Study Guide

International Graduate Programme

Environmental Chemistry (M.Sc.)

at the University of Bayreuth

Last update: 20.11.2019

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Abbreviations

A#	Modules from Module Area Air, # = consecutive numbers
C#	Modules from Module Area Chemistry and Analytics, # = consecutive numbers
EB#	Modules from Module Area Experimental Biogeochemistry, # = consecutive numbers
ECTS	Credit Points (European Credit Transfer System), 1 ECTS = 30 hours
E#	Modules from Module Area Elective, # = consecutive numbers
FT	Teaching Mode: Field Trip
Iso#	Modules from Module Area Isotope Biogeochemistry, # = consecutive numbers
L	Teaching Mode: Lecture
M#	Modules from Module Area Methods, # = consecutive numbers
OE	Performance Assessment: Oral Exam
PA	Performance Assessment
Pres	Performance Assessment: Presentation
Rep	Performance Assessment: Report
S	Teaching Mode: Seminar
S#	Modules from Module Area Soil, # = consecutive numbers
T	Master‘s Thesis
TP	Teaching Mode: Tutorial/Practical Course
W#	Modules from Module Area Water, # = consecutive numbers
WE	Performance Assessment: Written Exam
WHS	weekly hours per semester

1 Goal and focus of the programme

The increasing level of industrialisation and a worldwide overexploitation of natural resources are resulting in environmental problems. In this connection, contaminations are often not restricted to individual environmental compartments (atmosphere, pedosphere or hydrosphere) but rather affect entire ecosystems including the biosphere, often on the global scale. Well-known examples are forest decline caused by acid rain, ozone depletion caused by the persistence of halogenated hydrocarbons, the release of greenhouse gases caused by the combustion of fossil fuels or large-scale rice production, eutrophication of lakes caused by over-fertilisation of agricultural land, watercourse acidification and release of heavy metals in post-mine landscapes, coral bleaching as a consequence of global warming, damage to marine ecosystems caused by oil disasters, the enrichment of micro plastic particles in the environment and the appearance of pollutants in food products, and the depletion and lack of certain nutrients amongst many other examples. Knowledge of sustainable use of resources often lags behind industrial development. Emerging countries often repeat the same mistakes that industrialised countries did in the past, and nowadays are confronted with irreparable damage or cost-intensively trying to repair these.

The subject area of environmental chemistry studies the sources of environmentally relevant substances, their transport and degradation as well as their effects on the biosphere. It is an applied and highly interdisciplinary field of science. As such, it requires a fundamental understanding of relevant processes in air, soil and water as well as sound knowledge of (in-)organic chemistry, (micro-)biology, toxicology, system analysis and knowledge of the interactions of humans with the environment. Therefore, it requires the use of a variety of analytical tools. An increasing demand for experts in the field of environmental chemistry can be expected in view of increasing industrialisation and global integration. This will result in excellent employment opportunities in the academic and public and private sectors.

The degree programme Environmental Chemistry addresses students who focus their interests in chemistry and environmental sciences and who would like to work in an international context. This includes students from countries that already address environmental contaminations as well as students from countries in which environmental problems caused by increasing industrialisation are developing dramatically an in which approaches to efficiently addressing such problems have not yet been developed. One of the goals of the degree programme is to integrate different perceptions of environmental chemical problems from various stages of development and socio-economic backgrounds into the education of students, and to present environmental chemistry in an international context.

For entering the M.Sc. degree programme Environmental Chemistry, a B.Sc. (180 ECTS) is required. Possible disciplines of the B.Sc., for example, are biology, chemistry, geoecology, geology, forestry, agricultural science, hydrology, engineering ecology, limnology, meteorology, physical geography, environmental physics, environmental informatics, environment economy, environmental law, environmental sciences and related disciplines. Sound knowledge of physics, chemistry, biology and environmental sciences are required in any case. The focus of interest of the students must be documented by at least 20 ETCS that the students must have earned in physics/chemistry/biology and environmental sciences. A great deal is demanded regarding the profiles and skills of the applicants. The degree programme is open to excellent, efficient and motivated, national and international students. Participation in an assessment process is required that focuses on professional knowledge from the students’ B.Sc. degrees, distinct interests in environmental chemistry questions, the ability to reflect and think abstractly to follow an interdisciplinary programme of study, and the ability to delve deeply into the subject area, passively and actively, in the English language.

The concept of professional training in this degree programme is problem-oriented. The students receive a broad education in the natural sciences including the environmental compartments air, soil and water, in microbiology and toxicology, and in state of the art analytical approaches, modeling techniques and data analysis. Project-oriented modules encourage the students to independently analyse and process complex environmental interrelations by including various media. In this connection, creativity, flexibility, the ability to work in a team and the sense of responsibility are strongly encouraged. In general, methodological modules, students learn the ability of reflecting and arguing in a scientific context, and how to evaluate scientific reports. Furthermore they gain knowledge of project design and management. During a symposium and an excursion through Germany, the students have the opportunity to deal with global environmental challenges of countries of different stages of development as well as to learn how an industrialized country tries to cope with environmental challenges. In elective subjects, students can receive individual consultation on how to establish their individual profiles. These elective subjects in particular include entrepreneurial education. For their M.Sc. thesis, the students have the chance to participate in various national and international research projects of the lecturers, which also enables the students to establish efficient scientific networks. This direct participation in current research projects promotes an in-depth understanding of environmentally relevant problems in an international environment and through individual experiences.

Individual coaching in small groups, extensive discussions with lecturers and an early integration into the ongoing research of various work groups have always been characteristic for geoscience degree programmes at the University of Bayreuth. A campus where everything you need is right at your doorstep encourages the interdisciplinary exchange between students of various degree programmes and nationalities.

It is the goal of this programme to educate highly qualified executives for science, environmental protection, politics and the economy. Based on sound expert knowledge, they should be able to identify new types of problems, to analyse complex situations and to provide flexible solutions. On completion of the degree programme, the graduates have various attractive career opportunities in the academic sector, in industry (experts and consultants of national and international companies, heads of laboratories, company founders) and in the public sector (policy consultation, development cooperation). Other potential employers include international organisations (e.g. UN, EU, NGOs), national and state authorities (government departments, federal bodies, regional authorities), sustainability departments, consulting companies, insurance companies, universities and research centres. This offers excellent opportunities as communicators in particular for international students from developing countries and emerging countries with increasing industrialisation and the associated demands on know-how. An active community and network of alumni is planned to facilitate intellectual and personal exchange of graduates with environmental chemists who operate internationally.

