Rainwater Harvesting in Arid Regions: An Integrative Approach Aiming at Adapting to Climate Change

In complex problem-settings, the inclusion of data from different sectors is necessary to identify dependencies between needs and challenges. Neglecting such dependencies can lead to wrong or even false decisions on how to solve the problem. The inclusion of datasets from different sources is a necessity in a field such as climate change adaptation, because the above-mentioned dependencies are obvious: water management, for instance, concerns the balance of precipitation and discharge including processes like surface and groundwater runoff, interflow, and others. These processes are dependent from land cover, land use (e. g. agriculture, urban settling), sealing of ground surfaces, soil types, and more. Additionally, water management has also to take into account withdrawal of water (households, industrial and agricultural production). Creating a complete water balance for a region is therefore a suitable example for the necessity to integrate spatial data from various sources aiming at producing reliable results. Being situated in two geographically different regions, specific problems of water management are the topic of the Jordan-German project "RAIN-GIS". The problem settings, the project structure and goals are described followed by conclusions concerning scientific, management and socio-cultural aspects of this cooperation that is aimed at improving rainwater harvesting procedures which is necessary due to climate change.

Keywords: *Decision making, web map server, climate change, rainwater harvesting, image analysis*

Introduction

Geographical Information Services (GIS), Remote Sensing (RS), Artificial Intelligence (AI) and Spatial Decision Support Systems (SDSS) are helpful technologies to support spatial data analysis and visualization. During the foregoing decades it became increasingly difficult to assess the usability of spatial data due to the fact that thousands of data sources occurred, many of them openly. Planning procedures, regardless whether they occur on a national, regional or local level, in urban or rural environments, require the inclusion of spatial data in many cases, because the question *where* something happens and *where* a measure should be implemented is a crucial one in nearly all cases.

It is increasingly manifested that many problem solutions are of higher quality, if they are not only solved from one, directly concerned sector, but from all presumably relevant sectors that are concerned with the problem setting. "Scientific work is heterogeneous, requiring many different actors and viewpoints; yet it also requires convergence and cooperation in order to produce generalizable findings and a univocal product" (Klenk and Meehan 2015). The RAIN-GIS initiative that is discussed here is focusing on a specific field of water management, rainwater harvesting. Water provision becomes a more and more relevant subject in many countries of the world. However, in a country such as Jordan it is one of the most pressing problems that is going to be worsened due to climate change (Abu Qdais et al 2019). But droughts are also becoming problematic events in a country like Germany. Therefore, within RAIN-GIS, three key issues are considered:

- *Methodological* aspect: RAIN-GIS is aimed at a holistic approach to develop decisions on adequate rainwater harvesting strategies. This is due to the fact that rainwater harvesting concerns different sectors and represents a complex problem of higher quality.
- *Integrative* aspect: RAIN-GIS should aim at guaranteeing current scientific quality being considered when developing water harvesting methodologies, thus taking into account practice, and, if relevant, facts and data coming from citizens.
- *Socio-cultural* aspect: RAIN-GIS should consider the socio-cultural issues that play a role. Different countries use different approaches to solve complex problems, which is due to political, socio-economic, and cultural differences. The question, whether methodologies, and practical implementations, that perform nicely in one country, can be transformed easily to the other country, is of particular importance. In RAIN-GIS, German and Jordanian scientists aim at finding solutions for the optimization of water harvesting methods especially in urban environments. However, the different strategies, approaches, problem-solving-methods, as well as public participation processes, must be considered if innovative measures for water harvesting should end up in successful and sustainable results.

Taking the three issues into account, the next section discusses the envisaged holistic approach to be applied within RAIN-GIS. Following, some basic experiences are discussed that result from exemplary projects carried out independently in both countries. Based on such experiences, a framework for the future coordination of RAIN-GIS is introduced and finally some conclusions are drawn.

Decision making in multi-sector problem-settings

Holistic decision-making represents a framework for making deeply sound decisions, where “deeply sound” is meant to be in the tangible sense of honouring the whole situation, minimising unintended negative consequences (Moloney and Vikström 2016). These authors define three keypoints that lead to holistic decision-making:

1. *Clarify a “thing”*. This *“thing”* is what you are managing or making decisions about. This could be anything. Your life as a whole, your family, a business, a project, a day. Who is involved? What support is available?

