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SMART – IWRM

**Improved monitoring concepts for groundwater and
surface water quality**

Deliverable No. 501

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1. Introduction

This report deals with the application of improved monitoring concepts for groundwater quality within the SMART project. As the project intends to develop a transferable IWRM concept to solve water related issues in the Lower Jordan Valley, this problem was investigated mainly in the catchments of the Jordanian test sites. The following report gives an overview on different methods of qualitative and quantitative concepts to monitor groundwater quality, which can be divided into five applications and test sites:

- High-resolution groundwater monitoring of an urban influenced karst aquifer – Hazzir spring & Hisba well, Upper Wadi Shueib (chapter 2.1)
- Monitoring of wells in the Lower Jordan Valley – downstream Wadi Shueib (chapter 2.2)
- Wadi Wala: Monitoring of artificial and natural recharge from Wala reservoir and its effect on groundwater fluctuation (chapter 3)
- Organic trace pollutants as groundwater indicators of anthropogenic pollution (chapter 4)
- Methods of monitoring surface water pollution based on biological indicators, which is a transcript of the related chapter in deliverable no. 502 (chapter 5)

2. Wadi Shueib

2.1. High-resolution groundwater monitoring of an urban influenced karst aquifer – Hazzir spring & Hisba well, Upper Wadi Shueib

Author: Felix Grimmeisen

In Jordan the urban water systems, both in terms of sanitation systems as well as from industrial point source pollution are not sufficiently managed and provide ample potential for improvements towards sustainability. Within the SMART project study area, there are substantial amounts of raw sewage and treated wastewater that are discharged into the Wadis contributing to the Lower Jordan Valley. Due to the high vulnerability of mostly karst aquifers along the Wadis (Werz, 2006), the groundwater is frequently contaminated by these effluents. The upper part of Wadi Shueib with its cities As Salt and Fuheis was chosen as test site to investigate groundwater contamination problems caused by an urban area.

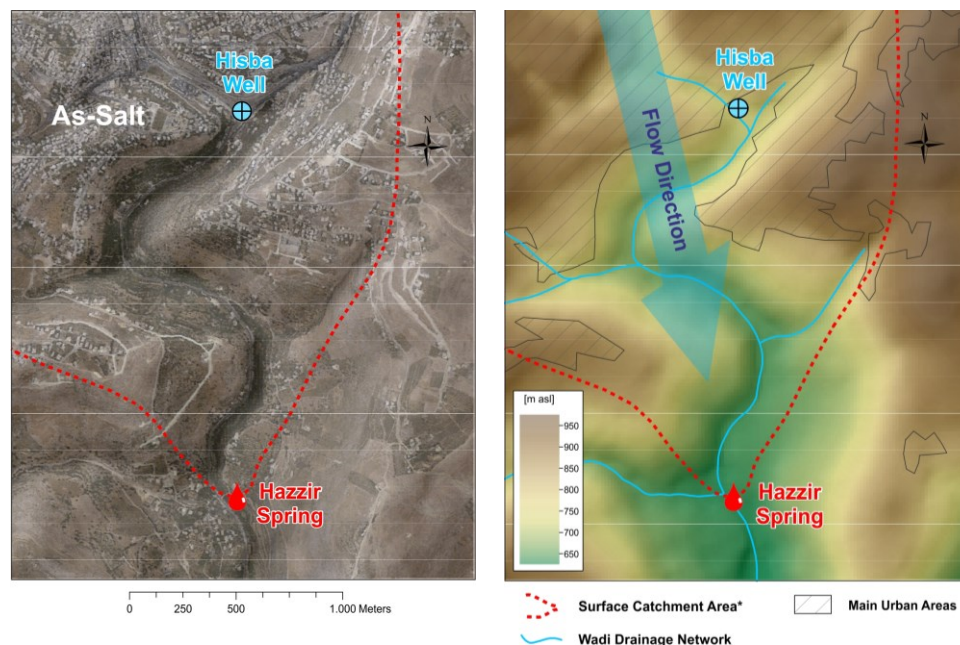


Figure 1 Location of the installed probes at Hazzir spring and Hisba well in the Upper Wadi Shueib

The frame of modern groundwater protection includes the four main components namely water protection zoning (1), the reduction of polluting activities (2), the water quality monitoring (3) and drinking water treatment (4;(Goldscheider, 2010). Whilst the importance of all of these measures is equal, within the case study of the Hazzir spring the focus was directed to the water quality monitoring. The development of a new monitoring system included the implementation of high resolution sensor technologies combined with up to date analytical methods and was applied to improve the existing data availability.

To establish a better understanding of the hydrochemical variability on detailed level, new technologies like a spectrometric sensor (UV-Vis for nitrate measurements, were used to get time series with high resolution (up to 1 minute intervals) and continuously accessible via telemetry. Based on time series analysis of parameters like electric conductivity (EC), nitrate and spring discharge, statistics on pollution frequency and appropriate sampling strategies were applied. The most critical problem of the Hazzir spring and a main challenge for the water quality monitoring are detections for fecal bacteria with high time resolution. Within this study the test method Colilert® (IDEXX) could be established on convenient time scale to improve a better early warning. Because of the increased nitrate concentrations and the frequency of bacteriological impacts these two parameters have been one focus in the investigations.

For a better understanding of groundwater quality variations underneath the city the Hisba well could be chosen as observation well to monitor electric conductivity (EC), water level and temperature. Furthermore a weather station was installed on top of the guard house next to Hazzir spring. Hourly measurements of precipitation, air temperature and air humidity are transferred via telemetry to a website to be downloadable every time.