2 Study concept

2.1 Organisation of the programme

The M.Sc. degree programme Environmental Chemistry should be undertaken in 4 semesters (full-time) or eight semesters (part-time). It requires presence and active participation and concludes with the M.Sc. thesis. All courses are offered on an annual basis, and new students can only enter the programme in the winter semester.

The students earn 30 ECTS per semester, 120 ECTS in total. In this calculation, 1 ETCS is equivalent to a workload of 30 hours. Thus, in this on-campus degree programme, each weekly 2-hour course is equivalent to 1 ECTS (2 WHS x 15 weeks = 30 hours). Additional credits can be earned for preparation and follow-up studies at cost. Exams and proofs of performance accompany the entire course programme and represent the progress of fact-based process-understanding as well as the progressive improvement of analytical abilities, handling of complex issues over all media, the analysis and presentation of contexts, and academic presentations. Basic modules are typically evaluated in written or oral exams. In seminars and practical courses, presentations and reports are typically used for evaluation. In project-oriented modules with a highly integrative character, presentations and discussions are accompanied by supervision and support, followed by a final evaluation.

The programme is structured in individual modules that focus on the environmental compartments air (A), soil (S) and water (W), as well as on chemical modeling, analytics and toxicology (chemistry and analytics C), experimental biogeochemistry (EB) and isotope geochemistry (ISO). Additionally, integrative and methodological modules (M) and electives/interships (E) are offered. Each module is equivalent to 5 ECTS, whereas the M.Sc. thesis is equivalent to 30 ECTS. The compulsory part of the degree programme in the first semester focuses on lectures, accompanied by practical courses to compensate for the potentially non-uniform level of education. In the second and third semester, the fraction of practical courses increases depending on the selection of subjects that are often taught in project-like modules and, in particular in the 3rd semester, in seminars to stimulate and further intensify scientific communication and discussion. Graduates receive a Master of Science (M.Sc.) degree.

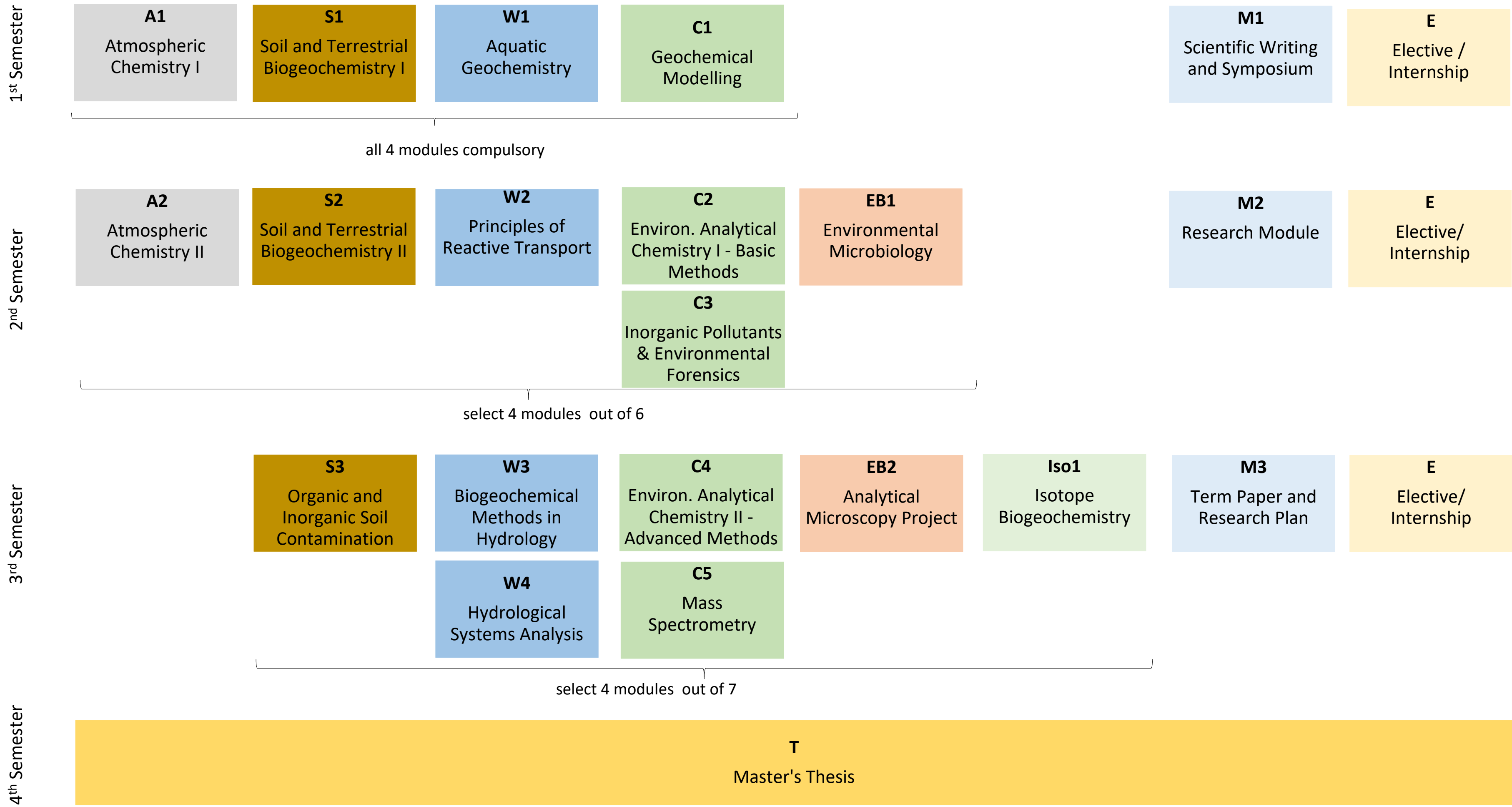

Fig. 1: Structure of the course of studies in thematic areas air (A), soil (S), water (W), chemistry and analytics (C), experimental biogeochemistry and environmental microbiology (EB), isotope biogeochemistry (Iso), methods (M) and elective (E). All modules equal 5 ECTS. Thirty ECTS points are awarded for the master’s thesis (T) . For further details, please see section 4.