2. *Aim that "thing"*. This involves tuning into what the key people involved most deeply want from "the thing" being managed – the destination, how you would like to navigate the path toward the destination, and what you depend on if you've any chance of getting there
3. *Steer that "thing"*. Make decisions toward the desired destination, act on them, and use feedback to stay on track.

The three points mentioned above can easily be related to current environmental challenges. Within the framework of RAIN-GIS this means the development of innovative methods to harvest rainwater taking into account the challenges resulting from climate change. Such environmental problems, however, need clear goal settings, but are often of a complex nature because different actors have to be involved. This leads to the necessity to collect and analyse spatial information coming from different sources and contexts. Sources are, among others:

- Topographic and thematic maps, digitally available via public administrations
- Field data collection measures
- Airborne scanner and satellite, as well as radar (Burke et al 2020).
- Open portals and information systems provided by a great variety of data producers, public, and private (openly, cost-free as well as chargeable)

Whereas the integration of data from different sources is necessary when decisions on environmental challenges are envisaged, data heterogeneity can be an obstacle. This does not only concern different formats, but also problems of semantic non-interoperability and unfitting contexts (Pundt 2017).

To minimize problems of data heterogeneity, standardization is seen as one solution. The World Wide Web Consortium (W3C) and the Open Geospatial Consortium (OGC) have published standards to increase interoperability that helped very much to enable data providers to offer data to a wide community. But pure exchange of data (syntactic interoperability), does not necessarily mean that data is usable in a specific context. Semantic interoperability, non-fitting contexts and data quality requirements can hinder the exchange and must therefore be considered fundamentally:

> *"Collecting, integrating, reconciling and efficiently extracting information from heterogeneous and autonomous data sources is regarded as a major challenge."* (Fusco and Aversano 2020)

Quality parameters like currentness, spatial resolution, accuracy, completeness, semantic correctness (context-relatedness), and others differ from sector to sector, and therefore all such parameters should be checked according "fitness-for-use", before data is applied in a specific problem setting

(Heilmann and Pundt 2021). This concerns both, the specific hydrologic, hydrographic and further data on the environment under investigation (Stewart 2015, Ingendahl et al 2014), and the data as they are stored for analyses using computerized systems. These thoughts lead to the conclusion that, among others, two key issues are essential in multi-sector projects:

1. *A holistic approach is essential*. A prerequisite is a functioning, communicative network of actors (researchers and stakeholders). Cooperation within the network should be based on common scientific methods and standards.
2. *Data integration is more than "setting up a database containing all relevant data for a specific region"*. Before data is used, it has to be evaluated in terms of syntactic, semantic and quality properties. An additional point is the origin of the data. In which context the data has been collected plays a major role for the question, if this data fits the new (and different) context in which the data will be used.

These key issues are of significance for transdisciplinary projects. Transdisciplinary research means that a lifeworld problem is dealt with by an interdisciplinary team. The researchers are working in cooperation with people who are affected by this lifeworld problem. Therefore, stakeholders provide the necessary practical knowledge and data, so they should be involved in the research process. In such a sense, RAIN-GIS is based on a transdisciplinary approach.

To build a solid fundament for RAIN-GIS, specific methodological approaches of the German and the Jordanian research teams were compared. The following section presents two exemplary projects carried out in Germany, and Jordan. The projects are meanwhile finished but serve as "hubs" of ideas and experiences from which the new initiative RAIN-GIS can profit.

Different geographies, similar challenges

As Szabo et al (2023) describe, climate change will lead to more and longer periods of drought, as well as a rising number of flood events causing environmental damages and those for health, infrastructure, and social and economic problems worldwide (Szabo et al 2023; Arnell 1996). These threats are, among others, reasons why water-related challenges have been included in the Sustainable Development Goals (SDGs), namely SDG No 6 (Clean Water and Sanitation).

