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Water resources pollution from urban areas in the LJV

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Table of Contents

1. Introduction.....	1
1.1. Groundwater Pollution in Urban Areas	1
1.2. Research on Groundwater Pollutions within the SMART-Project.....	1
2. SMART IWRM Study Area Wadi Shueib	2
2.1. Topography.....	2
2.2. Geological Setting	3
2.3. Hydrogeology.....	6
2.4. Climate	8
2.5. Landuse	8
2.6. Local Water Resources	10
2.6.1. Springs in the Wadi Shueib.....	12
2.6.2. Wells in the Wadi Shueib	13
2.6.3. Water Uses and Demand.....	14
2.7. Wastewater	14
2.7.1. Occurrence & Treatment.....	14
2.7.2. Wastewater Related Problems.....	15
3. Monitoring of the Water Quality in the Wadi Shueib	17
3.1. Water Sampling Campaigns between 2008 and 2012.....	17
3.2. Investigated Substances	17
3.2.1. Major Ions	17
3.2.2. Coliforms	17
3.2.3. Physio-Chemical Parameters.....	17
3.2.4. BOD, COD, TOC, DOC.....	18
3.3. Local Regulations	18
3.4. Status Quo February 2012	19
3.5. Historical Data and Recent Trends	21
3.6. Conclusions.....	22
4. Assessment and Temporal Evolution of Pharmaceutical Concentrations	23
4.1. Use of Pharmaceutical Substances as Quality Indicator	23
4.2. Sampling of Pharmaceutical Substances.....	23
4.3. Results for Pharmaceuticals in the Urban Catchment of the Wadi Shueib.....	24
4.4. Results for Pharmaceuticals in the Urban Catchment of the Wadi Kafrein	27

4.5.	Suitability of Pharmaceuticals as Contamination Indicator.....	28
4.6.	Conclusions.....	31
5.	Focus Monitoring Site Hazzir Spring.....	32
5.1.	Pollutant Content Variations of Nitrate and Bacteria at Hazzir spring.....	32
5.2.	Historical Review.....	33
5.3.	Present Spring Water Monitoring and Sampling Analysis.....	33
5.4.	Results.....	34
5.5.	Conclusions.....	40
6.	Macro Fauna and Flora as Indicators of Water Quality.....	41
6.1.	Plants and Animals used as Indicators to determine the Quality of Water – a Historical Overview	41
6.2.	Methodology	42
6.3.	Study Locations	44
6.4.	Macro Organisms in Jordan	46
6.5.	Detected Bio-Indicators	50
6.5.1.	Insects.....	50
6.5.2.	Crustaceans	52
6.5.3.	Molluscs Group as Bioindicators	53
6.5.4.	Worms	54
6.5.5.	Plants	55
6.6.	Results and Discussion.....	56
6.7.	Conclusions.....	64
7.	Biological Methods for Water Quality Determination	65
7.1.	Methods	65
7.2.	Biofilm Monitoring	66
7.3.	Macro-Invertebrate Survey.....	67
7.4.	Results	69
8.	Conclusions and Recommendations	70
8.1.	Common Conclusions	70
8.2.	Further Work for the SMART Follow-up Project.....	71
9.	References.....	72

