Freiburg HydroNotes

Series Paper 2

Fabian Ries and Sebastian Schmidt

Technical report on hydrological monitoring in semi-arid areas

Experiences from field work in the Middle East

Selection, installation and protection of instruments and evaluation of measurement techniques

2016
Chair of Hydrology

University of Freiburg

Table of content

Title page: Irrigation channel carrying water from Auja spring to agricultural areas in the East.

List of figures and tables

1. Introduction

Large parts of the Mediterranean consist of semi-arid areas that are often characterized by a limited water availability, which is increasingly exceeded due to the high water demand for domestic use and irrigated agriculture. Strong climatic gradients, high short-term and interannual rainfall variability and the prevalent karstified carbonate rock geology add an additional layer of complexity to the hydrological system. At the same time, our knowledge about hydrological processes as well as water resources quantity and quality strongly rely on monitoring networks and the observation of hydrological variables in the field. Especially in the Eastern Mediterranean such field-based data is often lacking or not available at the required spatial and temporal resolution. Hence, fieldwork to expand our understanding of dominant processes in Mediterranean landscapes is of fundamental importance. However, semi-arid environments may pose special challenges regarding measurement network installation, e.g. especially regarding the assessment of surface runoff. These short-time runoff events (flash floods) often reach high flow volumes and velocities and can have catastrophic impacts on infrastructure, including the measurement infrastructure installed.

Depending on the main research aim, the available budget, the spatial and temporal scale of interest and noteworthy, the research environment, different approaches, solutions and employed instruments may be appropriate. Due to this complexity it is not easy to provide specific recommendations, however we feel it is worth to pass on our experience and practical knowledge from the field. Naturally, there will always be failures due to inappropriate approaches, problems with instruments or missing protection measures but they can be minimized through careful planning and learning from the experience of others. This report aims to communicate the experience gained by two PhD students during fieldwork they performed as part of the project SMART (funded by the German Federal Ministry of Science and Education) (Schmidt, 2014; Ries, 2016), which assessed surface and subsurface water resources and dominant hydrological processes in a semi-arid area of the Eastern Mediterranean. The monitoring network was initiated during the first project phase (2006–2009, start of instrumentation in autumn 2007) and extended considerably during the second phase (2010–2014). It has remained in operation to this day and was recently again extended significantly for hydrogeological monitoring especially at springs during the follow-up-project SMART-MOVE (2015–2018). This latest extension is however not discussed in this report.

The first section of this report provides an overview on the instruments and approaches selected to fulfil the purpose of our studies. While most instruments were bought readily assembled, major effort was necessary for installation in order to ensure longevity and protection of the instruments from the harsh environmental conditions and vandalism. These protection and installation measures are introduced and later evaluated in the second part of the report. Finally, we provide a summary of our experiences and give further recommendations for realizing fieldwork in the Middle East. Even though numerous instruments and methods are not covered in this report, we hope this report will be of help to other researchers when conducting their fieldwork or to water authority personnel in semi-arid environments setting up monitoring networks.

2. Overview of the observation network in the study area

To undertake an in-depth assessment of water balance components and to identify dominant hydrological processes, a dense hydro-meteorological observation network was installed in the previously data scarce study area at the western escarpment of the Jordan Valley in the Middle East (Figure 1). Elevation ranges from approx. 1000 m at the highest peak of the mountainous western part of the study area down to 250 m below sea level in the Jordan Valley (Jericho and Auja village). The network consisted of the following systems (most but not all stations were permanent):

- Spring discharge amounts and water physicochemical and quality parameters (mainly temperature, electrical conductivity and turbidity)
- Surface runoff in ephemeral streams at flumes and weirs where available or affordable to construct or at road culverts
- Meteorological parameters (temperature, shortwave solar radiation, relative humidity, wind speed and wind direction)
- Precipitation
- Soil moisture in different depths (some with temperature observations)

A list of used sensor systems is compiled in the appendix at the end of this report.