Using GIS and Remote Sensing to enable new insights into water-related problem-settings (Germany)

Within the framework of the German "BebeR"-project, different problems of water management in view of climate change were addressed. One goal was the identification and evaluation of vulnerabilities concerning floods, droughts and erosion processes in a defined test area. The project setting included scientists, employees of different administrational units (e. g. agriculture, forestry, water management, regional and urban planning), and experts from other relevant organizations. In some cases, citizens were included due to their specific knowledge of local conditions. In such a way, a broad spatial information basis has been established (Pundt and Scheinert 2021). A web mapping server was implemented on the basis of OGC-based WMS-standards to provide data to all actors involved (de la Baujadiere 2006). In such a way, the stakeholders were able to use the online mapping service, thus providing not only the data relevant for their specific sectors, but instead all data layers from different fields involved. Based on the opportunity to overlay a great variety of data layers, the view of many stakeholders concerning the test area changed significantly. They were able to investigate "their" data integrated with other datasets, which opened new perspectives for thinking and acting.

Additionally, participating scientists provided a simulation tool to estimate erosion rates. This was coupled with data on the different IPCC scenarios concerning potential climate developments (IPCC 2024), and data provided by the map server. The fact that more heavy rainfall events are expected due to climate change in the concerned region led to challenging insights into potential future threats. Simulation results, IPCC data, land use information, precipitation data and a digital elevation model built an ideal information basis for the discussion on measures to mitigate the threats. Figure 1a, b gives exemplary views of the online mapping service. Here, a topographic map (OSM), satellite data from an online data provider, a 3D digital elevation model from the States' Agency of Geoinformation, and simulated erosion data derived using an external GIS-tool, enabled users to get new insights into environmental conditions of a test catchment (left), aiming at deciding on the location of a new rainwater retention reservoir (right: red areas are excluded due to reasons defined by different participating actors (Pundt and Scheinert 2021).

Figure 1a, b. *Integrating data from different sources opens new insights for opportunities to mitigate flood events*

During workshops with scientists and practitioners, the maps derived by the BebeR-web mapping system were discussed intensively aiming at finding answers on the challenges caused by more intensive flood events in future. Different scenarios were investigated. Scientific expertise on the one, and practical requirements on the other hand were brought together, looking on the same data from various perspectives (Heilmann and Pundt 2021). Situations as shown in Figure 1 are only one example focusing on erosion, and flood retention. Satellite and airborne scanner data, coupled with other datasets, built important support to find consensus on adaptation measures between the actors.

In such a way, some more problems were analysed, e. g. the threats for road and settlements infrastructures due to floods, the change of the management of (small) rivers to minimize harmful deep erosion and flooding of neighbored areas; the afforestation as a measure to mitigate soil erosion; the adaptation of water provision infrastructures and wastewater removal; the change of administrational planning procedures in an open and holistic way.

The results of the BebeR-project underline that “transdisciplinary uses of spatial information require seeing it as an enabler for societal problem solving across disciplinary boundaries, more so than as the subject of a discipline of its own.” (Kuhn 2012). GIS, and the integration of image processing and simulation tools, enable to support scientists of many disciplines in understanding and exploiting spatiality in their theories and models (Janelle and Goodchild 2011). Such visualizations support the discussion on alternative landscape development scenarios and the process to find commonly the best solution for a problem (Pundt 2017).

Object identification using remote sensing and AI (Jordan)

As it is one of the most promising options for a non-conventional water resource in rural and urban areas, rainwater rooftop water harvesting (RRWH) is discussed again in Jordan. It reduces people’s vulnerability to acute water shortages although it has often been a neglected opportunity in water resources management in Jordan while it continues to receive increased attention worldwide. There is a need for assessing the potential of rainwater harvesting opportunities and their feasibility using GIS techniques, aiming at providing an additional source of drinking water in Jordan, especially in response to urban population growth. Identifying, analysing and assessing the amount of potentially available amounts of water requires the availability and usability of adequate data sets. These include, comparable to the “Beber”-project, topographic data, information on the water sector and soils, climatic and weather-related data as well as data on the infrastructures and other anthropogenic measures. Satellite imagery, however, can serve as an important data source not only to get an overview of land use and land cover, but to ground simulations on the results of precise object classifications. Varying approaches of analysing satellite imagery using image processing methods enhanced by artificial intelligence were successfully implemented by Al Balqa university, Jordan (Shatnawi et al 2019; Shatnawi and Obeidat 2022). Within the framework of RAIN-GIS, first attempts have been made by classifying satellite data using an intelligent image processing tool aiming at identifying potential rooftops suitable for rainwater harvesting. To initiate the process, necessary data acquisition was paramount. This involved procuring a high-resolution orthoimage, which had undergone rigorous geometric correction to eliminate spatial distortions. This corrected orthoimage provided an accurate representation of the study area, forming the visual basis for subsequent analyses. In addition to the orthoimage, average annual rainfall data was collated, allowing for the quantitative assessment of the region's precipitation patterns over a year.

