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Enhancing of Environmental Quality through Groundwater Artificial Recharge in Dar es Salaam Coastal Aquifer, Tanzania

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Introduction

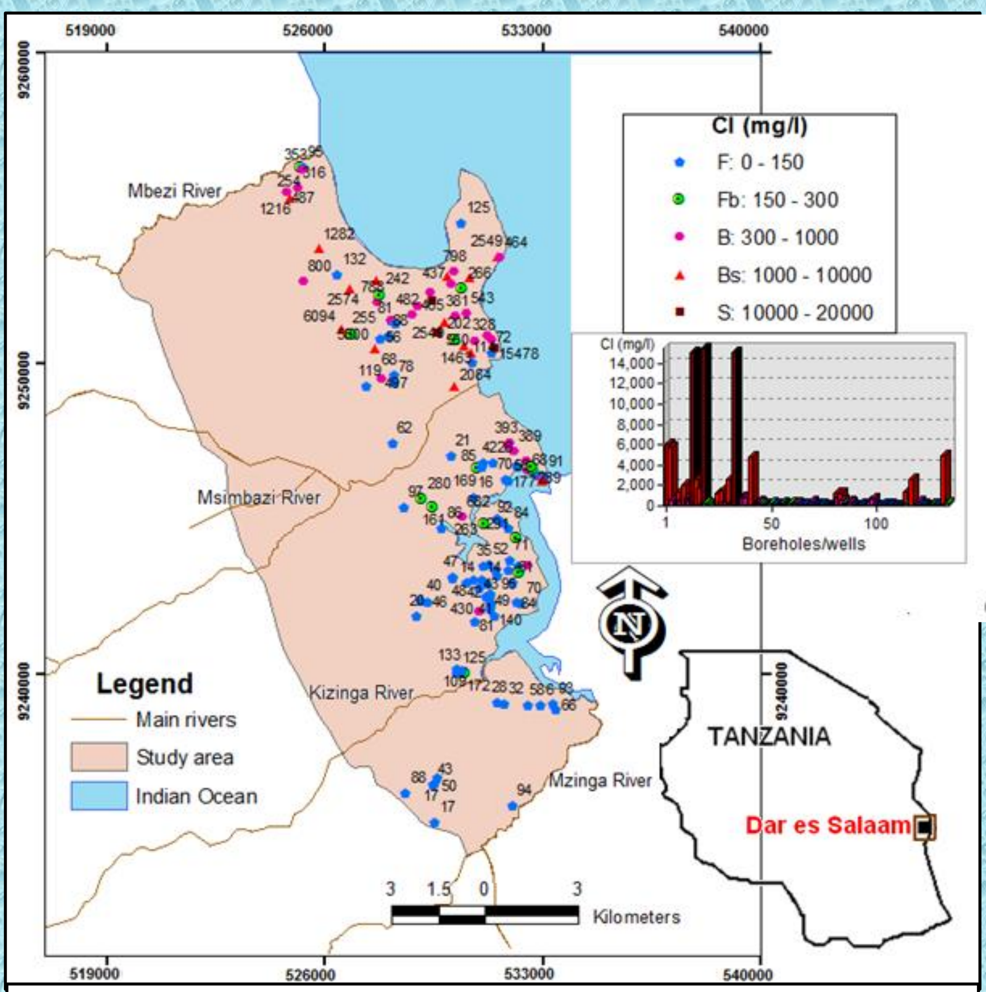
- Dar es Salaam City, a home of over 4 million people, is located on the coast of Indian Ocean.
- The city depends for over 50% on local groundwater resources.