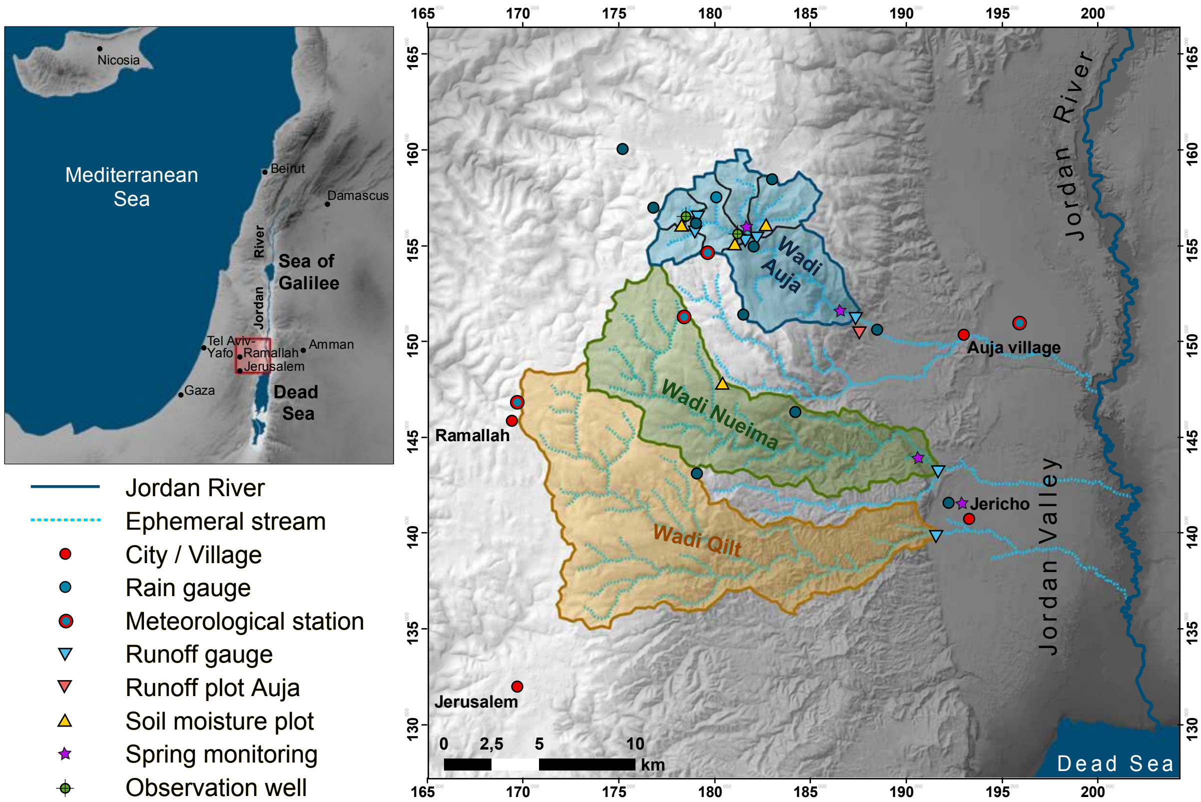

Figure 1: Instrumentation network in the Lower Jordan Valley region.

3. Field installations

Our hydrometeorological observation network implemented over a period of nearly 10 years (2007–2016) includes a large variety of instruments for the monitoring of spring discharge, rainfall, meteorological parameters, soil moisture and surface runoff. Artificial sprinkling experiments were realized during one spring season for the particular investigation of rainfall redistribution, infiltration characteristics and preferential flow within the headwaters of our study areas. The experimental setup is described in detail in Sohrt et al., (2014). Below we describe the individual instrumentation components in detail and report our experiences gained working with them in the field.

3.1 Meteorological stations

We installed two types of meteorological stations, which were distributed in our study area in order to cover the strong climatic gradient from the mountain range down towards the Jordan Valley. The first type is a relatively affordable HOBO-system (Onset Computer Corporation, Bourne, USA). The second climate station from Thies (Thies GmbH, Göttingen, Germany) is equipped with high accuracy sensors and made for professional application within hydro-meteorological monitoring networks.

HOBO climatic station

The HOBO weather station consists of a H-21-001 logger unit connected to sensors, which measure the same parameters as the Thies station (Figure 2). Unlike the Thies station, it does not require an external power source but instead runs on 6 AA batteries for a period of more than one year (measuring at 10-minute intervals). The system is capable of averaging shorter than 10 minute interval measurements for certain sensors, which we didn't take advantage of due to concerns about battery endurance. It is able to store 500,000 measurements that can easily and quickly be downloaded using the software HOBO-ware-pro and an USB-to-clinch connection. Overall, the HOBO software is easy to use and allows for a number of convenient logger settings (e.g. time-delayed measurements). It can also be used in combination with other HOBO logger types that were also used in this study (see sections below for more detail). The plug-and-play sensors are easily connected to the logger unit (no tools required). Overall, this makes for an affordable and fairly reliable station. Some of the sensors turned out to be rather fragile and short-lived, especially the wind sensor, which is made of plastic and turns brittle under strong UV radiation exposure. Due to temporarily high wind gust velocities (up to 30 m/s) in the highlands and the plastic type sensors, the wind direction sensor was blown off already during the first winter season; nevertheless the wind velocity sensor did continue to work. A second sensor, which had to be replaced repeatedly over a period of eight years, is the relative humidity/temperature sensor.

Thies climatic station

Based on the experience with the cost-benefit-efficient HOBO station, for the further installation of the highland parts (the main recharge area of the aquifers), a more robust type with fewer moving parts and heating elements was used. The two Thies climatic stations (Figure 2b) consist of a logger unit (model: DLx-MET) connected to a combined air temperature and humidity sensor, widely used shortwave solar radiation sensor (CMP 3, Kipp+Zonen, The Netherlands), a 2D ultrasonic wind sensor and a precipitation sensor.