Beginning in May 2011, monitoring devices with following components have been installed (cf. Figure 2 and 3):

Hazzir spring:

- UV-Vis spectrometer probe for NO₃-N, turbidity, DOC and TOC
- V-weir and ultrasonic flow device for discharge
- Climate station for rainfall, air humidity and air temperature hourly
- Multiparameter probe for electric conductivity (EC) and temperature

Hisba well:

- Multiparameter probe for electric conductivity (EC), temperature and water level
- Multiparameter probe for barometric pressure and air temperature

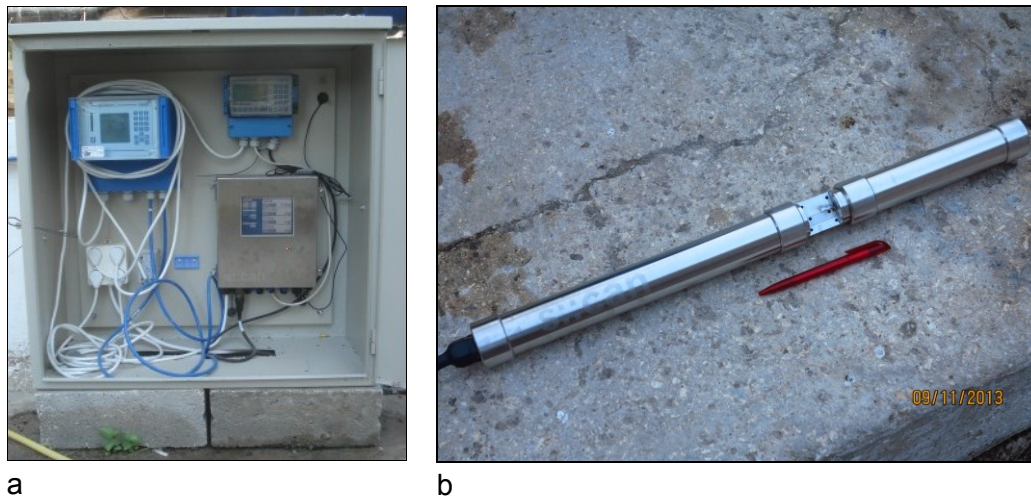


Figure 2 a Reading devices of installed sensors at Hazzir spring. b Scan Spectrolyser UV-Vis sensor of Hazzir spring. (Photos: Grimmeisen)

The following table 1 summarizes important information of all installed sensors at the Hazzir and Hisba well as well as the monitoring parameters of the devices. The field experiences about the used UV-Vis sensor are partly published in Huebsch et al. (2015).

Table 1 Key data of the sensors which are installed in the Upper Wadi Shueib

Location ID	Probe	Installation date	Rope length (m)	Measuring interval	Measurement parameter*
Hazzir spring (AM0512)	Aquitronic Aquilite Multiparameter probe	17.11.2008	2 m	15-min	EC, Temp, WL
	Scan Spectrolyser UV-Vis Probe	02.05.2011	2 m	15-min	Turb, NO3, TOC/DOC
	Nivus NivuMaster Ultrasonic sensor (+ V-weir)	02.05.2011	-	15-min	WL (Q)
	Nivus netModule telecontrol station	02.05.2011	-	-	Telemetry
	Pessl Instruments GmbH iMetos weather station	12.11.2012	-	hourly	R, AH, ATemp, Telemetry

Hisba well (AM1002)	Schlumberger CTD Diver	08.06.2013	90 m	15-min	EC, Temp, WL
	Schlumberger Baro Diver	08.06.2013	-	15-min	P, ATemp

* Q = Spring discharge; WL = Water level; EC = electric conductivity; Temp = Temperature; Turb = Turbidity; NO₃ = Nitrate conc.; TOC/DOC = Total/Dissolved organic carbon; R = Precipitation; AH = Air humidity; ATemp = Air Temperature; P = Barometric Pressure

Furthermore between May 2011 and April 2012, more than 50 water samples of Hazzir spring have been collected weekly to be analysed for nitrate and E. coli as well as 4 sampling campaigns (March & Sept. 2012, March & June 2013) for further hydrochemical parameters have been performed at Hazzir spring. Concerning the spring monitoring it was first measured with main parameters as EC to get a rudimentary composition of the hydrochemistry and the basic hydraulic characteristics of the aquifer system during the year.



Figure 3 Pessl iMetos® weather station installed next to Hazzir spring. (Photo: Grimmeisen)

2.2. Monitoring of wells in the Lower Jordan Valley – downstream Wadi Shueib

Author: Paulina Alfaro

The Lower Jordan Valley is one of the most important areas of Jordan, where agriculture is the most important activity and thus, the use of the water resource play an essential role in the area development. The source for this irrigation water is mainly groundwater, which is extracted with pumping wells located in the whole area.

In order to study the groundwater dynamics, the Ministry of Water and Irrigation (MWI) and the Water Authority of Jordan (WAJ) carry out the monitoring of both, groundwater levels and groundwater quality, which take places in different observations wells and operational wells, respectively. However, the need to create a groundwater model in the area downstream of Wadi

Shueib has shown that the amount and density of observations wells is not enough in order to generate a good register of time series and eventually, simulate scenarios to predict different behaviours.

Therefore, locations within the study area were searched with the purpose of installing continuous measurement devices, which record the water level and temperature. These instruments consist in three Mini Divers from the company Schlumberger, which were programmed to measure every hour and their information is read every three months during the period of study. Their locations are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** with the label "Private".