List of figures

Figure 1: The Wadi Shueib.....	2
Figure 2: Wadi Azraq next Shoreia spring (Source: Grimmeisen, 2012)	2
Figure 3: View from Salt city into Wadi Shueib southwest direction (Source: Grimmeisen, 2012).....	3
Figure 4: Outcrop of Wadi as Sir limestone (A7) in a closed quarry in the beginning of Wadi Shueib (Photo: Grimmeisen 2011)	4
Figure 5: Study area in Jordan with major towns and roads (WERZ & HÖTZL 2007).....	4
Figure 6: Geological Map (WERZ & HÖTZL 2007).....	5
Figure 7: Crossection (B-B', red ellipse in b,) showing geological situation of Hazzir and Shoreia springs (modified after HAHNE et al. 2008).	7
Figure 8: Geological map (clips of Map sheets No. 3154 II/III & No. 3153 I/IV) showing cross section B- B' (modified after Hahne et al. 2008).	7
Figure 9: Stratigraphic stack of geological units included a, and b,. (modified after Hahne et al. 2008).....	8
Figure 10: Long term average annual precipitation in the Wadi Shueib catchment area. Rainfall Gauge AM0001 is located in the city Salt (RIEPL 2013).	8
Figure 11: Land use in the Wadi Shueib (Dropedia, 2013).....	9
Figure 12: Water sources, treatment and distribution in the Salt directorate (MWI, unknown).....	11
Figure 13: Maturation pond of As Salt WWTP (Zemann, 2012).....	13
Figure 14: Hazzir spring (Zemann, 2011).....	13
Figure 15: Yesidia wells pumping station (Zemann, 2012).....	13
Figure 16: Wadi Shueib dam and reservoir (Zemann, 2012).....	13
Figure 17: Frequency of wastewater tank emptying in As Salt according to a household survey (taken from Riepl 2012 after Borgstedt and Subah 2008)	14
Figure 18: Risk intensity map in the Wadi Shueib (Werz, 2006)	15
Figure 19: Groundwater protection zones of the four main drinking water springs in the Wadi Shueib catchment (Margane et al., 2009).	16
Figure 20: Hydro-chemical map of Wadi Shueib/Kafrein February 2012 (modified after Huttenlocher, 2012).....	20
Figure 21: Time series of major ions, EC and pH at Azzraq spring between 1960 – 2012 (Huttenlocher, 2012).....	21
Figure 22: Time series of major ions, EC and pH at Baqquriah spring between 1960 – 2012 (Huttenlocher, 2012).....	22
Figure 23: Spatial distribution of diatrizoic acid concentrations from 2008 – 2012	26
Figure 24: Spatial distribution of iopamidol concentrations from 2008 – 2012	27

Figure 25: Correlation of diatrizoic azid and nitrate for measurements from 2011 – 2012.	29
Figure 26: Topographical overview on Wadi Shueib springs catchment with special focus on Hazzir Spring	32
Figure 27: Historical data of nitrate concentration and bacteriological impacts (<i>E. coli</i>) of Hazzir Spring water. (Source: data provided by MWI, preparation by Grimmeisen).....	33
Figure 28: Fotos of Hazzir Spring (left) and monitoring devices. Box with monitoring devices (middle) and UV-Vis probe (right).....	34
Figure 29: Nitrate concentrations and <i>E. coli</i> findings of water samples taken weekly at Hazzir spring.....	34
Figure 30: Large scale analysis of nitrate time series of UV-Vis measurements at Hazzir spring.	35
Figure 31: Small scale analysis of Hazzir Spring time series indicating the direct impact of anthropogenic contamination (Grimmeisen, 2014 in preparation).	36
Figure 32: Hazzir spring monitoring during a rainfall event in March 2012 (modified after Grimmeisen, 2014 in preparation).....	37
Figure 33: Foto of a small brook in the central area of Salt city after a rainfall event in March 2012 (Grimmeisen, 2012).	38
Figure 34: Hazzir Spring monitoring during summer season in September 2012 (modified after Grimmeisen 2014 in preparation).	39
Figure 35: Salt water supply zones (Source: data provided by MWI, preparation by Grimmeisen).....	40
Figure 36: Sampling and analyses of indicator organisms in the lab . Fehler! Textmarke nicht definiert.	
Figure 37: Collection of macroorganisms at different locations.	44
Figure 38: The study area covers wadis pouring into the Jordan Valley and the Dead Sea, ...	46
Figure 39: Different groups of aquatic fauna show different level of tolerance to pollution in Jordan.based on biological, physical and chemical parameters	47
Figure 40: Ephydridae larvae, brine flies larvae from Karama area	51
Figure 41: Red Chironomidae larvae in Wadi Shueib reservoir site.....	51
Figure 42: Mayfly larvae (Epheneroptera larvae) from Wadi Shueib location.	51
Figure 43: Potamon freshwater crab from Wadi Hisban location.	53
Figure 44: Isopod fauna from Wadi Shueib location.....	53
Figure 45: Freshwater amphipod fauna from Wadi Hisban location.	53
Figure 46: Theodoxus (Neritaea) jordani species with eggs in Hisban location.....	54
Figure 47: Physa snail from Wadi Mujib dam location.....	54
Figure 48: Tubifex worms dwelling in muddy substrate (Wadi Mujib site).	55
Figure 49: Freshwater turbellaria worm (Shita spring site)	55
Figure 50: Arthrocnemum macrostachyum species from Karama creek, location.....	56