2.2 Structure of the degree programme

Orientation week. Before the start of the first semester an orientation week will be offered especially for students from foreign countries. This course covers general organisational information and details on the goals and structure of the programme. Furthermore, the participants will become familiar with the campus and the structure of the University of Bayreuth, its research units and central facilities, like libraries, botanical garden, cafeteria, etc. Participants will have the opportunity to discuss their individual problems, weaknesses, and expectations with professors, such that individual needs and backgrounds can be integrated into the teaching courses. Environmental problems in the home region of the participants, including their cultural and socioeconomic aspects will be presented and discussed in a forum.

The first semester covers mainly lectures on basic chemical processes in the atmosphere, pedosphere and hydrosphere. The course on geochemical modelling will integrate these aspects and delivers predictive capabilities on geochemical processes. In a general methodical course on scientific work, the participants will improve their scientific writing standards and – in the context of a simulated symposium – their oral and poster presentation capabilities. The symposium “Global Environmental Challenges” provides an overview on environmental problems in different regions of the world. Problems to be presented might be selected from current developments or from the students’ own experiences.

In the **second semester**, the student`s understanding of chemical processes in the environment is deepened by lectures and practical laboratory work, e.g. in hydrology and soil sciences, as well by a project on atmospheric chemistry. The lecture and the practical course on environmental analytical chemistry provide expertise in field and basic laboratory methods to analyse environmental samples. A lecture on inorganic pollutants combined with a seminar on environmental forensics will deepen the understanding of environmental impacts. Moreover, a module on environmental microbiology will demonstrate the role of microorganisms in causing and remediating environmental problems. Four out of six modules must be chosen. The Research Module offers the opportunity to work in the specific departments of the programme and to get familiar with their methods in field and laboratory work as well as in modelling.

The **third semester** covers a course on inorganic and organic soil contamination and two more project modules on biogeochemistry/hydrology and environmental microbiology. In environmental analytical chemistry, a lecture and practical course present the latest developments in advanced laboratory methods, including visits to renown analytical facilities inside and outside the University. A specialization can be chosen in mass spectrometry with an own hands-on practical course. In their research seminar, students will present literature studies on current environmental problems and front-end research. Last but not least, students will have to develop a written research plan for their master’s thesis. The research plan will be presented and defended in group seminars.

In their **Master’s Thesis** students will work self-reliantly to a considerable extent on a specific topic of environmental chemistry. The master’s thesis is prepared in the **fourth semester** and should be finished within 6 months. Prior to the master’s thesis the research plan is established in the third semester. The results of the master’s thesis are to be presented in a group seminar prior to finishing the thesis.

During the **first 3 semesters** students have the opportunity for **electives** of courses up to 15 ECTS in total for further specialisation, the development of individual interests and to cope with deficits. Courses can be taken from other programmes of the University of Bayreuth like from NanoChemistry, Environmental Physics, Global Change Ecology, Experimental Geosciences, Microbiology/Molecular Genetics, Food and Health Science or from Environmental Law.

Electives choices may also include language courses or courses on **Entrepreneurial Education.** The latter provides expertise from different disciplines needed to run companies. In the electives also practical experience **(Internships)** in other universities, organisations, agencies and companies can be accepted upon request, as long as the practical work relates to the overall programme. To approve such internships by the supervisor, regularly a 4 week training time and a written report is required.

Students do not generally **spend time abroad** during their first 3 semesters of study, as many of the students come from foreign countries and have a heterogeneous background and require more individual supervision. Upon request and in accordance with the supervisor, the master's thesis may be written in a foreign country. This may be helpful to improve the professional career chances of the students.

3 Course content

The following compilation provides detailed information on the single modules. First, basic information on the responsible instructor, the goals and the content of modules is given. The module description moreover gives information on the format of courses, the required performance record, and the workload that results from active participation, preparation and follow-up for the exam or written report.

In most cases one module will be finished by a single performance record, however, in some modules a written report and a written or oral exam is requested. The description of modules also covers information on the frequency of courses (normally once per year) and suggestions for the specific semester in which the module should be finished.

Premises for specific modules are defined as well as the role of modules as premise for other modules. In case such premises for a specific module are lacking, the instructor can decide if a student participation is exceptionally possible. The lack of premises has to be declared by the student at the beginning of the courses.

Further information on the content of the modules and on suitable literature will be given at the beginning of the courses by the instructor. Any further questions regarding the modules should be addressed to the responsible coordinator.

3.1 Module Area Air (A)

A1 Atmospheric Chemistry I

Coordinator	Nölscher, Atmospheric Chemistry
Learning Objectives	After completion of this module, the students are capable of analysing fundamental chemical reactions in the atmosphere, and evaluating changes of the atmospheric composition.
Content	The lecture "Atmospheric Chemistry I" provides a wide overview of the environmental impact of atmospheric constituents. Fundamental concepts of chemical reactions in troposphere and stratosphere are introduced. The importance and danger of greenhouse gases, the formation of photochemical smog, and the natural and disturbed ozone layer are examples that are discussed by the means of land-mark publications and checked within small exercises. The "hands-on" supplements the lecture Atmospheric Chemistry I. It provides insides into atmospheric historic and recent literature, introduces concepts of how to work on atmospheric data sets and sets the basics of high-quality experimental work.
Prerequisites	none
Mode of Teaching	Atmospheric Chemistry I: lecture (2 WHS) Hands-on: seminar/exercise/practical work (2 WHS)
Performance Assessment	written exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 1st semester)
Number of places	not restricted
Required for subsequent modules	A2

A2 Atmospheric Chemistry II

Coordinator	Nölscher, Atmospheric Chemistry
Learning Objectives	This module extends the student's knowledge to topics of current research in atmospheric chemistry. Developing a research project the student trains basic skills to draft proposals and conduct small experiments in the field of atmospheric chemistry.
Content	The lecture "Atmospheric Chemistry II" presents in detail current issues of atmospheric research. Especially the role of volatile organic compounds in the environment is highlighted. Exchange processes between ecosystems, the mechanisms that form and grow atmospheric particles, and the potential for tropospheric ozone formation depending on different environmental parameters will be discussed in detail. Recent literature and datasets provide examples and serve to test introduced concepts. The "atmospheric chemistry research project" comprises all aspects of designing a new atmospheric research project. The students draft an original research project and present it within the course. Experiments to support the proposal writing process with e.g. proof-of-concept or first tests are defined and carried out in the laboratory or field. The training is concluded by submitting a final research proposal.
Prerequisites	A1 must be successfully completed
Mode of Teaching	Atmospheric Chemistry II: lecture (2SWS) Atmospheric Chemistry Research Project: seminar/tutorial (2 WHS)
Performance Assessment	report (graded)
Workload	active participation: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	maximum 10
Required for subsequent modules	---