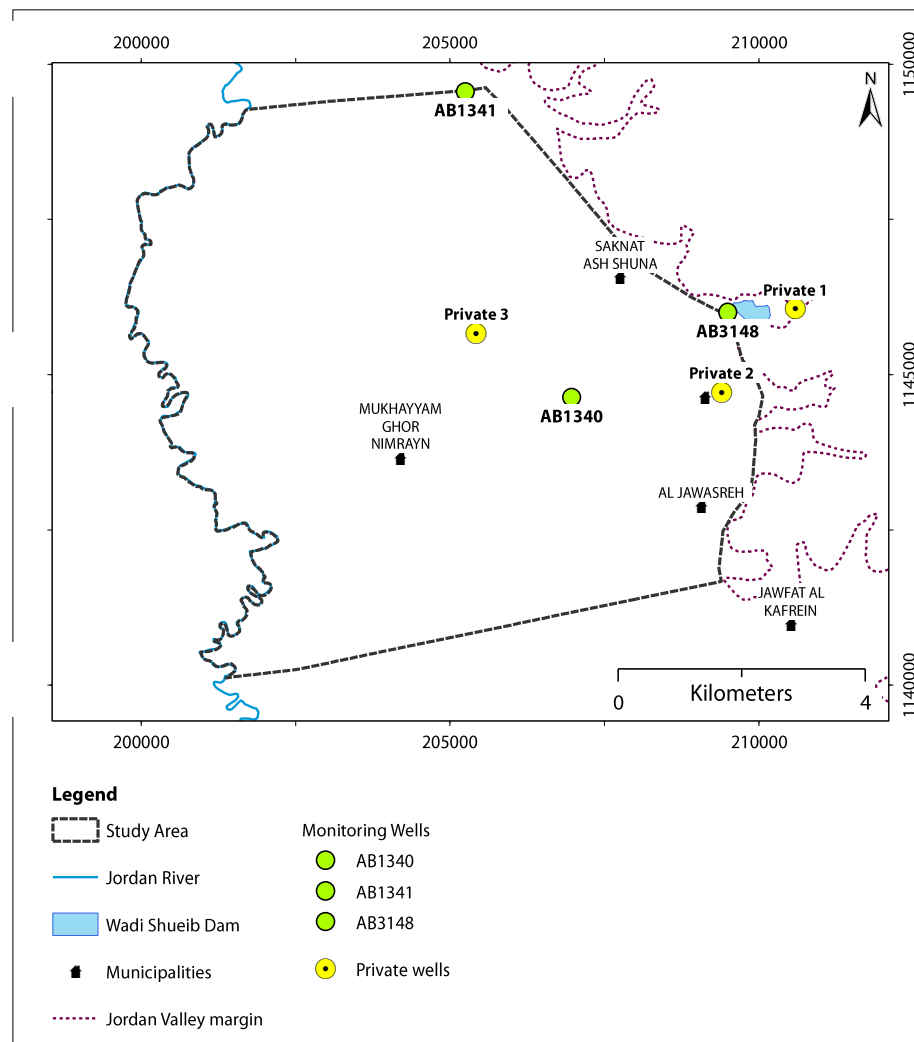


Figure 4 The green points show the location of the monitoring wells in the study area (Data from MWI Open files) whereas the yellow points show the location of the private wells where Divers were installed.

Furthermore, electrical conductivity deep profile measurements were conducted in the area of in the monitoring wells of the study area in February 2012, November 2012 and March. These measurements can show behaviour in the salinity content of the groundwater along the depth, which can eventually help to identify flows in the underground from lateral or underlying aquifers (Alfaro et al., 2012). This discrete measurements are reinforced with continuous measurements of the electrical conductivity, with the help of two instruments, called CTD Divers, which are installed at two different depths in a same monitoring well (AB1341), in order to identify seasonal variations in the electrical conductivity values.

Table 2 General information of devices installed in the study area

Well	ID	Well Name	Well depth (m)	Water level Nov 2012 (m)	Date divers installation
Monitoring well	AB1341	Karama observation well	105.0	59.0	07.Nov 2012
Private 1	AM1035	-	24.0	20.5	12. Nov 2012
Private 2	-	Royal Garden	125.8	93.5	12. Nov 2012
Private 3	AB1285	Sharif N. Bin Jamil 2	110.3	45.2	12. Nov 2012

The existence of observations wells is a good start to build a monitoring net in the Jordan Valley. The extensive exploitation of the groundwater resource in this area should require the enlargement of this monitoring system, in order to define better water management strategies, considering the water level fluctuations in the area.

3. Wadi Wala: Monitoring of artificial and natural recharge from Wala reservoir and its effect on groundwater fluctuation

Author: Julian Xanke

The Wala dam was constructed in 2002 to collect floodwaters and recharge it to the underlying limestone aquifer, from where it gets recovered and supplied for drinking water purposes to Jordan's capital Amman and nearby communities. Since the first floods, water is infiltrating into the ground naturally, but also artificially through recharge wells (since 2011). The objective of the monitoring program is to obtain a better understanding of the dynamic system of runoff and storage in the reservoir, recharge of the karstic aquifer and recovery of the water at Hidan well field (Xanke et al., 2012). This includes the observation of the water level fluctuations in the reservoir and the aquifer, caused by both recharge mechanism. For this purpose, six sensors were installed in November 2011 in the reservoir and certain wells downstream of it. An additional turbidity and electric conductivity (EC) sensor was installed at the Wala pumping station in February 2012.

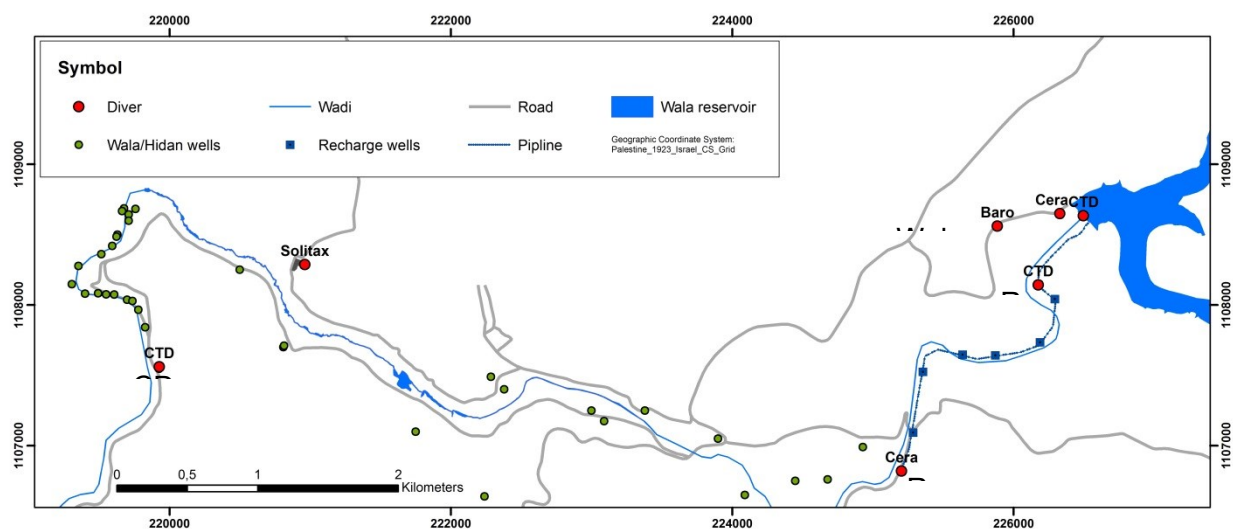


Figure 5 Location of the Divers in the Wala area

CTD divers are bar-shaped devices with a ceramic housing and a length of 13,5 cm and a diameter of 2,2 cm. Its shape allows an installation also in very narrow pipes or wells as well as in open waters. It is used for monitor water level, electric conductivity and temperature. Depend-ent on the installation depth (below water table), membranes for pressure measurement are available for 10 m depth, 50 m depth and 100 m depth, taking into account that the accuracy decreases from ± 0.5 cmH₂O to ± 2.5 cmH₂O to ± 5.0 cmH₂O. Additional temperature sensors measure from -20 °C to $+80$ °C and electric conductivity can be recorded up to 120 mS/cm. The possibility to record 48.000 measurements makes the diver suitable for long-term monitoring and high interval measurements.