This type of station has to be connected permanently to the electric grid system to due to the high power demand of the heated ultrasonic wind speed sensor and the heated funnel unit of the rainfall gauge. The system takes a reading every second and the logger subsequently saves the 10-minute mean of all measurement parameters in 10-minute intervals over the period of one year (approx. 500,000 measurements). Also, hourly extremes for all parameters are saved. Unlike with ready to use units, the installation of the Thies station is more time and work intensive as all sensors have to be connected to the proper logger unit channels individually as indicated by the circuit diagram. Once installed and connected to the grid, the station's heavy-duty design and high quality sensors enable long term use and promise very reliable and high quality data. Data can easily be downloaded via a USB port or SD card; however, the relatively slow speed of data transmission is a minor inconvenience (15 minutes when maximum storage capacity is reached). Theoretically, the station is capable of wireless data transmission (GMS modem), if access to necessary service providers is possible. In our study area, we frequently experienced power outages that ran down the back-up battery, requiring it to be replaced. We recommend the use of this or similar types of stations in locations where continuous power supply can be ensured, or alternative sensors with lower electricity requirements.

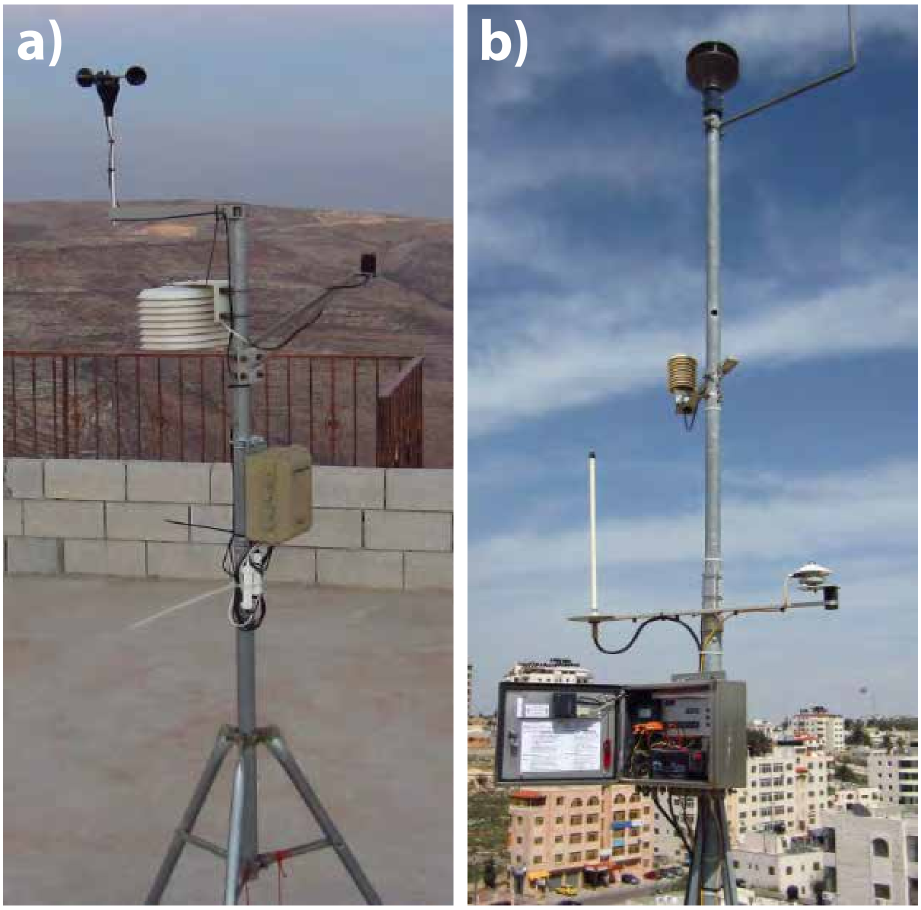

Figure 2: The two installed station types for the observation of meteorological variables: a) HOBO climate station and b) Thies climate station.

3.2 Rainfall gauges

The main type of automatic precipitation gauges for our observation network is the HOBO RG-M with a resolution of 0.2 mm of precipitation, which is connected to UA-003-64 event data loggers (both Onset Computer Corporation, Bourne, USA). These instruments are also called “tipping buckets” according to the measurement principle and shape. They were installed primarily on the roofs of public schools in the larger Ramallah area (Figure 3a), on houses of Bedouins, as well as on water facilities. Prior to installation, a simple but time-consuming calibration has to occur. The well-built tipping buckets and logger unit are made of durable materials and have low power requirements. In the event-logging mode, they run reliably on high quality 3V coin-cell lithium batteries (CR-2032) for a period of at least one year. As a precaution, we recommend replacing the battery in regular intervals of about one year to prevent interruption in data collection. The attached event logger with 64K internal memory can store over 16,000 tips. During the data read-out, direct sun light exposure should be avoided in order to prevent any interference with the logger-reading-unit communication. Particular attention should be paid to the successful command transmission between logger and reading unit following the initial launch. Further issues include potential blocking of the rocker by the logger cable and regularly required cleaning of the rocker containers due to dust exposure.