Problem setting

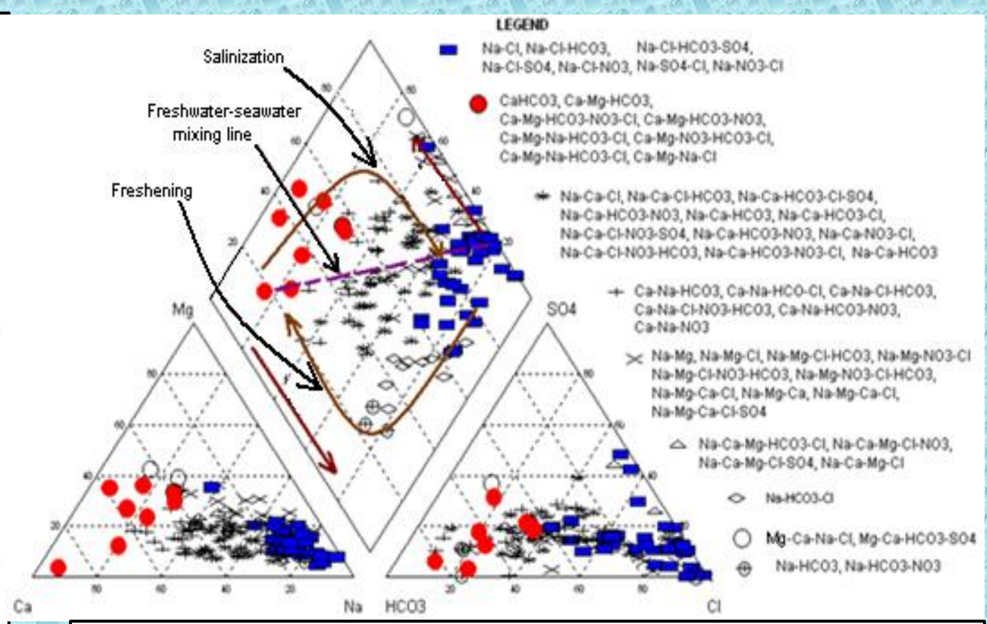
- The current groundwater replenishment under natural infiltration is about 184 mm (equivalent to 71.39 x 10^6 m^3 $year^{-1}$) indicating that only 16.5% of the long term average annual precipitation of 1114 mm ends up as groundwater recharge (Mtoni et al., 2011).
- The water balance of the catchment suggests for the average sustainable yield (calculated as 40% of natural groundwater recharge) a value of 28.56 x 10^6 m^3 $year^{-1}$.
- The current groundwater abstraction is approximately 69.3 x 10^6 m^3 $year^{-1}$) and such overexploitation of groundwater usually results in a rise of the freshwater-saltwater interface and lateral seawater intrusion in a coastal aquifer, and thus degradation of groundwater quality.

Objectives of the study

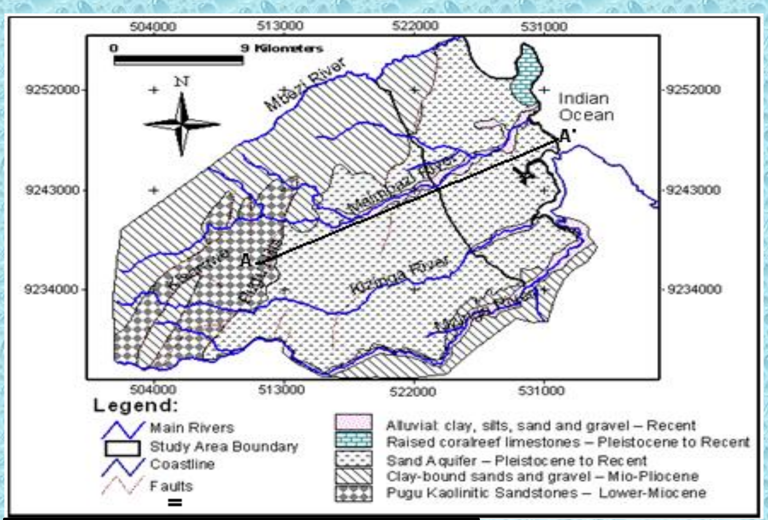
To assess the long term viability of the water supply, including water quality, and the potential to increase the yield of the aquifer through artificial groundwater recharge (AGR).