Building upon the foundation of acquired data, the methodology seamlessly transitioned into the phase of building footprint extraction and surface area calculation. By harnessing the power of an advanced artificial intelligence algorithm within the GIS environment, the research seamlessly identified and delineated building footprints from the orthoimage. This AI-driven approach greatly expedited the process while ensuring precise footprint extraction. Subsequently, these footprints were harnessed to calculate the surface area of each building, a critical parameter influencing the potential rainwater harvesting capacity (Figure 3).

However, the results of the image classifications provide a first idea of which rooftops are potentially suitable for water harvesting. But this is by far not enough. The problem occurs in a more complex light if further criteria are taken into account. Such criteria have to consider the whole technical arrangement. To store the harvested water, pipes and tanks must be built which requires space. This means that rooftops that are identified in a first step, have to be excluded from analysis if such spaces are not available, e. g. in narrow streets in old town areas. Furthermore, not every rooftop is suitable for harvesting rainwater, e. g. those that are made out of materials that are potentially dangerous due to included asbestos or other harmful or toxic substances. Here, the overlay with further GIS data and the classified imagery is a suitable approach to get to more realistic results concerning the water harvesting potential of rooftops.

Figure 2. *Classification of Suitable Rooftops in a part of Amman, Jordan*

Integrating Data, Experiences, and findings, in RAIN-GIS

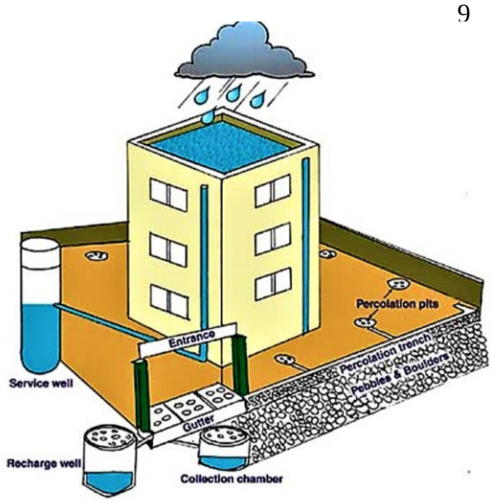
Background

As mentioned above, RAIN-GIS is focused on rainwater harvesting as one issue under the umbrella of water management. Of course, rooftop rainwater harvesting has been practiced since the dawn of history, as early as humans started to live in settlements, during the late Neolithic to the early Bronze ages. Inhabitants of Mesopotamia, and today Iraq and Jordan, are among the very early civilizations who practiced water harvesting to satisfy their water-related needs (Yannopoulos et al. 2017). Water harvesting has been known in Crete, in the Indus valley, and in South Asia. It has also been practiced in India and China starting in the third century (Al-Houri and Al-Omari 2022). Rainwater harvesting and storage has challenged engineers throughout the world for centuries. Meanwhile the world is facing climate change and the problem of increasing and long-term droughts is a threat not only in arid regions of the world. This brings rooftop rainwater harvesting in the spotlight again, and large amounts of water could be saved if suitable methods and techniques would be implementable.