Figure 6 CTD diver, Cera Diver and Baro diver (source: <http://www.swstechnology.com>)

The Cera divers differ only in the length (9.0 cm) and the missing electric conductivity electrode. The Baro Diver is used for compensating the air pressure from the water table records. For the installation of the divers a simple aramid rope is used. The divers are illustrated in Figure 5. For the wells, a pressure membrane for 100 m water column was chosen because the filter section of most of the wells starts around 70 m below well top. Other reasons are the productive zone of the aquifer, which is located around 100 m below surface level, and the high groundwater table. Only the CTD diver in the reservoir has a membrane for 10 m pressure because the water table fluctuation is in the range of 5-20 m. To have a detailed record of the parameters during fast changing conditions, the divers were programmed to measure in a 30 minutes interval.

Table 3 Key data of the sensors which are installed in the Wala area.

Well_ID	Probe	Installation date	Rope length (meter)	Measuring interval	Measurement WL = Water level EC = electric conductivity Temp = Temperature
Reservoir	CTD Diver	23.11.2011	12,77	30 min	WL, EC, Temp
PR 5	Cera Diver	23.11.2011	55	30 min	WL, Temp
RW 1	CTD Diver	23.11.2011	100	30 min	WL, EC, Temp
RW 8	Cera Diver	23.11.2011	100	30 min	WL, Temp
CD 1097	CTD Diver	30.11.2011	100	30 min	WL, EC, Temp
Wala office	Baro Diver	23.11.2011	-	30 min	Barometric pressure, Temp
Pumping station	SOLITAX sc	26.02.2012	-	60 min	Turbidity, EC

The Solitex sc device was installed to observe the turbidity and electric conductivity in the Wala pumping station. All abstracted water from Hidan wells and some Wala wells is collected in the reservoir of the Wala pumping station, from where it is passed a few kilometers north of it to Leb station for chlorination. Periodical turbidity occurrence in the past made the water undrinkable for several days or weeks. To put the turbidity into correlation to natural events, such as rainfall, but also to anthropogenic activities, such as artificial recharge and operation of the abstraction wells, the device was installed. The Measurement was done every hour to record also small changes. The records show only average values of all wells. Changes in single wells might not be detectable because of the mixing with non-effected water from the other wells. Contrariwise, changes in turbidity can't be associated to certain wells.



Figure 7 Solitex sc device with Turbidity probe (left) and EC probe (right).

4. Organic trace pollutants as groundwater indicators of anthropogenic pollution

Author: Natalie Schmidt

In the following chapter the focus for monitoring groundwater quality is set on trace organic compounds investigated in batch and column studies (see reports for Deliverables 311 and 315). Based on the experimental results a classification was derived which is presented here.

In total 36 different substances were analysed for their elimination behavior in soil column studies. Additionally many of them were also analysed in long term batch experiments considering aerobic and different anaerobic redox conditions. Table 3 shows the categorized results for the column experiments, where most of the substances showed high elimination rates throughout the experimental time of almost 3 years. Only five of the tested compounds showed marginal to no elimination. These were the two ionic contrast agents diatrizoic acid and iothalamic acid as well as the non-ionic iopamidol. Furthermore clofibric acid, the active metabolite of the lipid-lowering agent etofibrate, and the antiepileptic carbamazepine were not removed during soil passage. Since mean elimination rates for these five compounds were less than 50% they belong to category I. Batch experiments included all of these substances as well and for none of them a substantial concentration decline above 50% was denoted.

Substances within group II were eliminated to more than 90% but with a dependency on temperature and/or the concentrations applied. In total 14 substances showed such a behavior. However, for many of them the influence of temperature or concentration ceased over time indicating microbial adaptation (e.g. bezafibrate, naproxen). The amount to which a substance is degraded complies predominantly with the composition of the microbial community and its affinity towards the trace organic compounds.

Group III comprises the substances that showed a removal rate above 90% from the beginning of the experiments on, regardless of the temperature or concentration applied. Ibuprofen showed very good removal within the column tests irrespective of any influencing parameters. Bisphenol A and the natural estrogens belong to the substances ranked in class III as well. Like ibuprofen they were always completely eliminated under any condition. Furthermore their behavior during the batch experiments indicated easy degradability under aerobic and anaerobic conditions, respectively (see report on deliverable 311).

Table 4 Classification of emerging pollutants by their biodegradation behavior during soil passage through the laboratory soil columns with I = elimination < 50%, II = elimination >90% according to temperature and/or concentration, III = elimination > 90% without effects of temperature or concentration

		I	II	III
Analgesics/Antiphlogistics	Diclofenac		•	
	Ibuprofen			•
	Naproxen		•	
	Pentoxifylline			•
	Phenazone		•	
Antiepileptic	Carbamazepine	•		
Lipid-lowering agents	Bezafibrate		•	
	Gemfibrozil		•	
	Etofibrate			•
	Clofibric acid	•		
	Fenofibrate			•
	Fenofibric acid		•	
Beta blockers	Atenolol			•
	Metoprolol		•	
	Propranolol			•
	Sotalol		•	
Alkylphenols and Bisphenol A	4-iso-Nonylphenol			•
	4-tert-Octylphenol			•
	Bisphenol A			•
Estrogens	17 β -Estradiol			•
	Estriol			•
	Estrone			•
	17 α -Ethinylestradiol			•
X-ray contrast media	Diatrizoic acid	•		
	Iohexol		•	
	Iomeprol		•	
	Iopamidol	•		
	Iopromide		•	
	Iothalamic acid	•		
Trialkyl phosphates	Triethyl phosphate		•	
	Tricresyl phosphate (o-, m- and p-isomer)			•
	Tri-n-butyl phosphate			•
	Triphenyl phosphate			•
	Tris(2-chloroethyl) phosphate*		•	
	Tris(2-chloropropyl) phosphate*		•	
	Tris(2-ethylhexyl) phosphate			•

** Elimination of Tris(2-chloroethyl) phosphate and Tris(2-chloropropyl) phosphate on average was 78% and 89% during the last two measurements.*