Figure 51: <i>Juncus rigidus</i> species from Karama area.	56
Figure 52: Plenty of <i>Melanopsis praemorsa ferussac</i> and <i>Theodoxus jordani</i> species were present in Jadoor spring.	61
Figure 53: Physa snails associated with gelatin eggs, mayfly, isopoda macro-bioindicators are also present in site. 2.	61
Figure 54: Weakly water polluted in the site 2 caused by human activities.	62
Figure 55: Tubifex worms which are found in polluted water (site 3).	62
Figure 56: High densities of <i>Chironomus</i> Sp. Coexisting with eggs at the site.	63
Figure 57: In Wadi Shueib stream, aquatic macrobioindicators.	64
Figure 58: Study area (modified after Royal Botanic Garden and Google Earth)	65
Figure 59: Biofilm sampler as used in the project area.	66
Figure 60: Location of the biofilm samplers.	67
Figure 61: Classification based on chances in invertebrate community (modified after Barndt, Bohn, Köhler, 1996)	68

List of tables

Table 1: Hydraulic classification of the geological formations in the Wadi Shueib (modified after MARGANE et al. 2002)	6
Table 2: Landuse in the Wadi Shueib	9
Table 3: Threshold values for some drinking water quality parameter in Jordan (JISM, 2001)	18
Table 4: Application of the investigated pharmaceuticals	24
Table 5: Detections for diatrizoic acid and iopamidol for all sampling points in the Wadi Shueib. Red boxes mark the positive detections. Limit of detection (LOD) was 10 ng/l.	25
Table 6: Pharmaceutical detections in the Wadi Kafrein	28
Table 7: Juxtaposition of pharmaceutical detections, <i>E. coli</i> and nitrate concentration at different groundwater resources in Wadi Shueib and Wadi Kafrein.	30
Table 8: Macrobioindicators groups taxonomy (table part 1 of 2)	47
Table 9: Macrobioindicators groups taxonomy (table part 2 of 2)	49
Table 10: Jordanian Biomonitor System for Watercourses (JBSW).	56
Table 11: Main macroinvertebrate sample locations	67

Acronyms

BOD = Biological oxygen demand

COD = chemical oxygen demand

DOC = Dissolved organic carbon

DOS = Department of Statistics, Jordan

GIZ = Gesellschaft für Internationale Zusammenarbeit

JOD = Jordan Dinar

JUA = Jordan University, Amman

KIT = Karlsruhe Institute of Technology

LJV = Lower Jordan Valley

MCM = Million Cubic Meter

MWI = Ministry of Water and Irrigation

MWI = Ministry of Water and Irrigation

SOP = Standard operation procedure

TOC = Total organic carbon

TZW = Water Technology Centre, Karlsruhe, Germany

WAJ = Water Authority of Jordan

WW = wastewater

WWTP = Wastewater treatment plant

1. Introduction

Author: Moritz Zemann

1.1. Groundwater Pollution in Urban Areas

Sewer leakages are identified as one of the main sources of urban groundwater contamination (Eiswirth, 1995; Sacher F., 2002). Reports from all over the world are giving examples for the deterioration of water quality due to leaking sewer pipes like Klinger (2007) or Wolf (2006) for the German city of Rastatt, Powell et al. (2003) for Nottingham and Birmingham in the UK or Linz in Austria (Fenz et al., 2005). An example for groundwater contamination due to wastewater infiltration in an arid Arabian country is given from Foppen (2002) for Sana'a in Yemen.

