. The results are alarming for the conservation of natural forests (**Hung, 2001; Hung et al., 2004^b**) [7, 13].

Nguyet et al. (2004^b) prepared a groundwater vulnerability map for the Son La karst area, Vietnam, using an approach developed by the European COST action 620 on ‘vulnerability and risk mapping for the protection of carbonate (karst) areas’. It was necessary to adapt this approach to the local hydrogeological, climatic and economic conditions. The modified (simplified) method is proposed for vulnerability mapping in other Vietnamese karst areas [25].

e. Geological mapping

Binh (2003) and Hung et al. (2004^c) developed a methodology for integrating remotely sensed and geophysical data for geological mapping. Surface geological features may be traceable in bedrock outcroppings (ground surveys), from air photographs (photo-geological reconnaissance) and/or from satellite images. In the subsurface, geological features may be perceptible from boreholes, cuttings and/or surface geophysics methods. Geophysics is a scientific discipline involving the measurement of parameters that are diagnostic of the physical properties of the materials at and beneath the earth’s surface. This leads to the idea that geophysical data should be integrated with remotely sensed data because the two sources can complement each other. Remotely sensed data can detail features on the earth, while geophysical data can describe these features in the subsurface. Remotely sensed data (Landsat ETM) and geophysical data (aeromagnetic and gravity) were integrated to establish a geological map, and detail the structural conditions of the Tam Duong area in NW Vietnam. Different techniques are applied for both kinds of data: image transformation, lineament analysis, qualitative interpretation of gravity and magnetic anomalies, interactive analysis and model fitting of geophysical cross-section. The integration of remote sensing and geophysics is

promising in increasing the knowledge of the geological structure of the mountainous karst area of Tam Duong, NW Vietnam. This integration will be the key for further hydrogeological, cave development, and mining studies [3,16].

Van et al. (2004) mapped structural controls on karstic water occurrences in Ngoc Son - Ngo Luong natural reserve, Hoa Binh province by combining remote sensed data and geological ground truth information [40].

g. Natural hazard - Landslide

Hung et al. (2003^b), Thien (2004) [11, 37] investigated the potential of using remotely sensed imagery for natural hazard monitoring. Landslide is the result of processes, which include geological, geomorphological and meteorological factors. The most important factors are lithology, structure, drainage, slope, land-cover, and geomorphology. In order to make a landslide hazard map, all of these factors need to be analyzed in order to define the instability in a region. Remotely sensed data provide valuable information for determining the occurrence of landslides, such as recent land-cover and fractured zones.

Data integration was carried out using the ordinal scale (qualitative) relative weighting rating technique to give a Landslide Hazard Index (LHI) value. The breaks in the LHI frequency diagram were used to delineate various landslide hazard zones, namely, very low, low, moderate, high and very high. Field data on landslides were employed to evaluate and validate landslide hazard zonation map.

It is shown that the potential landslide hazard map can be established by statistical correlation of landslide frequency with factors. The applicability of the map is shown by the fact that the Vietnamese government and NGO-projects take account of the results for their development planning in Thuan Thien Hue province.

h. Ecosystem conservation

Van (2002) [39] brought together a number of tools for the study of biodiversity in relation to climatic variation. The tools included relational database, statistical analysis and GIS. The usefulness of this system was demonstrated by using a preliminary analysis of macrobenthos density and biodiversity data from selected sandy beaches of Ecuador, where the anomalous El Niño and La Niña events strongly influence this equatorial tropical climate region every 3-7 years. The anomalies have indeed led to fluctuating climatic conditions, which can have effects on several sensitive marine living organisms such as macrobenthos, which always has specific requirements towards the environment.

Spatial and temporal contexts for the effect of anomalous oceanographic conditions on the sandy beach macrobenthos were investigated. Special references for the monthly anomalies of the Sea Surface Temperature (SST) were correlated with the diversities of the macrobenthos community. The unevenness of the macrobenthos diversity in different months and years was supposed to be corresponding to the anomalies of SST, or related to the unstable climatic factor during the research. Thus, the factors causing the variation in macrobenthos composition may be explained by these factors.

Though the research have still been going on and needed to add more data, especially longer time series, the initial results were to suggest that the local people should preserve the natural habitats surrounding them such as mangrove forests and sandy beaches along the coast. No disturbance would lead to have a healthy living environment, where many marine organisms like the studied macrobenthos might be very helpful for us in order to predict / forecast a natural anomaly that is going to threaten to our life.