For very high rainfall intensities (> 20 mm/h), rarely observed in our study area, a certain underestimation of precipitation may occur due to water passing the balance during the tipping events unnoticed. Due to missing heating elements, these stations are also not suitable for measuring solid precipitation, especially snow, as it can only accumulate to a certain amount in the funnel. It can also be blown out of the funnel before above zero temperatures or subsequent liquid precipitation lead to the melting of the accumulated snow. Even if no snow is lost, the temporal variability of the snow event will not be documented. To accurately assess solid precipitation in the highland area the two THIES meteorological stations were equipped with heated precipitation sensors by the manufacturer (Figure 3b). These sensors apply the same measurement principle and display a resolution of 0.1 mm. In order to also accurately gauge very high precipitation intensities, the instruments are calibrated prior to delivery with various intensities and the respective calibration function is implemented in the data logging system.

Figure 3: Two types of implemented rainfall stations within the observation network. a) Simple rainfall gauge from HOBO without heating elements in an unconventional setting using a car tire as camouflage; b) Heated system from the THIES company.

3.3 Soil moisture monitoring sites

Soil moisture was observed mainly using decagon logger units (EM50) connected to type 5-TM sensors that were placed in different soil depths. Due to the often limited soil depth in the study area, the lowest sensor was usually placed at depths between 40 to 80 cm. The individual sensors were inserted in relatively stony and dense soils, exercising caution not to damage or break the sensitive sensor plate (Figure 4a). Loggers are powered by five AA batteries, which is sufficient to measure soil moisture of up to five sensors over a period of one year without any difficulties. The batteries box should be covered with duct tape, as batteries could move and cause unnecessary measurement logging failures (Figure 4b). Particular attention should also be paid to maintaining the connection between the sensors and the logger during the installation process. It is further strongly recommended to number and label the cables coming from the different sensors at the plug-end of the cable with information regarding sensor depth to avoid confusion. However, if a mix-up does occurred, different depth sequence can usually be identified after data readout due to the effect of temperature on soil moisture measurements. The sensor with the strongest diurnal cycle is the upper most one and the amplitude is attenuated and shifted towards the afternoon as sensors are placed in greater soil depths. While the logger units are designed to remain above ground and thus are not waterproof, we decided to bury them under ground to hide the instruments in order to avoid vandalism. Despite careful wrapping of the logger in multiple Zip-lock bag layers and the use of duct-tape to prevent water entry a complete and reliable seal could not always be achieved. As a result, some damage to the instruments was unavoidable. Alternative preventative measures in similar installation set-ups are strongly recommended.

Figure 4: Example for a soil moisture monitoring site. a) Soil moisture plot; b) Logger unit Decagon EM-50.

3.4 Runoff in ephemeral streams

Data on runoff in ephemeral streams was collected using pressure transducers made by different companies (SEBA, HOBO, Eijkelkamp). Measurement locations included rehabilitated or newly built weir and flume structures as well as road culverts. One of the flumes was build out of fibreglass by a local automotive body shop (Figure 5d), which turned out to be a better fitting, more affordable, lightweight and durable alternative to ready-to-install pre-fabricated solutions. Our experience confirms the importance of regular maintenance and sediment removal from these structures to ensure proper runoff observation and avoid the need for data correction. Flumes with a high sediment discharge capacity, such as the parshall flume (Figure 5b), were found to reduce the required amount of maintenance and are therefore strongly recommended in arid environments. The different sensors used, either compact absolute pressure transducers or systems with atmospheric pressure compensation tubes worked reliably, were easy to install and provided reliable measurements. Those with pressure compensation tubes eliminate the need for atmospheric pressure compensation but require considerably larger stilling wells, because the outlet of the tube has to always be above the water table.

We designed special casings, which were mounted to concrete elements of flumes and culverts to protect the probes against vandalism but also against damage caused by flash flood events. At times, high sediment loads clogged the ceramic membranes of the divers and interfered with accurate measurement taking. Even with regular maintenance, manual validation of the collected data is unavoidable in order to detect such measurement errors. With catchment sizes in our study area ranging between 3 and 130 km^2, a measurement interval of 5 to 10 minutes was well suited to characterize runoff dynamics. Higher measurement intervals would necessitate more frequent data download and considerably reduce the battery life span. The tendency of (in particular the young) local population to build dams to improve their swimming experience might interfere with water level observations.