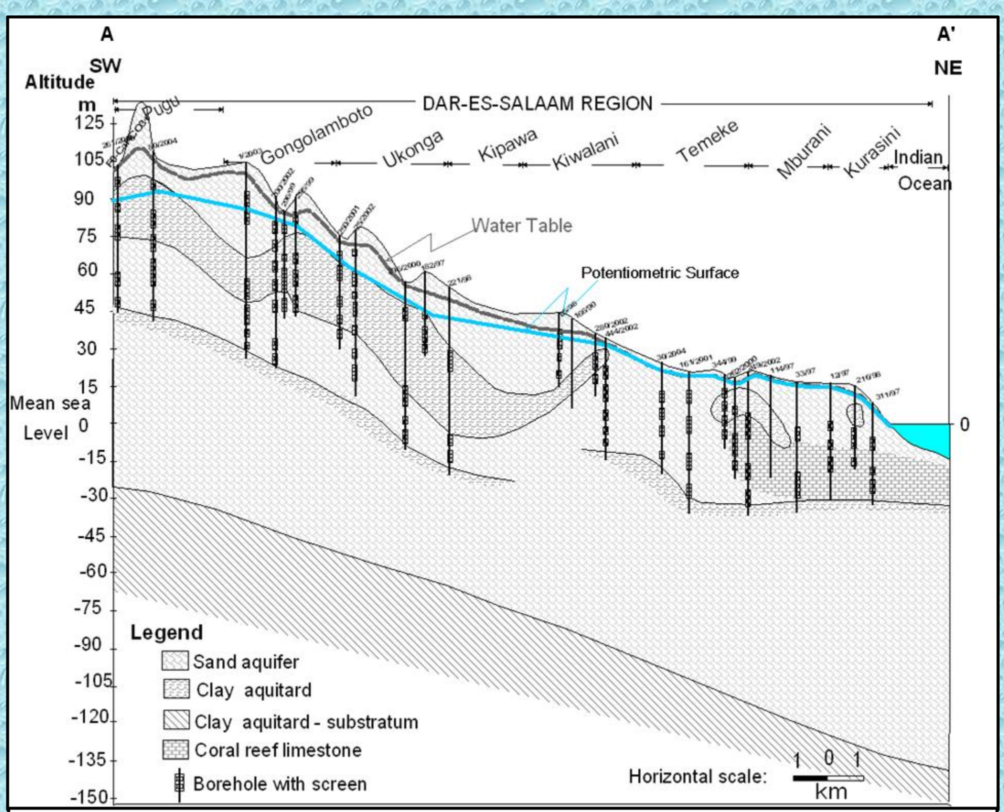
Location map of study area showing sampled points



Piper plot with representation of major ions and groundwater types in the study area

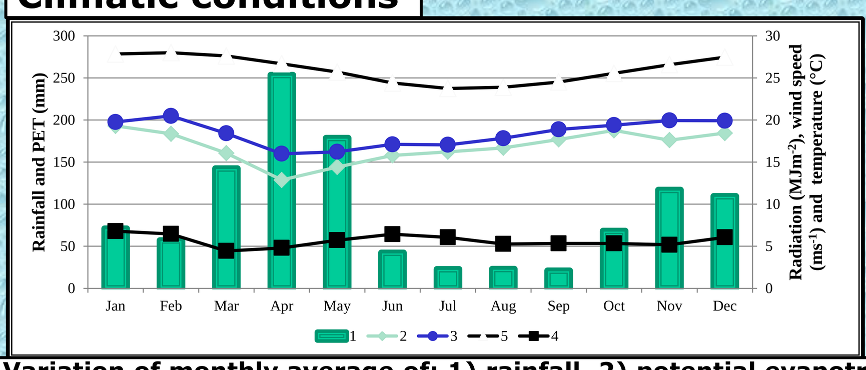


Geological map (Mjemah, 2007)

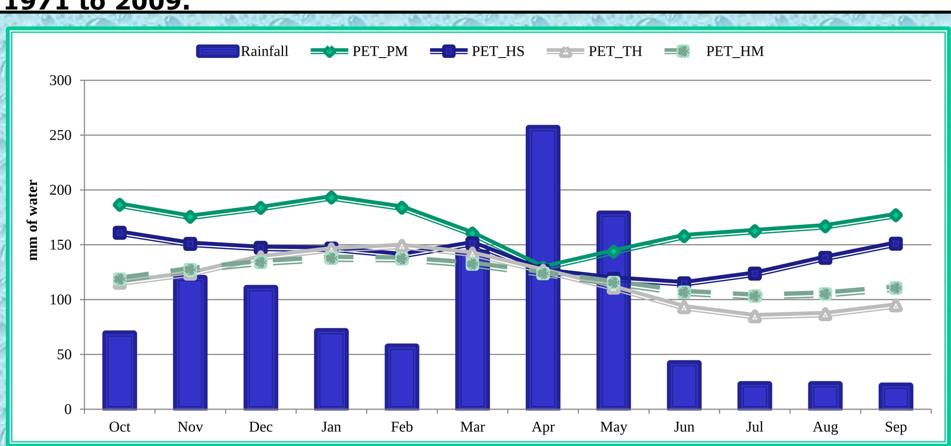


Hydrogeological cross-section A-A' (Mjemah, 2007); location of the profile is shown in Geological map