4. Hydrogeochemistry and water quality

Tin (2001), Nguyet (2004), Batelaan et al. (2004) analyzed water quality and bacteriological conditions in karstic catchments. Karstic groundwater and surface waters are extremely vulnerable to pollution. For karstic water resources management, it is therefore of utmost importance to monitor water qualities, such that appropriate protection of water resources can be set up. Surface waters and karstic groundwater springs in the Nam La and Suoi Muoi catchment (Vietnam) were sampled in 1999 and 2000 during several field campaigns. These samples were analyzed for standard parameters and for bacteriological content. Hydrochemical analysis, based on different indices, graphing, statistical analyses and calculation of saturation indices, explain the water qualities in relation to the regional geology. The bacteriological water analyses show for some springs poor qualities due to faecal coliforms. Observed qualities are explained as a result of the vulnerability caused by karst features. It is argued that the mapping of these features should form the basis for development of water resources systems that will have acceptable water qualities. It is shown that the results of the hydrochemical analysis can contribute to the research into karstic flow systems [38, 24, 2].

5. Mineral Polymerisation Technique

Mineral Polymerisation Technique (MiP) is a process with which minerals such as clay could be hardened and transformed into useful construction materials through chemical polymerisation reactions. These mineral polymers are produced at atmospheric pressure and low temperature by using minimal energy input. In this process aluminosilicate kaolinite reacts with alkali at low temperatures and poly-condenses into hydroxy-sodalite, which is a stable and hard material. The objective of this research is to evaluate the quality and suitability of kaolinitic soils from Vietnam for construction purposes, using the mentioned technique. These construction materials should be characterized by their low cost, using low energy resources and using a small amount of alkaline compounds. The primary characteristics of the samples, e.g. chemical composition and clay mineralogy, has been described by the Research Institute of Geology and Mineral Resource (RIGMR), some descriptions and analyses were carried out in the laboratory at the Vrije Universiteit Brussel. The specimens were tested under varying conditions, in order to check their physical and mechanical properties, stability and durability. The quality of the specimens is evaluated according to their compression strength (**Le, 2002; Linh, 2003; Alshaaer, 2004**) [18, 19, 1].

6. Ecosystem and marine environmental management

Son (2000) [27] used an Environmental Scanning Electron Microscope (ESEM), which allows highly detailed non-destructive scanning of materials in their natural state. In the study, the clay fabric of recent sediments (the North Sea and Scheldt River) and Pleistocene deposits (the Turnhout Clay Member) was analysed by use of ESEM in combination with other methods, i.e. field observation and description, X-ray radiography and grain size analysis. The results of the grain size analysis showed that all the sediments have very fine grain sizes, falling in the range of fine silt or clay. The grain sizes were used to re-define the stratigraphical units in the sampling profile.

Hieu (2001) [6] investigated and presented the results of the adsorption and desorption kinetic behaviour of heavy metals in sediments under different redox conditions. The factors influencing the adsorption capacity such as the initial concentration of heavy metal ions in the water, and the competition between heavy metal in adsorption were investigated. In addition, the characteristics such as the bioavailable fraction (by EDTA extraction) of the heavy metals in the sediment, the conditional stability constants for complexation of heavy metals with the surface sites of the sediment particles, and the maximum loading capacity of the sediments for the heavy metals were determined. The results of this study shows that a fundamental understanding of adsorption and desorption of heavy metals on sediments is a requirement in modelling environmental transport and fate of heavy metals, and to help policy-makers in setting environmental quality standards.

Phuong (2003) [26] set up a case study in Zeebrugge (Belgium) for research on benthos at the transition from sandy beaches to tidal flats. At the sandy beach of Zeebrugge, the morphological equilibrium was disturbed because of the port construction of Zeebrugge. From the results of this research, it can be concluded that the species composition, densities and zonation patterns of benthic fauna of sandy beaches are greatly influenced by the morphodynamics and morphology of the beaches.

II. CONCLUSION

From the overview of the training of RIGMR staff members at Belgian universities, it is observed that a large number of staff members obtained a chance to specialize themselves further in the geosciences. It can therefore be concluded that the cooperation projects VIBEKAP and LLINC catalyzed significant institutional capacity building by way of training, which was not foreseen within the cooperation projects.

However, the success of this capacity building is best judged from the quantity and quality of the research performed by RIGMR staff while studying in Belgium. From the overview of research results, it is observed that important contributions are given to karst research in NW Vietnam in general and more specifically to hydrology; hydrogeology; remote sensing and GIS supported analysis of lineaments, groundwater in fractured rock, cave development, environmental monitoring, geological mapping and natural hazards; geochemistry and water quality, application of mineral polymerisation technique and ecosystem and marine environmental management. The research is still going on and will in the coming years result in several PhD's. Previous and present research cooperation between Belgian universities and RIGMR contribute to the built up of the newly established Karst Research Center within RIGMR.

Future cooperation can be extended by way of new projects, in which RIGMR, due to the capacity building, will be able to take a leading role in karst research in SE Asia. Belgian researchers are very pleased with the cooperation so far and eager to further extend this cooperation.

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