Typical urban contaminants are bacteria like *E. coli* or different nitrate species originating from human feces and boron, which is used in detergents for bleaching as per-borate. Anthropogenic trace substances like pharmaceuticals or artificial sweeteners could be detected as well in the local groundwater of Rastatt (Wolf et al., 2012). Detections of those substances in drinking water, e.g. pharmaceutical residues at the Berlin waterworks (Heberer, 2002), already indicate the closed cycle between groundwater recharge, abstraction and reuse.

Those substances do not occur naturally in the aquatic environment, so they can be used as qualitative trace substances for groundwater contamination to the groundwater.

1.2. Research on Groundwater Pollutions within the SMART-Project

This report deals with the problem of urban groundwater contamination. As the SMART 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 catchment of the Wadi Shueib. The following report gives an overview on different methods to investigate the qualitative and quantitative impact of urban areas on the local aquifer system which can be divided into three main aspects:

- Water sampling and analysis for wastewater indicating substances as bacteria, pharmaceuticals and nitrate (chapter 3 & 4)
- Implementation of online monitoring systems (chapter 5)
- Biological indicators for water quality (chapter 6 & 7)

Whilst chapter 3, 4, 5 and parts of chapter 6 were focusing in the Wadi Shueib. chapter 7 shows the applicability of the method in another part of the project area.

2. SMART IWRM Study Area Wadi Shueib

Authors: Moritz Zemann (KIT) & Felix Grimmeisen (KIT)

2.1. Topography

Wadi is the arabic term traditionally referring to a valley, which also refers as geological and geographical term to a dry riverbed that contains water only during times of heavy rain or simply an intermittent stream (Wikipedia.org).

The Wadi Shueib (also: Wadi Shu'aib or Wadi Shuayb) is a Jordanian sub-catchment of the Lower Jordan River Basin at the eastern slopes of the Jordan Rift Valley, located about 30 km northwest of Jordan's capital Amman (see Figure 1). The geographical extension of the study area coincides an area of 198 km² upstream of the Wadi Shueib dam, characterized by a steep relief with elevations ranging from -200 m bsl in the southwest up to 1.240 m northeast in the Western Highlands (RIEPL 2013, WERZ et al. 2009). It is administrative belonging to the Balqa governorate including the cities of Salt and Fuheis in the upper part of Wadi Shueib (see Figure 2 and Figure 3).



Figure 1: The Wadi Shueib



Figure 2: Wadi Azraq next Shoreia spring (Source: Grimmeisen, 2012)



Figure 3: View from Salt city into Wadi Shueib southwest direction (Source: Grimmeisen, 2012)

2.2. Geological Setting

The geological setup of the study area is predominantly related to the Jordan Rift Valley fault system and the Dead Sea – Jordan Valley Transform Fault, a left-lateral strike-slip fault with a total amount of 105 km left-lateral movement (QUENNELL 1959 in HAHNE et al. 2008) in. The study area lies on the eastern side of the Dead Sea – Jordan Valley Transform Fault, which connects the active sea-floor spreading centre of the Red Sea in the south to Turkey in the north (BASEM & MUNEIZEL 1998). By headward erosion of the main wadis into the Arabian plateau following subsidence and faulting of the Dead Sea – Jordan Valley area, the geomorphology of the study area expresses its tectonic structure (QUENNELL 1956 in BASEM & MUNEIZEL 1998).

The outcropping rocks in the study area are all of sedimentary origin and range from Jurassic, Cretaceous, Tertiary to Pleistocene and recent (< 2 Ma) in age. After HAHNE et al. (2008) the study area is located at a junction of two major faults, which show dextral movements in broad zones, whereas hundreds of minor faults at different scales can be found. Expressed by numerous folding, block faulting and strike-slip faulting in various scales from kilometers to meters the prevailing fault directions are NW-SE and NNE-SSW, whereas the general trend of anticlines and synclines is NE-SW (BASEM & MUNEIZEL 1998, WERZ et al. 2009)