Climatic conditions

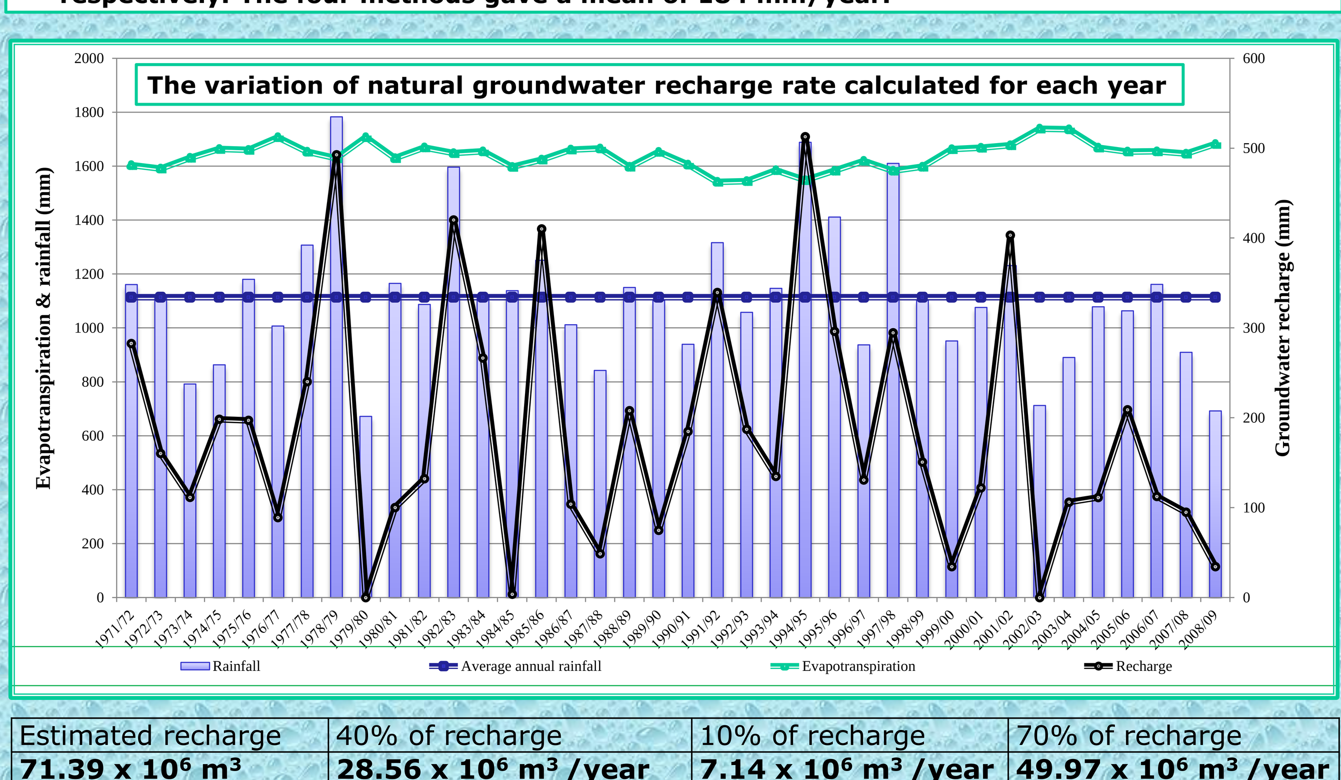


Variation of monthly average of: 1) rainfall, 2) potential evapotranspiration (PET), 3) radiation, 4) wind speed, and 5) temperature for the period from 1971 to 2009.



Comparison of average monthly potential evapotranspiration (PET) computed using different methods for the period 1971/1972-2008/2009.