3.2 Module Area Soil (S)

S1 Soil and Terrestrial Biogeochemistry I

Coordinator	Lehndorff, Soil Ecology
Learning Objectives	This module provides the competence to understand i) basics of soil science, ii) soil chemical processes and iii) the role of soils in the elemental cycling in ecosystems. This competence is needed to evaluate soil contamination related problems and the interaction of soil with other compartments like the hydrosphere and atmosphere.
Content	The lecture “Introduction to Soil Chemistry” is focusing on the principals of soil formation, the genesis and properties of soil organic matter and soil minerals. This includes litter decomposition and humification as well as the formation of neo-minerals during pedogenesis. Moreover, chemical processes in soils like ion exchange, sorption, and redox-reactions will be addressed using examples of soils formed under specific climates, management and contamination regimes. The lecture “Terrestrial Biogeochemistry I” covers fundamentals of measuring element fluxes in soils and ecosystems and the biogeochemical cycles of N, S and P in soils and terrestrial ecosystems.
Prerequisites	none
Mode of Teaching	Introduction to Soil Chemistry: lecture (2 WHS) Terrestrial Biogeochemistry I: lecture (2 WHS)
Performance Assessment	written exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 1st semester)
Number of places	not restricted
Required for subsequent modules	S2, S3; recommended for EB1

S2 Soil and Terrestrial Biogeochemistry II

Coordinator	Lehndorff, Soil Ecology
Learning Objectives	Students gain competence in methods of soil chemical analyses and in quantifying soil chemical processes. Moreover, the role of soils in the elemental cycling of ecosystems will be demonstrated in more detail. This competence is needed to evaluate soil contamination related problems and the interaction of soil with other compartments like the hydrosphere and atmosphere.
Content	The laboratory course "Soil Processes" covers methods to characterise basis soil chemical properties and processes. Samples will be taken from a former mining site, contaminated with various heavy metals. Experiments will be carried out in small groups. Parameters determined are: cation exchange capacity, element concentrations (C, N, P, Fe, Al, As, Cd, Cr, Cu, Pb) of soil fractions, sediments and plant tissues. The lecture "Terrestrial Biogeochemistry II" covers the biogeochemical cycling of Ca and Al, the turnover of protons and the soil C cycling. Special focus is on organic compound chemistry in soil including isotope and biomarker analyses in soil.
Prerequisites	S1 must be successfully completed
Mode of Teaching	Soil Processes: practical course (2 WHS) Terrestrial Biogeochemistry II: lecture (2 WHS)
Performance Assessment	written exam for lecture and report for practical course (both contribute 50% to the module grade)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	maximum 12 for practical course
Required for subsequent modules	S3; recommended for EB2

S3 Organic and Inorganic Soil Contamination

Coordinator	Lehndorff, Soil Ecology
Learning Objectives	The students acquire skills and abilities to identify soil contamination, to analyse processes that cause soil contamination, and to evaluate complex interactions of environmental contaminants at an advanced level.
Content	The lecture “Soil Contamination” comprises the entry path, toxicity, sorption, mobility, transformation and plant uptake of heavy metals, radioisotopes and organic contaminants. Additional topics include the loss of soil functions, plant and groundwater contamination, and the remediation of contaminated sites. The practical course “Organic Pollutants” trains techniques to characterize soil organic matter composition including biomarkers and organic pollutants. The analytical focus is on organic solvent extraction, solid phase extraction and gas chromatography-mass spectrometry.
Prerequisites	S1 and S2 must be successfully completed
Mode of Teaching	Soil Contamination: lecture (2 WHS) Organic Pollutants: tutorial (2 WHS)
Performance Assessment	written exam for lecture and report for practical course (both contribute 50% to the module grade)
Workload	active participation: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	maximum 12 for practical course
Required for subsequent modules	---

3.3 Module Area Water (W)

W1 Aquatic Geochemistry

Coordinator	Peiffer, Hydrology
Learning Objectives	The students acquire knowledge and ability to remove contaminants from groundwater, deal with chemical problems during drinking water production, and solve problems associated with acidic mine waters.
Content	Aquatic Geochemistry studies the interaction between water, its constituents and the surrounding solid phases. It emphasizes on principles of adsorption dissolved substances onto mineral surfaces, the dissolution of mineral surfaces, the underlying reactions in particular redox processes and complexation reactions. The lecture *Introduction to Aquatic Geochemistry* (2 WHS) provides an overview about the theoretical foundations, which are: Adsorption equilibria, surface complexation, redox potential and its measurement, kinetics of mineral dissolution. The tutorial *Methods in Aquatic Geochemistry* (2 WHS) examines selected problems that need to be quantitatively solved by use of the Computer code PHREEQC. Examples are complexation of arsenate onto ferric hydroxides, reductive dissolution of ferric hydroxides; phosphate retention in sediments.
Prerequisites	The timing of the tutorial ("*Methods in Aquatic Geochemistry*") will be coordinated with module C1 (*Geochemical modelling*)
Mode of Teaching	Introduction to Aquatic Geochemistry: lecture (2 WHS) Methods in Aquatic Geochemistry: tutorial (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 1st semester)
Number of places	not restricted
Required for subsequent modules	EB1, W2, W3