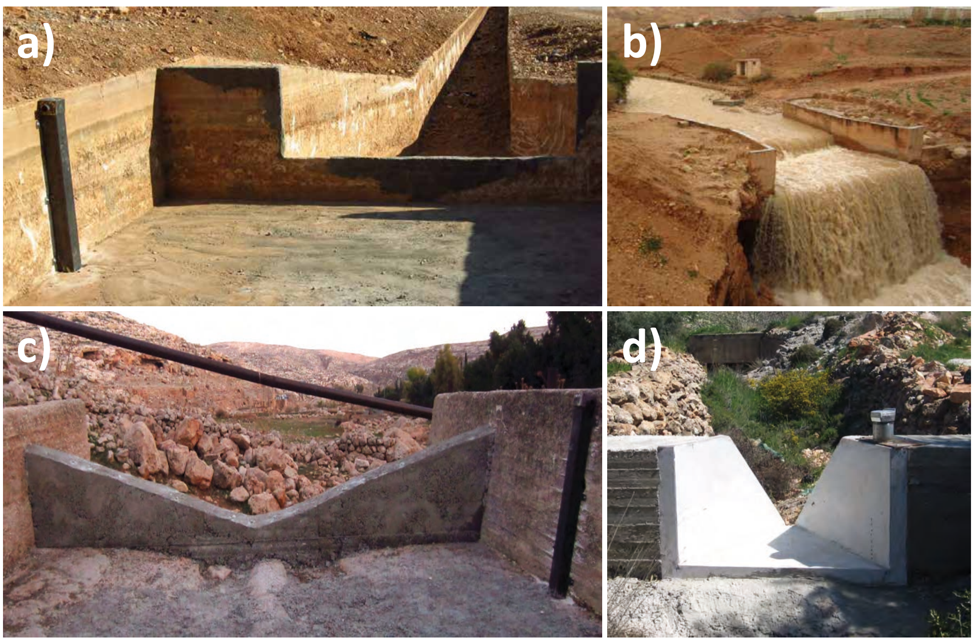

Figure 5: Flumes and weirs installed in the study area: a) Rectangular weir at Auja canal (rehabilitated); b) Parshall flume at Wadi Qilt (rehabilitated); c) v-notch weir at Ein Samia; d) H-flume in a headwater of Wadi Auja.

3.5 Runoff plot

To gain insights into runoff reactions from small hillslope areas with defined surface properties large, tipping buckets were developed that are able to measure up to approximately 200 l/min (Figure 6a and 6b). The design was adapted from systems build in the US to determine runoff and sediment production from forest roads (e.g. Black and Luce, 2013). The system consists of a large tipping bucket connected to a metal barrel, which serves as a sediment trap. Runoff from the plot (approx. 1000 m^2 in our case) is collected by a small barrier and diverted into a tube that leads to the metal tank and the connected tipping bucket, where each tip with a volume of 5.6 litre (Figure 6b) is counted with a HOBO event logger (UA-003-64). A prototype was built in Germany and a local metal company manufactured two copies in the Westbank. The intention was to install three runoff plots along the strong, local climatic gradient to investigate differences in runoff reaction connected to this climatic transition. Only one plot was installed in the arid part of the study area as the installation turned out to be very high effort and no suitable place for a safe installation was found at other locations. After one year the station had to be given up due to vandalism. Thus, our experience on this device is limited. Nevertheless, the installed plot performed well and valuable data was collected. It is recommended to install a coarse mash at the entrance of the tube to prevent clogging with vegetation and other material.

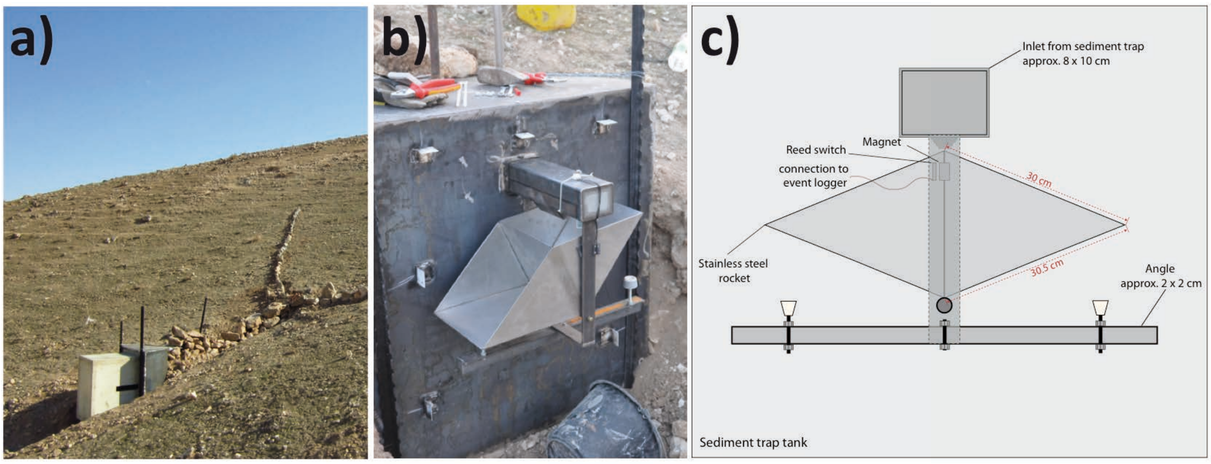

Figure 6: Runoff plot in the arid area of Wadi Auja (a); Large tipping bucket connected to the sediment trap (b); Technical details of the runoff tipping bucket (c).

3.6 Spring discharge observation

The spring observations are of major importance for the hydrogeological investigations (e.g. Schmidt, 2014; Schmidt et al., 2014) but also to constrain the hydrological observations and models, e.g. the recharge quantities and timing calculated by soil water balance calculations and models. For this purpose, discharge is the most important parameter. In order to calculate discharge continuously, head (water level) needs to be recorded at a suitable gauging station and a stage-discharge relationship needs to be established. Besides, time series of the physicochemical parameters of the water (e.g. electrical conductivity, temperature, turbidity) can be used to analyse the fast flow component due to recharge events.

