Summary

This thesis presents the results of the first investigation on the drinking water circuit of the megacity Karachi, Pakistan. The essential resource water can only be supplied sufficiently in densely populated areas, if the necessary ecological prerequisites are given. This awareness slowly settles in the minds of local decision-makers. For a long time international organisations as the UN acknowledge the necessity of a secure water supply for further socio-economical development. In this connection, there is urgent need of technology transfer and local capacity building. Holistic and multi-disciplinary methods, which not only include exposure characteristics, are particularly recommended. Recognising this, a method was developed which enables to collect data of the current contamination situation and supplies a preliminary risk assessment of the condition of the drinking water circuit of Karachi. In a joint endeavour the developed method was applied in Karachi including the scientific exchange in terms of training Pakistanian Ph. D. students in Karachi and Hamburg. Thus foundations were laid on-site for knowledge transfer and capacity building regarding environmental analytics.

The developed method follows an integrative approach combining chemical-analytical and ecotoxicological test methods. Due to the specific objectives of this thesis and the prevailing circumstances in Karachi, the configuration and application of this effect-directed approach differs in its premises from those of conventional effect-directed approaches. The historic idea of this concept is the confirmation of a causal link between an effect and a distinct substance or group of substances. Due to the local circumstances concerning the massive contamination this seemed not to be feasible. Moreover, this is not expedient in the first characterisation of the exposure situation of a drinking water circuit in a megacity of the developing world. Therefore, the purpose of the biological test system was to prioritize the vast number of resulting fractions with regard to their relevance. Thus, the effort in instrumental analysis and its evaluation could be kept in acceptable limits. At the same time no relevant information can be overlooked. Another important condition which had substantial influence on the method development was the suitability for technology transfer into the study area.

The exposure situation of the study area was characterized successfully by the developed method. 768 fractions from 32 samples were screened for their ecotoxicological relevance by the luminescent bacteria test. The samples originate from all parts of the investigated drinking water circuit. These included the sources (surface and groundwaters), distribution, processing and tapping points for drinking water as well as waste water and the surface waters in which it is discharged. The determined pollution status indicates the alarming condition of the drinking water circuit of Karachi. The waste and surface waters of the city area are severely contaminated, especially with PPCP and industrial chemicals. Particularly the high burden of PPCP contamination is a distinctive feature of the exposure characteristic, which has not been observed in comparable investigations originating from other countries. In an international comparison, the drinking and groundwaters are highly polluted by

disinfection by-products and industrial chemicals. The pollution profiles vary regionally and reflect the contamination of the surrounding area. In the samples of the surface waters from outside Karachi, industrial chemicals dominate the pollution profiles.

The expected high pollution of the rural surface waters by pesticides, originating from the agricultural usage in the investigated area and the monocultures upstream the Indus, could not be confirmed. The same result was obtained regarding the contamination with historical POPs, dioxins and PCBs which is merely existent. These results disprove the thesis that the exposure characteristics in third world countries reflect the situation of the industrialised nations in former times. The official isolated studies regarding environmental pollution as well as first approaches to monitoring in Pakistan are focused exclusively on pesticides, POPs, dioxins and PCBs on the basis of the above mentioned theoretical thoughts regarding the exposure characteristics. Due to the outcome of the present study, focussing on these groups of contaminants has been proven absolutely wrong, resulting in a hazardous underestimation of the current situation and the derived toxic risk potential.

In toxicological terms the status of the waste and surface waters of the city area is particularly alarming. Many contaminants are present in concentrations exceeding their effect thresholds and in some cases even their EC_{50}/LC_{50} levels. The respective water bodies are all in a disastrous condition from an ecological point of view. In some of the drinking water samples, strict EU-limits and “GOWs” of the German UBA are violated, yet there is no acute hazard to consumer health. On the other hand, many identified substances exhibit chronic toxicity effects. The greatest risk, however, is derived from the pollution profiles. These profiles reflect those of the severely contaminated waste and surface waters of the respective surrounding areas. This fact proves that the leaching of waste water and the cross contamination in the dilapidated piping systems is already taking place. The water resource systems of the Indus and Hub River exhibit no acute toxic hazards, apart from occasionally increased concentrations of certain contaminants, but already bear a high burden of pollution. In summary, the usage of these surface waters as drinking water resources can be ensured if immediate measures are taken, concerning the reduction of the emission of contaminants. In the consideration of the individual concentrations and distribution profiles of these substances, conclusions can be drawn regarding their origins. In the general context of environmental sciences a new major introductory pathway of PPCP can be postulated regarding the situation in Karachi. The relation of mother compounds to their transformation products as well as locally restricted high increases in concentrations prove that industrial emissions are the major pathway of PPCP into the aqueous environment in the study area. This is in clear contrast to the situation in industrialised countries, where municipal waste water originating from households are responsible for the major share of PPCP contamination.

The results of this thesis further show the advantage of the combined chemical and ecotoxicological approach compared with the conventional chemical analytical screenings regarding the gained knowledge. In addition to the description of the exposure characteristics, a preliminary risk assessment could be estimated in the joint reflection of the chemical-analytical and ecotoxicological

results. This mainly includes the introductory pathways of which some conclusions have been mentioned already. Concerning a holistic view of this aspect a deeper cognisance was gained and recommendations for immediate measures could be suggested. On the basis of the results of this work it can be confirmed that the lacking treatment of waste water, next to the rudimentary infrastructure of solid waste disposal, is the main reason for the disastrous situation in Karachi. Apart from a sustainable concept of liquid and solid waste disposal, a comprehensive approach of emission prevention is needed. A further important issue tolerating no delay is the maintenance and improvement of the derelict piping system. The results of the presented investigations clearly show the threat towards the viability of the megacity Karachi due to the severe contamination of its drinking water circuit. Solely by fundamental and holistic reforms of the infrastructure an effective resolution can be achieved, requiring a huge endeavour by the responsible decision makers.

Furthermore, many hitherto unknown environmental contaminants were identified in the analysed samples. Several compounds belonging to different classes of organic pollutants, such as pharmaceuticals, pesticides, industrial chemicals and disinfection by-products as well as new transformation products have been identified for the first time in aqueous matrices in the course of this work. This fact proves the outstanding efficacy and performance of the developed effect-directed approach also in the context of current environmental analytical issues. The results of the presented thesis disprove the negation of the suitability of effect-directed analysis cited in the relevant literature, concerning non-target approaches in aqueous media, particularly using a non-specific biotest.