On the basis of the experimental results substances like diatrizoic acid and carbamazepine are expected to be eliminated neither during soil passage nor during storage in the aquifer, since the batch studies (25 to 31 months) did not result in considerable elimination rates either. However, conventional waste water treatment does not remove these substances sufficiently and consequently they will be contained in the effluent of waste water treatment plants and may reach the groundwater thereafter. Thereby it needs to be considered that the composition of waste water can differ, depending on the pharmaceuticals prescribed in each country and not all substances mentioned here necessarily have to be in a certain WWTP effluent. This needs to be analysed case by case. Still the possibility to find some of the substances listed under I is high, as the usage of carbamazepine and the X-ray contrast agents is widely spread (Kümmerer 2009). Furthermore due to their high persistency and the frequency with which they have been detected in the environment recalcitrant substances like clofibric acid and carbamazepine are rather unlikely to be degraded during underground storage, even after long time spans (Heberer 2002, Scheytt et al. 2004, Arye et al. 2011). With regard to these five substances the one with the highest prescription in a country should be included in a monitoring system in order to trace possible constant and long term influences of waste water in groundwater.

Compared to that substances like ibuprofen or bezafibrate, which are known for their high degradability during waste water treatment (Clara et al. 2005, Smook et al. 2008) can denote a recent entry of insufficiently treated waste water. If they are detected in groundwater, deficiencies of aeration, hydraulic retention times or sludge age within the biological treatment step of the respective waste water treatment plant of the catchment area are indicated.

Furthermore the boundary conditions during soil passage have to be known (e.g. temperature, retention time, redox conditions). Since the column experiments were run under unsaturated conditions and no distinct nitrate reduction occurred it can be deduced that aerobic conditions prevailed along the 1.10 m passage through the columns. Therefore the results of the degradability of the emerging pollutants tested in the columns have to be estimated based on aerobic conditions. If others than aerobic conditions predominate the soil passage, the outcome for the elimination rate of the emerging pollutants might be different.

The classification shown here provides a decision support for the selection of adequate tracers for a groundwater monitoring concept. The substances were ranked into three main classes, according to their behavior in soil column experiments. The classification can support field experiments by giving a first hint as to what to expect from the investigations, e.g. the elimination of these compounds during soil passage and the subsequent storage in the underground. According to the results a method for the combined detection of e.g. carbamazepine, clofibric acid and ibuprofen, as it is already standard at the analytics department of the TZW, would be appropriate to detect long term as well as acute anthropogenic influences in a groundwater system. Since all these substances have been also detected in water samples in the Lower Jordan Valley (see report on deliverable 317), they can be suitable tracers for groundwater monitoring in the area as well.

5. Methods of monitoring surface water pollution based on biological indicators (c.f. D502)

Author: Miriam Leicht

Biological methods are highly recommended to describe the quality and pollution of surface water bodies and are an excellent instrument to evaluate the overall ecological quality. Their advantage is the allowance of an integrated assessment of surface water quality, considering several parameters such as organic load, discharge, bottom substrates and pollutants. To offer all necessary information regarding water quality, physical and chemical measurements should be conducted in addition to biological parameters. As the aquatic environment can be affected by both natural and anthropogenic influences and organisms living in a water body are sensitive due to any changes in their environment, the response of an organism to those changes can be used to determine the water quality regarding its ability for aquatic organisms living there (G. Friedrich, D. Chapman and A. Beim, 1996).

Within D 502, two biological methods were tested and applied in Jordan Rivers and Wadis around the King Talal Dam, Jordan:

- Biofilm monitoring for the assessment of water pollution e.g. heavy metals
- Macro-invertebrate survey to evaluate the overall ecological status

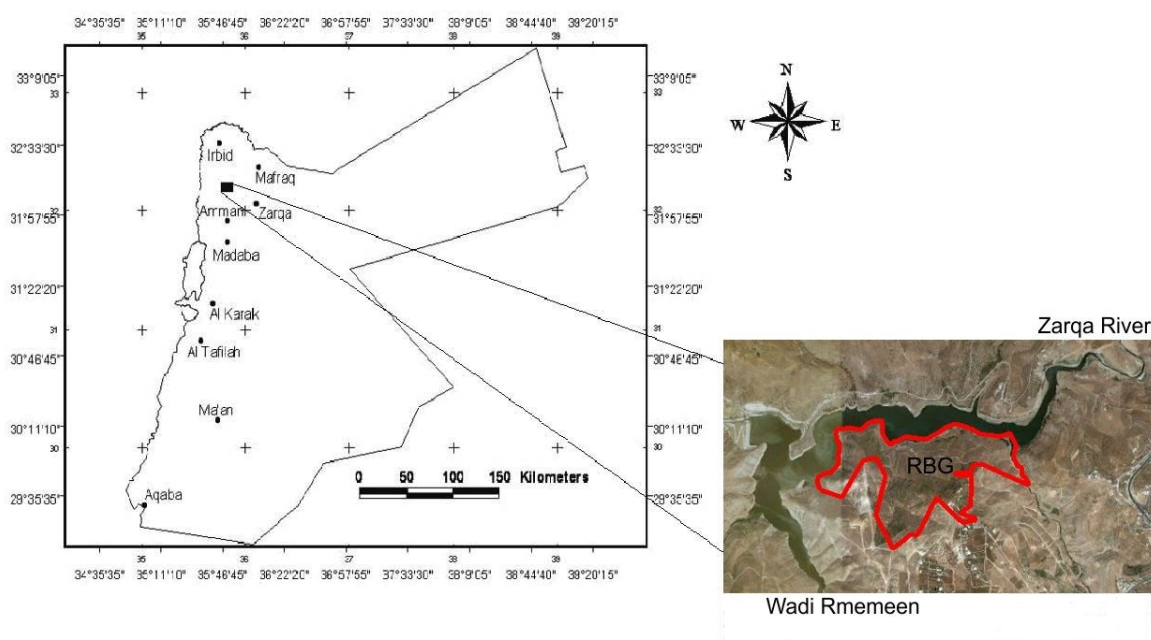


Figure 8 Study area (modified after Royal Botanic Garden and Google Earth)

Biofilm monitoring

The method of biofilm monitoring is based on aquatic biofilms and is used to monitor surface water pollution. Biofilms have the ability to adsorb and incorporate material, they can be found at any surface exposed to water and they represent a microbial community with various inhabitants such as sessile bacteria, protozoa, fungi and algae (Fuchs, 1996).