During the first project phase, mainly the two main springs Auja (ca. 1 km upstream of the main catchment surface runoff gauging station of Wadi Auja) and Sultan (the main spring of Jericho) were equipped. At the start of the second project phase, observations were extended to the large spring Duyuk (near the outlet of the surface catchment of Wadi Nueima) and the Samia spring (located within the surface catchment of Wadi Auja). As the springs Sultan and Duyuk display a low variation in discharge and a very complex setting (multiple outlets, pumping abstraction for public water supply at a number of points in the spring ponds etc.) discharge monitoring at those springs was mainly conducted in form of discrete discharge measurements with the salt dilution method. Those were performed mainly in the spring (relative high-flow conditions) and autumn (low-flow conditions). At the springs Auja (Figure 7a and 7b) and Samia, which are characterised by a high fluctuation in discharge, major effort had to be directed to the construction of permanent gauging stations. At the Samia spring, for the largest parts of the year no spring outflow is observed due to pumping abstraction in a nearby well tapping the spring's aquifer. Therefore, the instruments for measuring water level, electrical conductivity and temperature were installed in the well. A V-notch weir was constructed in an existing concrete channel section of the Wadi downstream from the spring outlet (Figure 5c) to assess both, surface runoff, but also spring discharge. During periods where both flows occurred, they had to be separated, e.g. by the difference in water temperature of groundwater and surface water.

Figure 7: Auja spring monitoring with the constructed weir in front (a) and springhouse in the background with installed probes (b).

For weirs and flumes not build in concrete channels but in alluvial sediments, caution has to be directed to the tailwater section of the structure, i.e. the channel after the critical section, in order to avoid continuous erosion (e.g. see concrete bottom of the tailwater section in Figure 7). The Parshall flume (Figure 5b) was constructed about 50 years ago in a presumably relatively even section of the Wadi. Due to the steep slope in the streambed the tailwater was deeply eroded, which even let to a partial collapse of the flume. If no maintenance is performed on this valuable structure, the observations on stream discharge in Wadi Qilt, realized within this project for the first time on high temporal resolution, will end soon.

4. Instrument protection

General remarks

Safe installation of monitoring equipment is a major problem in a wide range of monitoring studies. Scientific instruments are often quite fragile and the surroundings of the station (e.g. runoff stations) also need to be insensitive to modifications in order to provide a stable monitoring environment. Apart from sheer vandalism it is often more the curiosity of people that is of concern, i.e. the interest in the instruments and a damage of the instruments or a modification of the measuring setup, causing a malfunction, at least until the next field visit. For example, out tipping bucket rainfall measuring system was frequently the subject of interest; someone had a look at the measurement principle (tipping balance) and the data logger, manually tipped the bucked a few times and subsequently misplaced the logger slightly, which lead to the logger cable blocking the balance and thus prevented rainfall from being measured. Recorded tips caused by people just having a look at the station are quite easily identified with the information on the time of the day, but also comparing the station data with surrounding station where no disturbance took place.

Due to the limited choice of safe places for the instruments, certain “trade-offs” were necessary especially regarding the monitoring of meteorological parameters. Despite the WMO observation standards for e.g. precipitation at a height of 1 m above ground surface (e.g. Goodison et al., 1997), all of our stations are installed on top of buildings, mostly schools or water supply infrastructure and municipalities. We hardly found any side that was be suitable for an installation on the ground, i.e. in a well-fenced open space. This might also pose problems for certain other meteorological parameters, which are used for the calculation of e.g. potential evapotranspiration with the Penman-Monteith equation, assuming a measurement height of wind velocity in only 2 m above the natural ground.

It is however questionable if this deviation from the standard procedures results in large errors. It is rather much more in line with typically applied meteorological practice in the region, where rainfall and meteorological stations are usually installed on top of public buildings. In the West Bank for example, most rainfall stations are installed on public schools. Even the meteorological station of Jerusalem (IMS - http://www.ims.gov.il), having a continuous record since 1949 is installed on top of a building in the densly built-up area of Jerusalem. In summary, we had to accept possible inaccuracies for certain factors in order to ensure a maximum possible chance of observation time series without major gaps. A particular detail from our observations is that stations mounted on the roofs of girls-only schools are much safer than on boys-only schools, and is thus strongly recommended.

With the intent of obtaining long-term observation in remote semi-arid areas, thought should be given to a number of issues including instrument location and protection, as well as communication with the local population.

Choice of location

The first decision is on where to place certain measurement devices in the landscape. Oftentimes, the choice falls on a site that represents a compromise between an optimal location from a scientific perspective, but at the same time allows for easy access and most importantly, a certain level of protection against potential damage, e.g. such as vandalisms. Based on our experience, a number of different ways result in good instrument protection; for small devices, simply placing them in hidden locations and out of direct sight was fairly effective in many cases. Alternatively, using materials that make the device less obvious, such as using rusty casings instead of shiny stainless steal containers. A third option is to use heavy-duty materials (e.g. thick metal casings in concrete setting) when placing the instruments that can only be opened using specialized tools (see below). Finally, we found the most effective way to protect measurement devices is to place them in fenced-in areas of utility companies, such as municipal water suppliers.