- **Hargreaves and Penman methods show a comparable trend, as opposed to Thornthwaite and Hamon methods.**
- **Mostly, Thornthwaite and Hamon show lower values, except in April where all methods show more or less the same value.**
- **The average annual recharge computed using the evapotranspiration calculated respectively by Penman-Monteith (PM_PET), Hargreaves (HS_PET), Thornthwaite (TH_PET) and Hamon (HN_PET), gave the values of 166 mm/year, 174 mm/year, 198 mm/year and 199 mm/year respectively. The four methods gave a mean of 184 mm/year.**



Estimated recharge	40% of recharge	10% of recharge	70% of recharge
71.39 x 10^6 m^3 /year	**28.56 x 10^6 m^3 /year**	**7.14 x 10^6 m^3 /year**	**49.97 x 10^6 m^3 /year**

Estimated groundwater recharge: 184 mm/year equivalent to 71.39 x 10^6 m^3/year; abstraction (for different uses) in Dar es Salaam: 69.3 x 10^6 m^3/year

Methodology

The assessment of the potential for AGR included the evaluation of the dynamics of groundwater flow and recharge, and consideration of the options for artificial recharge techniques that can be used. A primary concern was to understand the hydrological variability within the aquifers, as well as to identify potential sources of water for aquifer recharge. Based on meteorological data, groundwater recharge was estimated using a soil moisture water balance. Calculations with monthly meteorological data were used for the period 1971–2009.

Groundwater quality analysis

From 134 groundwater samples analysed, groundwater is mainly affected by three factors: seawater intrusion due to aquifer overexploitation, dissolution of calcite and dolomite in recharge areas, and nitrate pollution mainly caused by the use of onsite sewage disposal systems (pit latrines and septic tanks). High enrichment of Na^+ and Cl^- gives an indication of seawater intrusion into the aquifer as also supported from the Na-Cl signature on the Piper diagram. The boreholes close to the coast have much higher Na/Cl molar ratios than the boreholes located further inland. The latter have a major ion composition characteristic of freshly recharged groundwater (Ca-Mg-HCO_3). The dissolution of calcite and dolomite in recharge areas results in Ca-HCO_3 and Ca-Mg-HCO_3 groundwater types. Ca^{2+} and Na^+ ion exchange causes groundwater evolution to Na-HCO_3 type. Chloride (Cl) concentration shows a general increase down gradient to the east towards the coastline. Cl^- values range from 6.4 mg/l to 15,478 mg/l.

Hydrogeological formations (Mjemah, 2007)

The groundwater reservoir consists of two aquifers:

i. Unconfined sand aquifer(1-10 m). Average transmissivity and hydraulic conductivity is 34 m^2/d and 1.58 m/d respectively.
ii. Lower semi-confined sand aquifer (5-50m). Average transmissivity and hydraulic conductivity is 63 m^2/d and 2.14 m/d respectively.
iii. Aquifers are separated by a clay aquitard (1-30m) except in the area close to the ocean.

The general groundwater flow direction is towards the sea.

Hydrogeologic suitability and natural groundwater recharge

Permeable strata are available at shallow and medium depths. Due to the sandy nature of the subsoil in many parts of the city, sinking of boreholes is easy and this has led to the increased supply of groundwater. The are two recharge mechanisms: i) replenishment of the aquifer from direct infiltration from rainfall through vadose zone, and ii) lateral recharge from Pugu Hills occurring through the faults and joints. Recharge mainly occurs from rainfall that falls on the sandy sediments which favour infiltration. Only a small portion of the rainfall reaches the water table. Water also drains into the aquifer from some rivers (Msimbazi and Kizinga) within the coastal plain. In other reaches of the rivers, groundwater discharges into streams as base flow. Recharge through the clay-bound sands outcrops in the northeast and southeast of the study area is generally small and is mainly favouring runoff.

Artificial groundwater recharge to augment natural replenishment

Groundwater is the major resource of water for Dar es Salaam City which has a high and expanding population of over 4 millions. Groundwater level has decreased since 1997 when boreholes drilling began to expand quickly following the weakening of the surface water supply and the rapid growth of the city and its suburbs. Over 7,500 active boreholes/wells exist. In view of increasing reliance on groundwater and prolonged aquifer overexploitation, further lowering of groundwater levels is expected. In order to enhance the sustainability of the aquifer, artificial groundwater recharge (AGR) is considered as one of the options to increase groundwater storage.