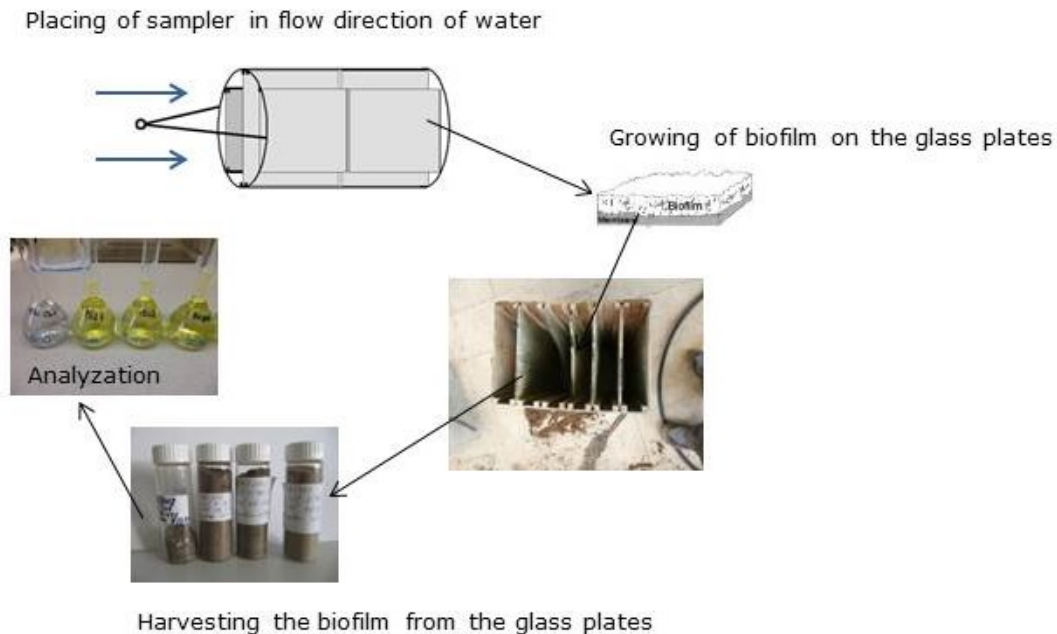


Figure 9 Steps of Biofilm monitoring (modified after Flemming, H.C., 1999)

They are, according to their structure, able to incorporate contaminants and to grow rapidly and thus these aquatic microbial communities can be used as a pollutant-monitor (Fuchs, 1996). Due to their low cost, easy handling and low site specific requirements, the method allows a high spatial resolution of monitoring. Furthermore, the analysis of the biofilm will deliver reliable and time integrated results on sources and state of surface water pollution.

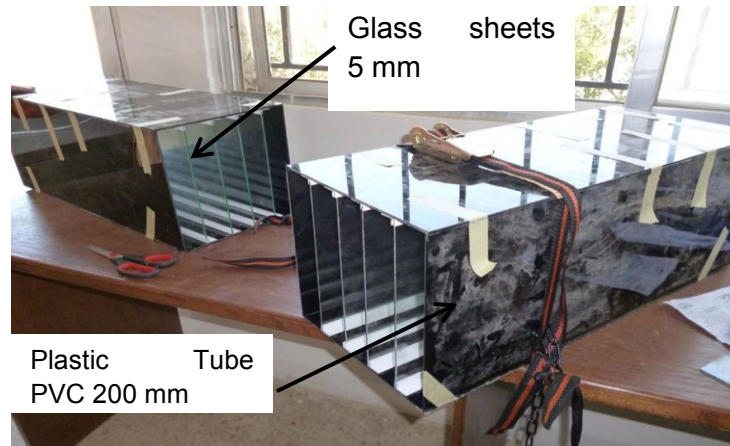


Figure 10 Biofilm samplers used at the RBG

Macro-invertebrate survey

Macro-invertebrates have been collected up- and downstream of a point of waste water discharge.



Figure 11 Sample preserved in a vial showing



Figure 12 Stereo microscope used

One method to utilize the data of the macro invertebrates is the Saprobic Index by Kolkwitz and Marsson (1908).