Independent of any of these measures, cooperation and communication with local partners in research and resource management is very helpful in identifying suitable locations and gaining credibility in the public's eye. Furthermore, being in touch with local communities and taking time to inform residents about the installations is an important aspect of ensuring successful data collection. Often we found it to be very helpful to be accompanied by a community member or official when setting up or maintaining the measurement network, in part to bridge the language barrier but mostly to help gain trust among the local population. Hiring locals to help with the actual installation of network units can thus have multiple benefits.

Logger casing and stilling wells

In order to protect certain devices located in well accessible areas, we designed and built specialized casings for diver and water quality probes. Aside from accommodating different probe shapes and sizes, all casing share in common that they are made of strong materials and accessible only with specialized keys or tools. Uncommon or large screws, preferably a combination of two different types prevented interference with the instruments in all of our locations. For complete protection, the casings were mounted to solid objects such as concrete walls or large rocks by means of high-quality mollies or quick-drying cement.

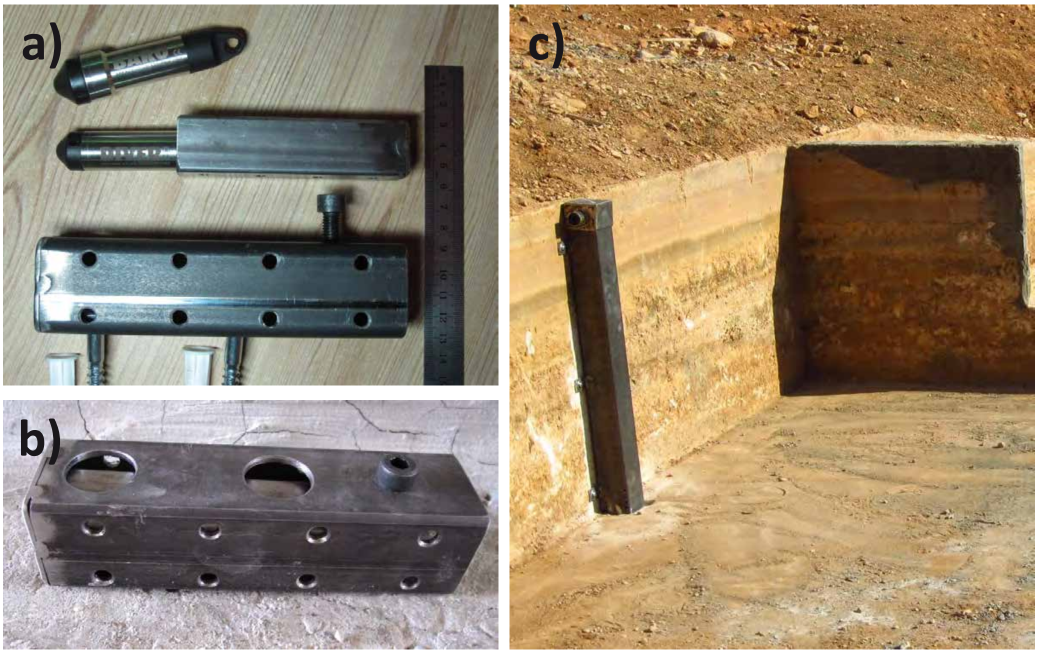

Figure 8: Instrument protection measures: a) Diver outer and inner casing; b) mounted diver casing; c) Stilling well and protection case for larger probes

5. Conclusion and further recommendations

The instruments applied within this study showed different performances. For certain sensors and loggers frequent technical malfunctions were observed. Even with maximum precautions, data and instrument losses could not totally be prevented due to very harsh conditions and curious people or vandalism. Therefore, even for small catchments, we recommend measuring meteorological parameters and rainfall at more than one location in order to be able to fill data gaps in the time series using neighbouring stations. For important parameters and locations, the installation of a doubled observation device (e.g. pressure transducers) might be appropriate if financially possible.

Regarding the meteorological stations, including the precipitation gauges, simple solutions and instruments might be the best choice. This can be demonstrated for different aspects: (1) if financial aspects are a major constraint, we advocate using the budget primarily for the installation of a spatially dense network of automatic rainfall gauges. For example, the investment costs of the 15 HOBO type rainfall gauges installed during our study are approximately equal or even less compared to one heavy duty meteorological station installed. Moreover, those relatively cheap instruments performed very well, showed excellent durability due to their metal housing and only very few technical malfunctions. In this low-cost scenario, the estimation of potential evapotranspiration can be achieved with continuous measurements of air temperature and humidity, which can be measured at very low installation costs. (2) The more expensive 2D ultrasonic wind velocity and direction sensors were selected because they do not involve moving parts and have heating elements in case of snow events (see above, section 3.2). However, these sensors require a constant power supply due to the measurement principle and the heating elements. Accordingly, they were not working during times of power outages, which are more likely to occur during periods of intense rainfall or snow events, which were of special importance for us to measure. Instead we recommend the installation of cup-anemometer made of metal, which also runs on the 12 Volt buffer battery during those periods and requires only a fraction of the investment costs.