As figure 4 shows, a rooftop can be seen as a “mini catchment”, from which the rainwater can be harvested if adequate pipes and storage facilities are installed. Storing the water requires tanks or reservoirs, both requiring space. This is a crucial issue, remind that the figure presents an ideal situation. In many real life situations, especially in urban environments, rainwater harvesting is a more complex problem because installing the necessary components is inevitably more difficult due to less space around buildings, small alleys in old towns, paved surfaces and challenges when envisaging the restoration of pipe networks or installing new ones. However, urban environments in Germany, and Jordan, are totally different which requires different approaches to the same problem.

The subject becomes more complex in view of related problems. For instance, the mitigation of harmful consequences of the “urban heat island” is leading to questions of which future role rooftops play in urban environments (Gur and Spuhler 2019, Macintyre and Vardoulakis 2017). Benefits from

Figure 3. *Ideal situation to harvest rainwater from rooftop mini catchments (Gur and Spuhler 2019)*

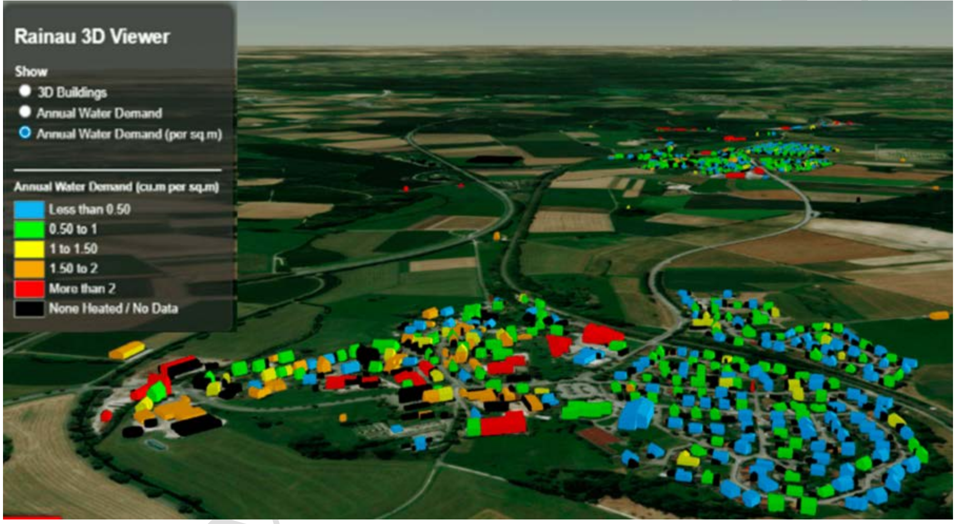


Reductions in urban heat islands intensity from reflective roofs may have unintended consequences in terms of increasing concentrations of some air pollutants, depending on the method employed, for example changes in solar reflectivity can affect local chemical production of ozone (Fallmann et al. 2016). Green roofs, as another example, are a method employed to mitigate urban heat island intensity by introducing vegetation at roof level to increase evapotranspiration. In such a way, rooftops can serve for different purposes in climate change adaptation efforts, but the goals that are envisaged can be contradictory: a green roof, as well as vertical greenwalls, may store humidity and improve micro climate (Price et al. 2015), but both do not lead to large amounts of water, which is envisaged by harvesting rainwater. Even more aspects have to be considered. As aforementioned, old buildings may have roofs that are made out of inadequate materials for water harvesting. These should be excluded from measures to gain water.

All such aspects should support the argument that a holistic view would be beneficial for finding sustainable measures to harvest rainwater from rooftop mini catchments. Thinking all pros and cons of the relevant stakeholders in an integrative way supports the analyses on how rooftop rainwater harvesting can be fostered by simultaneously guaranteeing the collection of pure, not contaminated water, as well as roofs contributing to better micro-climate, thus mitigating urban heat. These problems must be tackled in an integrative way combined with the answer on the question how to store the water. Having identified the problem, the solution requires a functioning communication network as well as proper data sharing facilities, together with a mechanism that guarantees data quality and therefore usability.

As a first step toward an integrative way of dealing with the problem, satellite data can help to classify suitable roofs for water harvesting. The mapping of such roofs can support the estimation of potential water quantities. Figures 3 and 4 should underline that satellite imagery and 3D-models of buildings and larger urban environments can support both, the simulation of the urban heat island, as well as the visualization of the buildings that are envisaged to be included in harvesting strategies. Such models, developed using a standardized XML-based description language (City GML; OGC 2024) can further help to assess, whether new infrastructures can be implemented, or if the city structure does not provide the prerequisites for rainwater harvesting.