Potential sources of water for artificial groundwater recharge (AGR) in Dar es Salaam

1. Non-committed surface runoff that flows out to the ocean (about 10% of the rainfall).
2. Grey water (from baths, kitchens, washing machines and sinks) accounting for over 50% of the outflow from homes. Grey water has less pathogens and nitrogen compared to the wastewater from the toilets and does not require expensive treatment, and is a potential resource for AGR.

Available wastewater treatment techniques in Dar es Salaam

1. Constructed wetland at University of Dar es Salaam (Mashauri et al., 2000): The field tests were conducted at low and high infiltration rates of 0.27 m/h and 2.3 m/h respectively. Treatment effectiveness: high mean removal efficiencies: 80% for suspended solids (SS), 66% for COD, 91% for faecal coliforms (FC) and 90% for total coliforms (TC) achieved at the low infiltration rate.
2. Grey water treatment system (Kaguongo and Kocanda, 2010): The treatment system is cost-effective; it consists of concrete boxes placed over each other, filled with inner porous material and planted with plants. The system purifies grey water as it percolates through it and at the same time provides a vertical space for growing plants (Typhalatifolia and Scirpus species) used for wastewater treatment purposes. Water treated suits best for irrigation as well as groundwater recharge. The system is similar to the treatment system built in Gotland, Sweden.

Recharging techniques

Artificial groundwater recharge in Dar es Salaam coastal aquifer can be attained by several methods depending on the local topographical, geological and soil conditions. It can employ an integrated series of techniques, which, for example, can include damming the gullies of minor streams, constructing subsurface dikes and/or percolation tanks along their tributaries, contour bunding and trenching on slopes and establishing farm ponds. Terracing and forestation of open spaces, which help to retain runoff and increase infiltration, may also form part of an integrated basin-scale water resources development plan. On channel system such as constructing a dam or weir in a river or stream, over a highly permeable area in the unsaturated zone can as well be useful. The pooling of water over a recharge zone allows a greater rate of infiltration when compared to a flowing stream. This method can be particularly useful in ephemeral streams to maintain a constant head of water recharging the aquifer throughout the year.

Conclusion

The coastal aquifer in Dar es Salaam is clearly overexploited. Utilizing runoff (which otherwise drains off) and grey water (which is improperly disposed) will bring great benefits for improving groundwater levels (which have dropped due to overexploitation), providing a barrier for seawater intrusion and prevention of diseases and floods by deviating peak flows. By implementing AGR, excess water in the catchment area can be collected and allowed to infiltrate, to increase groundwater storage in rainy seasons to be utilized later in dry seasons.

Further research needs

There is a need of establishment of a warning system for drop in piezometric head and the encroachment of saltwater by placement of piezometers along the edge of the sea. Accordingly monitoring wells should be strategically established inland to monitor groundwater fluctuation and quality. By continuously monitoring the head and the water quality, it will be possible to detect some long-term trends and to devise management strategies.

Detailed study is needed to determine sites and design structures for artificial groundwater recharge. Future work should also focus on designing a test programme which includes chemical and physical modelling of recharge options, and measurement of recharge rates. Close follow-up of infiltrated water quality to prevent aquifer pollution is crucial.

References

1. Kaguongo, M. and Kocanda, J. (2010). Reuse of grey water in peri-urban areas in Dar es Salaam, Tanzania. Bachelor degree project. Lunds Techniska Hogskola, Lunds Universitet.
2. Mashauri, D.A., Mulungu, D.M.M and Abdulhussein, B.S. (2000). Constructed wetland at the university of Dar es Salaam, Wat. Res. Vol. 34, No. 4, pp. 1135 – 1144, Elsevier Science Ltd.
3. Mjemah, I.C. (2007). Hydrogeological and Hydrogeochemical Investigation of a Coastal aquifer in Dar es Salaam, Tanzania. PhD thesis, Ghent University, Belgium, 222p.
4. Mtoni, Y., Mjemah, I.C., Van Camp, M. & Walraevens, K. (2011). Enhancing Protection of Dar es Salaam Quaternary Aquifer: Groundwater Recharge Assessment. Springer, Environmental Earth Sciences, Advances in Research of Aquatic Environment volume 1, pp. 299 - 306 (DOI 10.1007/978-3-642-19902-8).