W2 Principles of Reactive Transport

Coordinator	Peiffer, Hydrology
Learning Objectives	The students will know the physical-chemical principles of reactive transport as well as the rate laws to simulate the reaction of contaminants (adsorption, degradation) and will be able to implement these relationships into the corresponding transport equations. They are familiar with the physical-chemical properties of various types of contaminants.
Content	The fate of contaminants in aquatic systems is closely linked with the transport of water. The goal of this module therefore is to introduce the principles of reactive transport with a special emphasis on groundwater, to consider the physical-chemical properties of the substances, and to discuss this with case studies. The lecture "*Introduction to reactive Transport"* (2 WHS) *is* transmitting the theoretical foundations of reactive transport (Advection-dispersions-equation, diffusion, reaction kinetics, Monod kinetics, Peclet- and Damköhler numbers. In the tutorial "*Problems in Reactive Transport" (*2 WHS) the students work on tasks covering the material of the lecture and learn how to use the computer code PhreeqC to quantitatively solve transport problems in combination with retention of chemical substances (e. g. application of filterbeds to remove contaminants).
Prerequisites	W1 must be successfully completed
Mode of Teaching	Introduction to Reactive Transport: lecture (2 WHS) Problems in Reactive Transport: tutorial (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	not restricted
Required for subsequent modules	W3, W4; recommended for EB2

W3 Biogeochemical Methods in Hydrology

Coordinator	Gilfedder, Hydrology
Learning Objectives	This course aims to teach a deeper understanding of biogeochemical processes in the natural environment with a focus on aqueous systems (streams, rivers lakes). It will also provide the practical skills to study aquatic ecosystems. The course will involve both conceptual understanding of biogeochemical processes and how practically to sample, measure and interpret biogeochemically relevant compounds at different spatial scales.
Content	The lecture "*Introduction to Aquatic Biogeochemistry* (V, 1 SWS) will study the connection between groundwater and surface water, chemical fluxes, production and cycling of elements such as carbon and nutrients through the aqueous environment. Specifically the course will make the students familiar with the following topics: • Groundwater – surface water interactions and chemical fluxes in streams • Biogeochemical element cycling within streams • Coupling between physical and biogeochemical processes in lakes • Peatlands as carbon reactors The tutorial "Aquatic Biogeochemistry Project" (Ü, 3 SWS) will provide the necessary methodological and practical expertise to study these topics with the framework of a small research project.
Prerequisites	W1 and W2 must be successfully completed
Mode of Teaching	Introduction to Aquatic Biogeochemistry: lecture (1 WHS) Aquatic Biogeochemistry Project: tutorial (3 WHS)
Performance Assessment	presentation/report (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	maximum 5
Required for subsequent modules	---

W4 Hydrological Systems Analysis

Coordinator	Peiffer, Hydrology
Learning Objectives	The aim of the module is the introduction into the principles of the coupling between hydrological (i.e. physical) and geochemical processes in hydrological systems. The module will discuss the dynamic nature of hydrological processes and emphasize on the processes occurring at hydrological interfaces e.g. between streams and groundwater. It shall provide a comprehensive overview about material processing in catchments and their compartments (groundwater, wetlands, lakes, streams) including contaminants.
Content	In the lecture "*Hydrological Systems*" (2 WHS) the dynamic processes characteristic for the function of lakes and wetlands as the main transformation reservoirs in catchment areas, are presented using system-analytical approaches (box models). Tracer based tools to characterize hydrological and geochemical processes are discussed and presented by the students as oral contributions. In the seminar „*Organic Contaminants in the Water Cycle*" (2 WHS) the specific physical-chemical properties of organic contaminants will be discussed and how these properties affect their fate in hydrological systems. The focus will be on the discussion of case studies.
Prerequisites	W1 and W2 must be successfully completed
Mode of Teaching	Hydrological Systems: lecture with oral presentations (2 WHS) Organic Contaminants in the Water Cycle: seminar with oral contributions (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up including oral contributions: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	not restricted
Required for subsequent modules	---

3.4 Module Area Chemistry and Analytics (C)

C1 Geochemical Modelling

Coordinator	Planer-Friedrich, Environmental Geochemistry
Learning Objectives	Students refresh their basic chemistry knowledge and learn to apply it for explaining environmental chemistry processes in the air, soil, and water. Independently working on practical examples, students increase their chemical understanding of processes and learn to apply, test, and evaluate different solution approaches.
Content	As part of an introduction, the main thermodynamic principles (mass action law, Henry's law) will be repeated and one of the most commonly used computer programmes for hydrogeochemical modeling (PhreeqC) will be explained. Students will then work on practical examples, for which the chemical bases will be repeated briefly in the group before each student carries out calculations, interpretations, and predictions on its own. Afterwards, results will be compared and discussed within the group. The examples range from calculation of thermodynamic equilibria (e.g. modeling the buffer capacity of limestone for acid mine waters, the effects of reactive iron barriers, or measures of drinking water treatment), to modeling of kinetic processes (e.g. tritium degradation in the unsaturated zone or biodegradation) to modeling of one-dimensional and three-dimensional reactive mass transport.
Prerequisites	none
Mode of Teaching	Introduction to Environmental Geochemistry and Geochemical Modeling: tutorial (4 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 1st semester)
Number of places	not restricted
Required for subsequent modules	---

C2 Environmental Analytical Chemistry I – Basic Methods

Coordinator	Planer-Friedrich, Environmental Geochemistry
Learning Objectives	Students get an overview of basic analytical techniques used in modern environmental chemistry. They will increase their practical skills in hands-on experiments and learn the correct application of methods as well as critical evaluation of the results obtained.
Content	The lecture Introduction to Environmental Analytical Chemistry provides basic knowledge for water, gas, soil sampling and stabilisation, for determination and critical evaluation of simple chemical parameters by means of electrochemistry, photometry and titrimetry. All these methods will be applied in practice on topics already known from Module C1 (e.g. calcite-carbonic acid equilibrium or Fe-Sulfide redox reactions). Planning, preparing, and conducting a field sampling trip and practicing laboratory routines such as preparing standards from salts or concentrated solutions, doing calibrations, standard additions and other quality control are part of the course. Basic information on determination of major and trace elements with chromatography and spectrometry will be given in the lecture.
Prerequisites	none
Mode of Teaching	Introduction to Environmental Analytical Chemistry: lecture (2 WHS) Basic Laboratory and Field Method Training: tutorial (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2^{nd} semester)
Number of places	not restricted
Required for subsequent modules	C4, C5; recommended for EB2