Figure 4. *A 3D-model of a residential area, combined with satellite data, to determine the water demand per building (Bao et al. 2020)*



The RAIN-GIS approach

A methodological and technical approach that enables scientists, as well as practitioners, to assess urban regions concerning their potential for rainwater harvesting, would help to evaluate current situations which is a prerequisite for further action. Referring to the project examples mentioned before, the two countries face similar problems in different contexts, geographical regions, and extents. As Germany is envisaging increasingly dry periods, as well as flooding, Jordan also faces both threats. Jordan is suffering from severe water scarcity which is caused by rapid population growth, frequent droughts and hydro-political tensions in the Middle East (Al-Bakri et al. 2013). As such, the continuously increasing demand for water is exceeding the supply causing a serious water deficit. The Jordan climate and development report expresses this more strongly: “Jordan is facing an existential water crisis. As one of the most water scarce countries in the world with only 97 m³ per capita per year, available water is well below the absolute water scarcity threshold of 500 m³ per year. Climate change will decrease water availability even further for agriculture, cities, firms, and social systems (30 percent less water per capita by 2040) while increasing water demand" (World Bank Group 2022).

On the other hand, an example of extreme flooding is from 2022. After long terms of drought, heavy rainfalls occurred thus causing floods that could not be handled due to current infrastructures and architectures: "Tourists have been evacuated from the ancient rock city of Petra after it was flooded as freak rainfall hit the archaeological site. Footage shared on social media showed a river of water pouring into the entrance of Jordan's 2000 year-old attraction, situated 150 miles south of Jerusalem, as panicked tourists attempted to flee." This message came as the Petra authority had warned citizens to stay away from flood drains and valleys and not to risk leaving their homes during the period of rainfall, due to the rising water level (itvNEWS 2022).

Re-visiting Fundamental Considerations

Local and regional governments are obliged to develop realistic plans to react on threats that are increased by climate change. Based on the project experiences, the aforementioned challenging aspects are revisited:

- Methodology
  Enlarging the perspective: Single-sector solutions fall short. Considering and integrating the multiple views of different sectors can lead to completely new ideas for developing improved problem solutions. A holistic approach is needed to steer discussions of actors, and to find sustainable answers on pressing questions.

- Integration
  It is necessary to collect and process data from different sectors and in such a way they help to carry out multiple-view analysis in the field of water harvesting. However, a comprehensive data check (quality, context-relatedness) must precede before data is used.

- Socio-cultural acceptance
  If actors agree on measures to be taken to foster improved rainwater harvesting methods in urban settings, the question must be raised if such measures will find societal acceptance. The network activities, leading to the inclusion of all relevant actors, can help to open the discussion with decision-makers and possibly citizens.

Methodology

Referring to the foregoing chapters, table 1 summarizes the relevant points, thus related to the necessity of multi-perspective, holistic decision making.

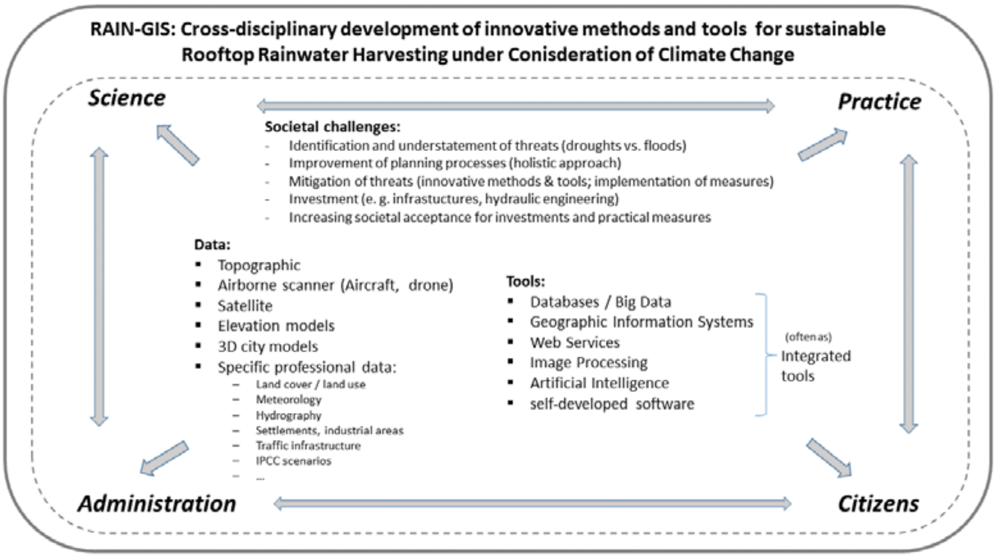
Table 1. *Leading aspects to holistic decision making in water management, esp. rainwater harvesting (Moloney and Vikström 2016; adapted to RAIN-GIS problem settings)*