In general our experience shows that besides choosing appropriate instruments, special effort should be invested into a proper protection of instrumentation sites in order to ensure uninterrupted, high quality data. Simple, reliable and economic measurement solutions and event self-build or modified sensors, for which numerous building instructions and reports can be found (see e.g. Chapin et al., 2014), may be the best choice for obtaining hydrological data in semi-arid regions. Given the high importance of water resources especially in semi-arid areas, we encourage all scientists to invest maximum possible effort in the acquisition of field data rather than to rely on rough estimations, as it can provide fundamentally new insights into burning hydrological questions and enable water resources assessments and integrated water resources management.

Acknowledgements

The work during our PhD-theses was realized within the framework of the multi-lateral research project “SMART – Sustainable Management of Available Water Resources with Innovative Technologies”. Funding of the project by the BMBF (German Federal Ministry of Education and Research), references No. 02WM0802 and 02WM1081, is greatly acknowledged. Furthermore, we would like to thank our supervisors Martin Sauter and Jens Lange for providing general support and guidance.

During the years of fieldwork we have had the opportunity to meet many remarkable people who helped us in the field in very refreshing ways. They turned what could have simply been a lot of work into a great experience for us as foreign researchers. Without their commitment this work would not have been possible. We also thank all of the people who contributed to fieldwork during different phases of the project: Abu Ashraf, Amer, Andrea Hanf, Anwar Zuhluf, Awad Rashid, Ayman Shawana, Hazem Jumaa, Jakob Sohrt, Kayan Manasra, Klaus Haaken, Markus Giese, Mathias Toll, Mohammed Khalaf, Mohammed Najmi, Sandra Oehlmann, Shadha Musallam, Steffen Fischer. We are grateful to Clemens Messerschmid for the valuable reports on problems faced within his fieldwork campaigns from which we learned a lot. Thanks to “Karim Abu Ein tools” store in Betunia for having such an excellent and surprising assortment of screws and tools. Special thanks also goes to the different metal workshops for having great patience listening to our explanations on special orders and great skill and improvisation talent manufacturing the multiple instrument protection pieces for the field installation. Thanks to the metal workshops of the University of Göttingen – Geoscientific Centre and the University of Freiburg – Institute of Physics for discussing and constructing various devices and prototypes. The Ministry of Education and teachers from public schools in the West Bank are greatly acknowledged for giving us the friendly permission to install rainfall gauges and meteorological stations on the roofs of their schools and for the very friendly reception during field visits and various technical and logistical supports.

References

Black, T.A., and Luce, C.H. (2013). Measuring water and sediment discharge from a road plot with a settling basin and tipping bucket. Gen. Tech. Rep. RMRS-GTR-287. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 38 pp.

Chapin, T.P., Todd, A.S., and Zeigler, M.P. (2014). Robust, low-cost data loggers for stream temperature, flow intermittency, and relative conductivity monitoring. Water Resources Research, 50(8), 6542–6548.

Goodison, B.E., Louie, P.Y.T., and Yang, D. (1997). The WMO solid precipitation measurement intercomparison. World Meteorological Organization-Publications-WMO TD, 65–70.

Ries, F. (2016): Runoff-recharge processes under a strong, semi-arid climatic gradient in the Eastern Mediterranean. Ph.D. dissertation in the process of examination and evaluation, University of Freiburg, Germany.

Ries, F., Lange, J, Schmidt, S., Puhlmann, H., and Sauter, M. (2015). Recharge estimation and soil moisture dynamics in a Mediterranean, semi-arid karst region. Hydrology and Earth System Sciences, 19, 1439–1456, doi: 10.5194/hess-19-1439-2015.

Schmidt, S. (2014): Hydrogeological characterisation of karst aquifers in semi-arid environments at the catchment scale – Example of the Western Lower Jordan Valley. Ph.D. dissertation, University of Göttingen, Germany.

Schmidt, S., Geyer, T., Guttman, J., Marei, A., Ries, F., and Sauter, M.: Characterisation and modelling of conduit restricted karst aquifers – example of the Auja spring, Jordan Valley, Journal of Hydrology, 511, 750–763, 2014.

Sohrt, J., Ries, F., Sauter, M., and Lange, J. (2014). Significance of preferential flow at the rock soil interface in a semi-arid karst environment. Catena, 123, 1–10.

Appendix

Table 1: Overview of deployed instruments and observation systems.

Observation	Instrument
Meteorological parameters	Hobo weather station with H-21-001 logger and sensors wind speed, temperature, relative humidity, radiation
	Thies Climatic station with DLx-MET logger and sensors for wind speed and wind direction (ultrasonic), temperature, relative humidity, radiation
Rainfall	HOBO RG-M tipping bucket with UA-003-64 event data logger
	Thies rainfall gauge connected to DLx-MET logger and integrated heating system
Soil moisture	Decagon 5-TM probes connected to EM50 logger
Runoff	SEBA Dipper 3, Eijkelkamp Mini-Diver; Eijkelkamp CTD-Diver; HOBO 4 meter fresh water level data logger
	Large tipping bucket system (own construction) connected to a UA-003-64 event data logger
Spring discharge	SEBA Dipper PT; SEBA MPS (multi-parameter probe)