C3 Inorganic Pollutants & Environmental Forensics

Coordinator	Planer-Friedrich, Environmental Geochemistry
Learning Objectives	Knowledge of the biogeochemistry of selected trace elements is intensified, interdisciplinary connections to ecosystem functions are made, and students instructed to independently analyse complex chemical interactions. The seminar environmental forensics intensifies and links previous content on a specific case study and students learn in a role-play to present scientific content precisely, construct logical chains of argumentation, defend contrary positions, and lead scientifically correct, in-depth discussions.
Content	The lecture on inorganic pollutants focuses on geochemical and biological influences on biogeochemical cycles of selected metal(oid)s, rare earth elements, and radionuclides. In addition to classical pollutants (As, Sr, Cs, Cd, U) elements are considered, which also serve as nutrients (Mn, Fe, Co, Cu, Zn). The influence of the availability of certain elements on important ecosystem functions, such as biomass production, will be presented. In the seminar environmental forensics a historical or current case of contamination will be discussed. Students will form teams that represent contrasting and potentially conflicting interests. They will gather scientific expertise to create a causal chain from contamination event to its cause and will present and defend their findings e.g. in the form of a court hearing.
Prerequisites	none
Mode of Teaching	Inorganic Pollutants: lecture (2 WHS) Environmental Forensics: seminar (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3^{rd} semester)
Number of places	not restricted
Required for subsequent modules	---

C4 Environmental Analytical Chemistry II – Advanced Methods

Coordinator	Planer-Friedrich, Environmental Geochemistry
Learning Objectives	Students get deeper insights into advanced analytical techniques used in modern environmental chemistry. Based on elaboration of selected topics in hands-on laboratory experiments and computer work, students will collect valuable experience for independent work in environmental analytical chemistry. Students will also learn about availability of advanced analytical methods inside and outside of Bayreuth University.
Content	The lecture Introduction to Environmental Analytical Chemistry II will continue where module C2 ended. It will focus on advanced laboratory methods, getting into more details, mainly of chromatographic and spectroscopic methods. The tutorial will focus on selected topics of current research interest and include both practical laboratory work, e.g. development of a chromatographic separation method for trace elements by IC-ICP-MS, but also detailed digital data interpretation, e.g. of results from optical measurements of natural organic matter or of XAS spectra from trace element binding to solid mineral phases. The tutorial will also include visits to other laboratories at Bayreuth University to get an overview of available techniques as well as one visit to an analytical facility outside Bayreuth University, such as e.g. the environmental research center Leipzig-Halle. The visits will be scientifically prepared by studying and discussing research papers of the respective groups.
Prerequisites	C2 must be successfully completed
Mode of Teaching	Environmental Analytical Chemistry II: lecture (2 WHS) Advanced Laboratory Methods: tutorial (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	not restricted
Required for subsequent modules	C5

C5 Mass Spectrometry

Coordinator	Planer-Friedrich, Environmental Geochemistry
Learning Objectives	Based on knowledge from module C2 and C4, theoretical and analytical knowledge in mass spectrometry will be intensified. Students learn how to independently acquire knowledge from a textbook and consolidate it in the discussion with peers. After successful completion of the course, students are able to select and use a suitable method to determine both total content and speciation of trace elements in solution and thus make an assessment of their mobility and toxicity.
Content	Students will learn the theoretical basis of mass spectrometry based on a textbook. Each chapter will be read prior to a seminar by each participant, then discussed in the group and completed by the lecturer in the seminar. In the accompanying tutorials, students are introduced to tuning, analysis and data interpretation as well as to trouble shooting and instrument maintenance. As an applied example, students then receive real samples in a difficult matrix (e.g., sewage sludge or sea water) and must independently carry out sample preparation, analysis and data interpretation including quality control and error calculations and they must evaluate their results in an environmental chemistry context.
Prerequisites	C2 must be successfully completed, C4 must be attended
Mode of Teaching	Basics in Mass Spectrometry: seminar (2 WHS) Application of Mass Spectrometry in Trace Element Analysis: tutorial (2 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	maximum 10
Required for subsequent modules	---

3.5 Module Area Experimental Biogeochemistry (EB)

EB1 Environmental Microbiology

Coordinator	Obst, Experimental Biogeochemistry
Learning Objectives	In this module, the students should gain knowledge of the influence of microorganisms on biogeochemical cycling. A fundamental understanding of thermodynamics and kinetics of the conversion and transformation of materials by microbes is of importance. The students should learn principles of the binding, release and transformation of inorganic and organic contaminants. In a parallel seminar, the students will gain detailed knowledge of current research topics in environmental microbiology and geomicrobiology, in scientific literature research as well as in the critical evaluation of literature sources. Furthermore, they should practice presenting in front of an interdisciplinary audience. In the practical part, the previously acquired knowledge should be intensified and the documentation of scientific research should be learned and practiced in a small project.
Content	Topics of this module are general, environmental microbiology and geomicrobiology, biogeochemical cycling, microbial degradation and transformation of contaminants, thermodynamics and redox-zonation as well as interactions between microorganisms and mineral phases.
Prerequisites	W1 must be successfully completed, recommended: S1
Mode of Teaching	Introduction to Environmental Microbiology: lecture/seminar (2 WHS) Environmental Microbiology Project: tutorial (2 WHS)
Performance Assessment	written exam (L/S) and report (Ex) (both with grades)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 30 hours performance assessment: 60 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	maximum 14
Required for subsequent modules	EB2

EB2 Analytical Microscopy Project

Coordinator	Obst, Experimental Biogeochemistry
Learning Objectives	In this module, the students should gain theoretical and practical experience in spatially resolved analytical approaches that are used for biogeochemical process identification. The module is organised as a project-study so that the students gain experience in project organisation. The students should learn how to plan and conduct a specific field-sampling trip. Using their own samples, the students will gain knowledge of analysis planning, sample preparation and several analytical microscopy approaches for process. Finally, the students should learn the principles and gain experience in scientific image data analysis approaches and interpretation, as well as in scientific presenting and critical discussions.
Content	In lectures, the students will learn the required theoretical basics of spatially resolved analytics and will apply this knowledge afterwards in their projects. Techniques will include visible light microscopy, fluorescence microscopy, confocal laser scanning microscopy and electron microscopy in bio- geo and environmental sciences; sample preparation including fluorescence staining for analytical measurements; principles of scanning electron microscopy including sample preparation techniques. In the theoretical part also state-of-the-art approaches such as synchrotron-based scanning transmission X-ray microscopy will be covered. The students will also learn basics of scientific, quantitative image analysis.
Prerequisites	EB1 must be successfully completed; recommended: S2, W2, C2
Mode of Teaching	Analytical Microscopy in Bio-, Geo- and Environmental Sciences: lecture/tutorial (4 WHS)
Performance Assessment	report (with grade)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 45 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	maximum 10
Required for subsequent modules	---