The "thing"	**Aim that "thing"**	**Steer that "thing"**
Any environmental problems, independently of the specific subject	What do the entire actors that deal with "the thing" expect from the problem solution; which way should they go to reach commonly defined goal(s)	Decisions should be made commonly, taking into account the entire perspectives of the relevant actors. Single-view (or – sector) solutions are not sufficient
Examples		
"Water management", more specifically "Rooftop rainwater harvesting" ("The thing").	Multi-perspective goal-settings in communicative, agile and interactive projects; using collaborative procedures to achieve commonly accepted aims and methods. Measures to be implemented are aimed at adaptation to climate change	Project management has to guarantee the equal consideration of all perspectives on the problem; decisions must be derived in a consensual procedure; compromises must be achieved without restricting opinions.
Goal: To establish a collaborative discussion process, resulting in commonly generated decisions on sustainable measures to improve rainwater harvesting strategies in urban environments		

Project framework

Figure 5 presents a potential architecture of the RAIN-GIS project, including actors, communication pipes, and tools. The approach follows the methodology of transdisciplinary research. In a first step, test areas in Germany and Jordan are identified aiming at collecting data and selecting suitable tools to process this data. All relevant actors should be included to support discussions on the status quo and following adaptation measures. The latter should be based on commonly accepted methodological, scientific and practical arguments, composed in resulting consensually developed results. However, all arguments should be based on data that were evaluated concerning their fitness-for-use.

Figure 5. *Coordination plan of the RAIN-GIS-network*



Conclusions

Within the framework of RAIN-GIS, rooftop rainwater harvesting has been identified as an old and widely applied, but urgently needed method to mitigate the growing problems of increasing water shortages. Based on the experiences made in projects as those presented in section 2, the cooperation between scientists from Jordan and Germany should result in a methodologically sophisticated, holistic approach to ensure the development of measures that ensure secure water provision in threatened regions.

The usage of GIS and image processing, supported by AI techniques, will foster transparency of results and therefore adaptation measures significantly (Dindaroglu et al 2022, Shatnawi and Abu Qdais, 2019). If scientists, civil engineers, local and regional planners, policy and decision makers and possibly citizens work together, sustainable problem solutions seem to be more sophisticated, as single-sector-activities (Schulte and Heilmann 2019, Pundt 2017).

> *"The idea that policy issues involving high levels of uncertainty, complexity, incompleteness, and conflict particularly those pivoting on science, technology and the environment should be analyzed and addressed using a plurality of theories and methodologies."* (Klenk and Meehan 2015).

The special aspect of uncertainty, however, is related to data, to methodologies, and therefore decisions. But even uncertainty is not excludable totally, an advantage of using computer-based tools is that results are transparent. They can be explained because the input and the algorithms to process them are known. In such a way, the results can be questioned, and underlying datasets as well as parameter settings can be changed if experts agree on how to improve the results. Here, the circle closes: Grounding decisions on commonly accepted data and methods, should lead to qualitatively better and well justified problem solutions. They should replace uncertain suppositions, single-view opinions and should minimize dangers occurring due to omission of data, malfunction of methods or ignorance of actors that could possibly contribute with important knowledge.

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