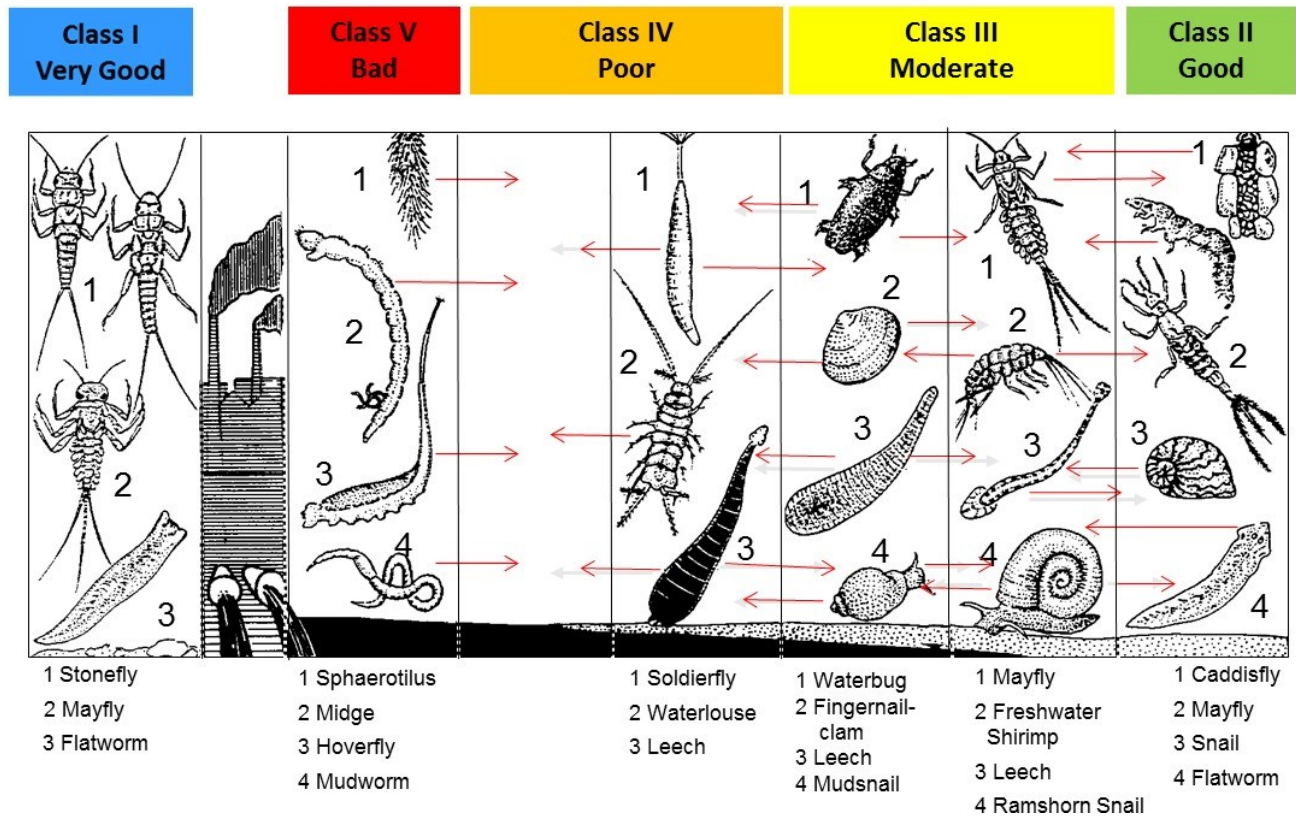


Figure 13 Water quality and Saprobien system – self-purification in flowing waters (modified after Barndt et al., 1996)

Kolkwitz and Marsson (1902, 1908, 1909) presented a practical system for water quality assessment using biota. This system, known as the Saprobic system, has been used intensively and mainly in Central Europe. Figure 2 shows the classification, the Saprobic system is based on. It shows that all organisms have specific environmental demands and will only settle down if a spot meets all their demands. Downstream of a heavy pollution caused by the discharge of untreated wastewater in the surface water body, a change in biota occurs. Directly after the inlet point a rapid decay of organic material occurs which will consume all oxygen that's available in the water and thus leads to a significant change in freshwater community. In class number 5, only organisms which can stand very low oxygen concentration or very high organic pollutant will survive. Due to self-purification the community will recover and a change in the ecosystem can be observed, principally in the components of the biotic communities. Odor and other chemical variants in the water also change.

Distribution of heavy metals according Igeo classes

I_{geo} = Index of Geo-accumulation

Table 5 I_{geo} classes with respect to sediment quality (Müller, 1981)

I_{geo}	I_{geo} Class	Pollution intensity
0 - 0	0	Undetected
0 - 1	1	Unpolluted
1 - 2	2	Unpolluted to moderately polluted
2 - 3	3	Moderately polluted
3 - 4	4	Moderately to highly polluted
4 - 5	5	Highly polluted
>5	>5	Very highly polluted

To establish pollution status of the Zarqa River and King Talal Dam reservoir (based on sediment sampling in the study area), a geochemical index (I_{geo}) was calculated according to Müller's (1981) formula (Muzungaire, L., 2012):

$$I_{geo} = \log_2 C_n \cdot 1.5 B_n^{-1}$$

Where:

C_n = trace element concentration in the sediment at the particular station,

B_n = geochemical background of the element given by Turekian and Wedepohl (1961).

I_{geo} classes with respect to sediment quality Müller's (1981) is indicated in table x (Appendix).

6. Summary

All monitoring techniques and installations were conducted with the special focus on anthropogenic contaminations to the local water resources. This kind problem-oriented monitoring is a very effective tool to identify future problems and optimized solutions. The following two tables shortly summarize the used monitoring devices (Table 6) and the setup of the different improved monitoring concepts at the SMART observation sites (Table 7). The last column includes recommendations regarding a continuation of monitoring and the time resolution of measuring intervals.

Table 6 Monitoring devices for continuous measurements (high temporal resolution)

<i>Location</i>	<i>Monitoring administered by Water Authority</i>	<i>SMART: adapted monitoring set-up at specific site</i>	<i>Recommendation</i>
Wadi Shueib (part 1)			
Baqqouria spring	• Discharge: manual recording - irregular	• Multiparameter probe (electrical conductivity, temperature, turbidity) - 15 min interval	Permanent electronic recording of discharge - hourly and <i>E. coli</i> testing daily
Hazzir spring	• Discharge: manual recording - irregular	• Two Multiparameter probes (electrical conductivity, temperature, turbidity, TOC/DOC, nitrate) - 15 min interval • Ultrasonic device + V-weir (discharge) - 15 min interval • Climate station (precipitation, air temperature, air humidity) - hourly • telemetry device	Permanent electronic recording of discharge - hourly and <i>E. coli</i> testing daily
Shoreia spring	no measurements	• Multiparameter probe (electrical conductivity, temperature) - 15 min interval	Permanent electronic recording of discharge - hourly
Hisba well	no measurements	• Multiparameter probe (water level, electrical conductivity, temperature) - 15 min interval	Permanent electronic recording of water level, temperature and electric conductivity - hourly
Um Attija well	• Abstraction: manual recording - daily • <i>E. coli</i> : manual sampling - weekly		Permanent electronic recording of electric conductivity- hourly
Yesidia wells	• Abstraction: manual recording - daily • <i>E. coli</i> : manual sampling - weekly		Permanent electronic recording of electric conductivity- hourly

Table 6 Monitoring devices for continuous measurements (high temporal resolution) (part 2)