3.6 Module Area Isotope Biogeochemistry (ISO)

Iso1 Isotope Biogeochemistry

Coordinator	Gebauer, Isotope Biogeochemistry
Learning Objectives	Students will learn the theoretical and methodological bases to use isotopes to investigate biogeochemical processes and fluxes and apply their knowledge to practical examples from ecology and environmental research.
Content	The module consists of a lecture "Isotopes in Biogeochemistry" as well as tutorials. The lecture is divided into two parts. Part 1 deals with stable isotopes, Part 2 with radioisotopes and tracer applications. In both parts, students will learn theoretical foundations of frequency variations of isotopes, methods for determining these frequencies and their use in the identification of processes and source/sink functions in element cycles of ecosystems. Furthermore, the use of stable and radioactive isotopes as tracers to elucidate complex mass flows in ecosystems is explained. In the tutorials, practical applications of isotope ratio mass spectrometry will be demonstrated.
Prerequisites	none
Mode of Teaching	Stable Isotopes: lecture (2 WHS) Radioactive Isotopes: lecture (1 WHS) Isotope Ratio Mass Spectrometry: tutorial (1 WHS)
Performance Assessment	written/oral exam (graded)
Workload	active participation in 2 courses: 60 hours preparation and follow-up: 60 hours performance assessment: 30 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	not restricted
Required for subsequent modules	---

3.7 Module Area Methods (M)

M1 Scientific Writing and Symposium

Coordinator	Obst, Experimental Biogeochemistry
Learning Objectives	In the seminar “Scientific writing” students should acquire skills in scientific literature research and writing of scientific manuscripts on an advanced level. The students should learn and practice the critical evaluation of scientific Content and to present their own results precisely in manuscripts. In the symposium, students should learn and practice to present in front of an audience, to design posters, to provide critical feedback and to lead scientific discussions. Communication, reflection and argumentation skills will be trained.
Content	In the seminar “scientific writing”, common software tools for scientific literature research will be presented. In short talks, students will present the structure of selected chapters of scientific manuscripts. Students will also write a manuscript based on their own B. Sc. thesis and critically evaluate the manuscripts of other students. In the symposium “Global Environmental Challenges”, students will present environmental problems of countries at different stages of development and at different times. Topics include current political themes, recent developments or experiences of the students in their home countries.
Prerequisites	none
Mode of Teaching	Seminar Scientific writing: seminar (2 WHS) Symposium Global Environmental Challenges: seminar (1 WHS)
Performance Assessment	Report (scientific writing) and presentation (symposium); both without grades
Workload	active participation in 2 courses: 45 hours preparation and follow-up: 60 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 1st semester)
Number of places	not restricted
Required for subsequent modules	T

M2 Research Module

Coordinator	Study Programme Coordinator
Learning Objectives	The students get a first insight into the research practice of the research groups in Environmental Chemistry at Bayreuth University. Under individual guidance, they can deepen their practical skills in field or laboratory work, literature research, and/or modeling. The module is in content and methods an intensive preparation for independent research as it will be required in the later master's thesis.
Content	Content depend on current research projects of the selected research group. M2 is usually performed on a research group of one of the lecturers of the study programme Environmental Chemistry. Other research modules inside or outside the University of Bayreuth can only be taken after prior approval by the board of examiners. In agreement with the respective supervisor, the M2 module may include experimental work in the field or laboratory, a literature review, attending seminars of the research group, workshops or conferences with an own presentation and/or the compilation of a research report.
Prerequisites	none
Mode of Teaching	tutorial: 3 weeks (15 days*8 hours/days = 120 hours); in agreement with the supervisor this research module can be taken as a 3 weeks block or on an hourly basis
Performance Assessment	presentation/report (without grade)
Workload	active participation: 120 hours performance assessment: 30 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	summer semester (recommendation: 2nd semester)
Number of places	not restricted
Required for subsequent modules	T

M3 Paper seminar, Research plan

Coordinator	Study Programme Coordinator
Learning Objectives	The paper seminar serves thematic education and promotes critical reflection of scientific content and presentation. The critical evaluation of published data should simultaneously help the students designing their master's thesis. In the seminar "research plan" the students learn in more detail how to plan and to organise a more elaborate project study. The search of scientific topics and work scheduling as well as organisational skills, time management and creativity should be learned and practised.
Content	For the paper seminar, the student attends the group seminar of the group they do their thesis with, presents the scientific content of a current research paper, and evaluates critically the quality of research and presentation. Feedback will be given from other members of the group seminar. In the seminar „research plan" the students learn in the respective work groups based on literature research how to define and limit their upcoming M.Sc. thesis, how to draft precise work hypotheses that can be verified/falsified, how to identify required instrumentation and how to establish a realistic schedule for the project that can be controlled via well-defined milestones.
Prerequisites	none
Mode of Teaching	Paper Seminar: seminar (2 WHS) Seminar Designing and presenting a research plan: seminar (1 WHS)
Performance Assessment	presentation (paper seminar) and report (research plan); both without grades
Workload	active participation in 2 courses: 45 hours preparation and follow-up: 60 hours performance assessment: 45 hours total: 150 hours
Credit Points	5 ECTS points
Frequency	winter semester (recommendation: 3rd semester)
Number of places	not restricted
Required for subsequent modules	T

3.8 Module Area Elective/ Internship (E)

E Elective/ Internship

Coordinator	Study Programme Coordinator
Learning Objectives	The Elective Module serves to address existing knowledge gaps and to achieve a strong, individual profile based on each student´s individual priorities. This can, for example, be further education in natural sciences but also the acquisition of additional qualification in a language, legal issues, business administration, or internships.
Content	Either a complete module or several courses from all courses offered throughout the University can be taken, Examples include but are not limited to specialisation in Nano Chemistry, Environmental Physics, Global Change Ecology, and Experimental Geosciences, or microbiology/molecular genetics, food and health sciences, or environmental law, and language courses or courses in "Entrepreneurial Education". After prior approval by the board of examiners also Internships inside or outside the University can be taken. In the first semester, an individual consultation is offered to help selecting the appropriate courses taking into account differing previous knowledge and intended specialisation. Lecturers also help in selecting suitable internships.
Prerequisites	Will be defined by the respective lecturer of each course.
Mode of Teaching	Will be defined by the respective lecturer of each course.
Performance Assessment	Will be defined by the respective lecturer of each course; for internships, the board of examiners defines performance assessment; grades acquired in courses within modules F1-3 will not be considered for the final calculation of the overall master´s degree grade
Workload	Will be defined by the respective lecturer of each course; for internships, the board of examiners defines equality to the requirement of 5 ECTS points.
Credit Points	15 ECTS points in total (can be achieved in any combination of ECTS)
Frequency	Winter and summer semester (semester 1, 2, and 3)
Number of places	not restricted
Required for subsequent modules	Depends on individual choice of modules.

3.9 Module Area Master’s Thesis (T)

T Master‘s Thesis

Coordinator	Study Programme Coordinator
Learning Objectives	The master’s thesis is an independent research task on a selected topic within a desired specialisation. The goal is to practice the hypothesis-driven investigation of a given research question by selecting appropriate methods and tools based on previously acquired theoretical and practical knowledge, find within a given time answers to scientific problems, and correctly reflect them both in presentation and thesis. Flexibility, creativity, time and task management as well as abstraction and communication skills will be trained.
Content	The topic of the thesis can be freely chosen in consultation with the supervisor and must have a clear connection to the Content of the Environmental Chemistry programme. In consultation with a University-based supervisor and by request to the board of examiners external theses are also possible, provided that the subject is of equal scientific quality and challenge.
Prerequisites	Ideally, all modules have been completed successfully before starting with the master’s thesis, especially those that are from within the same research area Modules M1, M2, and M3 must be successfully completed
Mode of Teaching	Independent work in close contact to the supervisor and the respective research group
Performance Assessment	Master’s thesis as well as at least one presentation in the group seminar of the respective research group
Workload	independent work (6 months): 900 hours total: 900 hours
Credit Points	30 LP; the grade of the thesis will be the grade of the whole module
Frequency	the thesis will be completed during the 4^{th} semester; total duration is 6 months.
Number of places	not restricted
Required for subsequent modules	---

4 Study guide and performance assessment

1st Semester	Mode	WHS	PA	ECTS
A1 Atmospheric Chemistry I				5
Atmospheric Chemistry I	L	2	WE	
Hands-on	TP	2		
S1 Soil and Terrestrial Biogeochemistry I				5
Introduction to Soil Chemistry	L	2	WE	
Terrestrial Biogeochemistry I	L	2		
W1 Aquatic Geochemistry				5
Introduction to Aquatic Geochemistry	L	2	WE/OE	
Methods in Aquatic Geochemistry	TP	2		
C1 Geochemical Modeling				5
Introduction to Environmental Geochemistry and Geochemical Modeling	TP	4	WE/OE	
M1 Scientific Writing and Symposium				5
Scientific Writing	S	2	Rep	
Symposium Global Environmental Challenges	S	1	Pres	
E Elective/ Internship [a)]	according to specifications			5

2nd Semester	Mode	WHS	PA	ECTS
A2 Atmospheric Chemistry II [b)]				5
Atmospheric Chemistry II	L	2	Rep	
Atmospheric Chemistry Research Project	TP	2		
S2 Soil and Terrestrial Biogeochemistry II [b)]				5
Terrestrial Biogeochemistry II	L	2	WE (50%)	
Soil Processes	TP	2	Rep (50%)	
W2 Principles of Reactive Transport [b)]				5
Introduction to Reactive Transport	L	2	WE/OE	
Problems in Reactive Transport	S	2		
C2 Environmental Analytical Chemistry I – Basic Methods [b)]				5
Introduction to Environmental Analytical Chemistry	L	2	WE/OE	
Basic Laboratory and Field Method Training	TP	2		
C3 Inorganic Pollutants & Environmental Forensics [b)]				5
Inorganic Pollutants	L	2	WE/OE	
Environmental Forensics	S	2		
EB1 Environmental Microbiology [b)]				5
Introduction to Environmental Microbiology	L/S	2	WE (50%)	
Environmental Microbiology Project	TP	2	Rep (50%)	
M2 Research Module				5
Research Project	TP	8	Pres/Rep	
E Elective/ Internship [a)]	according to specifications			5

3rd Semester	Mode	WHS	PA	ECTS
S3 Organic and Inorganic Soil Contamination [c)]				5
Soil Contamination	L	2	WE (50%)	
Organic Pollutants	TP	2	Rep (50%)	
W3 Biogeochemical Methods in Hydrology [c)]				5
Introduction to Aquatic Biogeochemistry	L	1	Pres/Rep	
Aquatic Biogeochemistry Project	TP	3		
W4 Hydrological Systems Analysis [c)]				5
Hydrological Systems	L	2	WE/OE	
Organic Contaminants in the Water Cycle	S	2		
C4 Environmental Analytical Chemistry II – Advanced Methods [c)]				5
Environmental Analytical Chemistry II	L/S	2	WE/OE	
Advanced Laboratory Methods	TP	2		
C5 Mass Spectrometry [c)]				5
Basics in Mass Spectrometry	S	2	WE/OE	
Application of Mass Spectrometry in Trace Element Analysis	TP	2		
EB2 Analytical Microscopy Project [c)]				5
Analytical Microscopy in Geomicrobiology and Environmental Science	L/TP	4	Rep	
Iso1 Isotope Biogeochemistry [c)]				5
Stable Isotopes	L	2	WE/OE	
Radioactive Isotopes	L	1		
Isotope Ratio Mass Spectrometry	TP	1		
M3 Paper Seminar and Research Plan				5
Paper Seminar	S	2	Pres	
Designing and Presenting a Research Plan	S	1	Rep	
E Elective/ Internship [a)]	according to specifications			5

4th Semester	ECTS
T Master's Thesis	30
Master's Thesis including 1 presentation	

[a)] The total numbers of credit points for all E-modules together is 15 ECTS; the 15 ECTS can be achieved in any combination of different lectures or modules with different ECTS.
[b)] select 4 out of 6 modules (A2, S2, W2, C2, C3, and EB1)
[c)] select 4 out of 7 modules (S3, W3, W4, C4, C5, EB2, and Iso1)

All modules excluding the M- and E-modules are graded. The weighting for calculating the overall grade of the master´s degree is based on the ECTS points indicated for each module.