<i>Location</i>	<i>Monitoring administered by Water Authority</i>	<i>SMART: adapted monitoring set-up at specific site</i>	<i>Recommendation</i>
Wadi Shueib (part 2)			
As Salt station no. 268	• Precipitation: mechanical recording - every six hours (Meteorological Department)		
AM0001-0007 meteo stations	• Precipitation: manual recording - daily (Agricultural Department)		Permanent electronic recording of precipitation - hourly
Wadi Wala			
Reservoir	• Water level: manual recording - daily	• Multiparameter probe (water level, electrical conductivity, temperature) - 30 min interval	Permanent electronic recording of water level, temperature - hourly
Recharge wells	• Water level: manual recording - weekly	• Multiparameter probe (water level, electrical conductivity, temperature); RW 1+8 - 30 min interval	Permanent electronic recording of water level, temperature - hourly in RW 1 + 8
Hidan and Wala wells	• Water level: manual recording (CD 1097 and CD 3133) - daily	• Electronic measurement of water level, electrical conductivity and temperature (CD 1097); time resolution?	Permanent electronic reading of the water level, electrical conductivity and temperature (CD 3133, CD 1097, CD 1095)
Wala pumping station	• Total abstraction - daily	• Electronic measuring device for turbidity and electrical conductivity - 30 min interval	Permanent electronic recording of turbidity and EC probe - hourly
South Shuna			
AB3141 Karama observation well	• Water level: mechanical recording - daily	• 2 Multiparameter probes (water level, electrical conductivity, temperature) - hourly	
AM 1035 Private well	no measurements	• Multiparameter probe (water level, temperature) - hourly	Permanent electronic recording of electric conductivity
Royal Garden well	no measurements	• Multiparameter probe (water level, temperature) - hourly	Permanent electronic recording of electric conductivity
AM1285 Sharif N. Bin Jamil 2 private well	no measurements	• Multiparameter probe (water level, temperature) - hourly	Permanent electronic recording of electric conductivity
AB3140 monitoring well	• Water level: mechanical recording - daily		Permanent electronic recording of electric conductivity
AB3148 monitoring well	• Water level: mechanical recording - daily		Permanent electronic recording of electric conductivity

Table 6 Monitoring devices for continuous measurements (high temporal resolution) (part 3)

<i>Location</i>	<i>Monitoring administered by Water Authority</i>	<i>SMART: adapted monitoring set-up at specific site</i>	<i>Recommendation</i>
Wadi Rmemeen / Royal Botanic Garden			
Royal Botanic Garden		• Biofilm: manual sampling - monthly • Macro-invertebrates: manual collecting (Saprobic system)	

Table 7 Water quality monitoring in surface and groundwater bodies (part 1)

<i>Location</i>	<i>currently installed Monitoring administered by Water Authority</i>	<i>SMART: Monitoring Set-up at specific site</i>	<i>Recommendation</i>
Wadi Shueib (part 1)			
Baqqouria spring	• Manual sampling and analyses of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, ammonium - irregularly • Biological parameters: E.coli and total coliforms - biweekly	• biannual sampling campaigns to analyse physical and chemical parameters: major anions, O-18 and H-2 isotopes and nitrate isotopes • biological parameters: <i>E coli</i> and total coliforms • four sampling campaigns to analyse physical and chemical parameters: including 16 pharmaceuticals and 9 ICM	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual
Hazzir spring	• Manual sampling and analyses of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, ammonium – irregularly • Biological parameters: E.coli and total coliforms - biweekly	• Two year biannual sampling campaigns to analyse physical and chemical parameters: major anions, O-18 and H-2 isotopes • Biological parameters: 4 sampling campaigns including <i>E. coli</i> and total coliforms and 3 sampling campaigns viruses (Norovirus, Rotavirus, Adenovirus) and bacteriophages (phiX, MS2) • four sampling campaigns to analyse physical and chemical parameters: including 16 pharmaceuticals and 9 ICM	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual

Table 7 Water quality monitoring in surface and groundwater bodies (part 2)

Location	currently installed Monitoring administered by Water Authority	SMART: Monitoring Set-up at specific site	Recommendation
Wadi Shueib (part 1)			
Shoreia spring:	- Manual sampling and analyses of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, ammonium – irregularly - Biological parameters: <i>E.coli</i> and total coliforms – irregularly	- biannual sampling campaigns to analyse physical and chemical parameters: major anions, O-18 and H-2 isotopes and nitrate isotopes - four sampling campaigns to analyse physical and chemical parameters: including 16 pharmaceuticals and 9 ICM - biological parameters: <i>E coli</i> and total coliforms	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual
Hisba well:	no monitoring	- two sampling campaigns to analyse physical and chemical parameters: major anions, O-18 and H-2 isotopes and nitrate isotopes - biological parameters: <i>E coli</i> and total coliforms	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual
Um Attija well:	- Manual sampling and analyses of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, ammonium – irregularly - Biological parameters: <i>E.coli</i> and total coliforms - weekly	four sampling campaigns to analyse physical and chemical parameters: including 16 pharmaceuticals and 9 ICM, major ions, fecal bacteria, and physico-chemical parameters (EC)	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual
Yesidia wells:	- Manual sampling and analyses of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, ammonium – irregularly - Biological parameters: <i>E.coli</i> and total coliforms - weekly	four sampling campaigns to analyse physical and chemical parameters: including 16 pharmaceuticals and 9 ICM, major ions, fecal bacteria, and physico-chemical parameters (EC)	Periodical sampling for nitrate, chloride and isotopes analyses (O-18 and H-2 for groundwater - surface water mixing calculations - biannual

Table 7 Water quality monitoring in surface and groundwater bodies (part 2)

Location	currently installed Monitoring administered by Water Authority	SMART: Monitoring Set-up at specific site	Recommendation
Wadi Wala			
Reservoir	Manual sampling and analysing of physical and chemical parameters: pH, temperature, electrical conductivity, major ions, heavy metals. Biological parameter: <i>E.coli</i>, chlorophyl, nematodes - monthly (daily or weekly during flood)		Periodical sampling of pH, electrical conductivity, temperature, major ions, isotopes (tritium, O-18 and H-2 for groundwater/surface water mixing calculations, C-13,C-14 for age dating) -monthly. Installation of a climate station (rainfall, temperature, evaporation, wind speed)
Hidan and Wala wells	Manual sampling and analysing of physical and chemical parameters: pH, temperature, electrical conductivity, major ions - irregular (1-4 per year)	electrical measurement of turbidity at Wala pumping station - hourly	Periodical sampling of pH,electrical conductivity, temperature, major ions, isotopes (tritium, O-18 and H-2 for groundwater/surface water mixing calculations, C-13,C-14 for age dating) - monthly
Wadi Rmemeen / Royal Botanic Garden			
Zarqa River & King Talal Dam reservoir		Heavy metals: manual sediment sampling - biannual	
Lower Jordan Valley (see D311 and D315)			
Lower Jordan Valley		sampling campaigns to be analysed for their elimination behaviour in soil column studies including 36 different substances: Analgesics/Antiphlogistics, Antiepileptic, Lipid-lowering agents, Beta blockers, Alkylphenols and Bisphenol A, Estrogens, X-ray contrast media, Trialkyl phosphates	Combined long-term monitoring of carbamazepine, clofibric acid and ibuprofen - biannually

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