The Wadi Shueib structure a fold belt with a general trend of their axes in NW-SE direction (Figure 6), is one of the two mentioned major faults and is the dominating structural elements in the study area (WERZ et al. 2009). Most sedimentary rocks comprise of limestones, dolomites and marls of Upper Cretaceous and are summarized as *Ajlun* and *Belqa* Groups (Cenomanian to Maastrichtian). The *Ajlun* Group (Shueib, Hummar, Fuheis, Naur) consists of approximately 350 - 400 m thick interbedded limestones, marly limestones and dolomitic limestones and provides basis of the investigated aquifer complexes (Figure 6 & Figure 7 & Figure 8). The sequence of the *Belqa* Group (Wadi as Sir, Wadi Um Ghudran, Amman al Hisa) includes mainly limestones intercalated by thick-bedded chert, chalk, marls, silicified limestones and phosphatic horizons (Figure 4). The Kurnub sandstone of Lower Cretaceous age builds the footwall of Ajlun and Belqa Groups, but rarely disclosed at the fault zone of the Wadi Shueib structure (WERZ et al. 2009).



Figure 4: Outcrop of Wadi as Sir limestone (A7) in a closed quarry in the beginning of Wadi Shueib (Photo: Grimmeisen 2011)

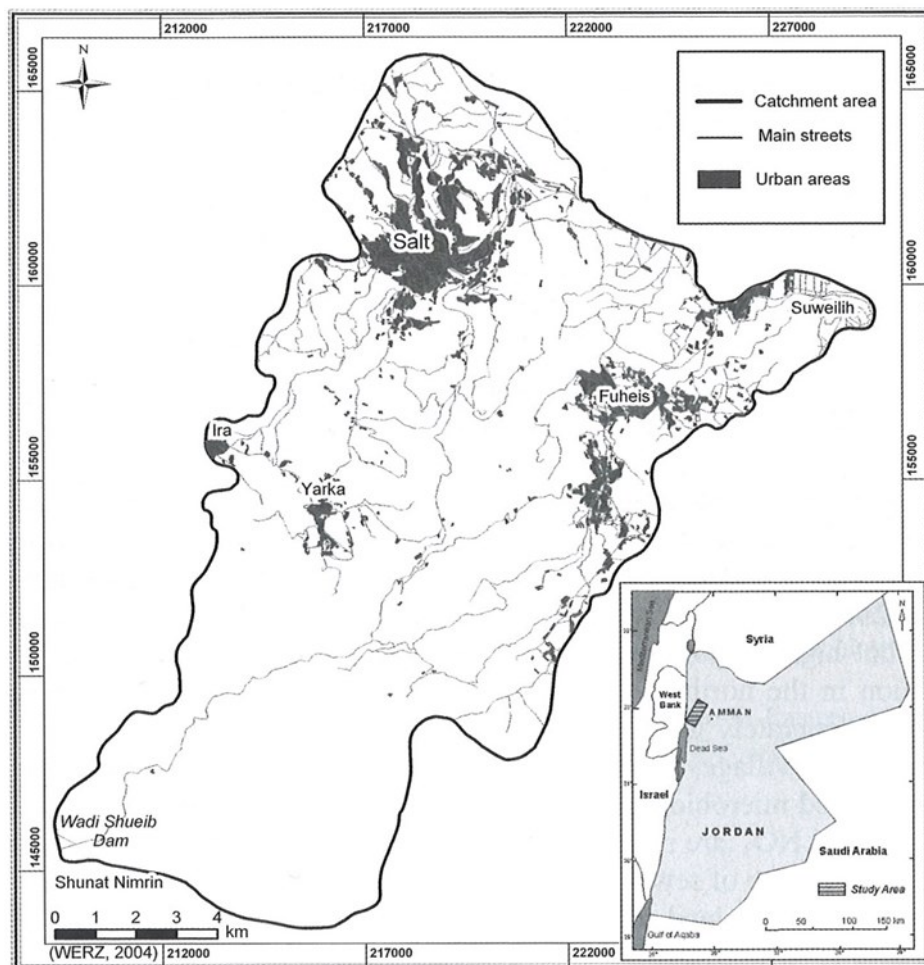


Figure 5: Study area in Jordan with major towns and roads (WERZ & HÖTZL 2007)

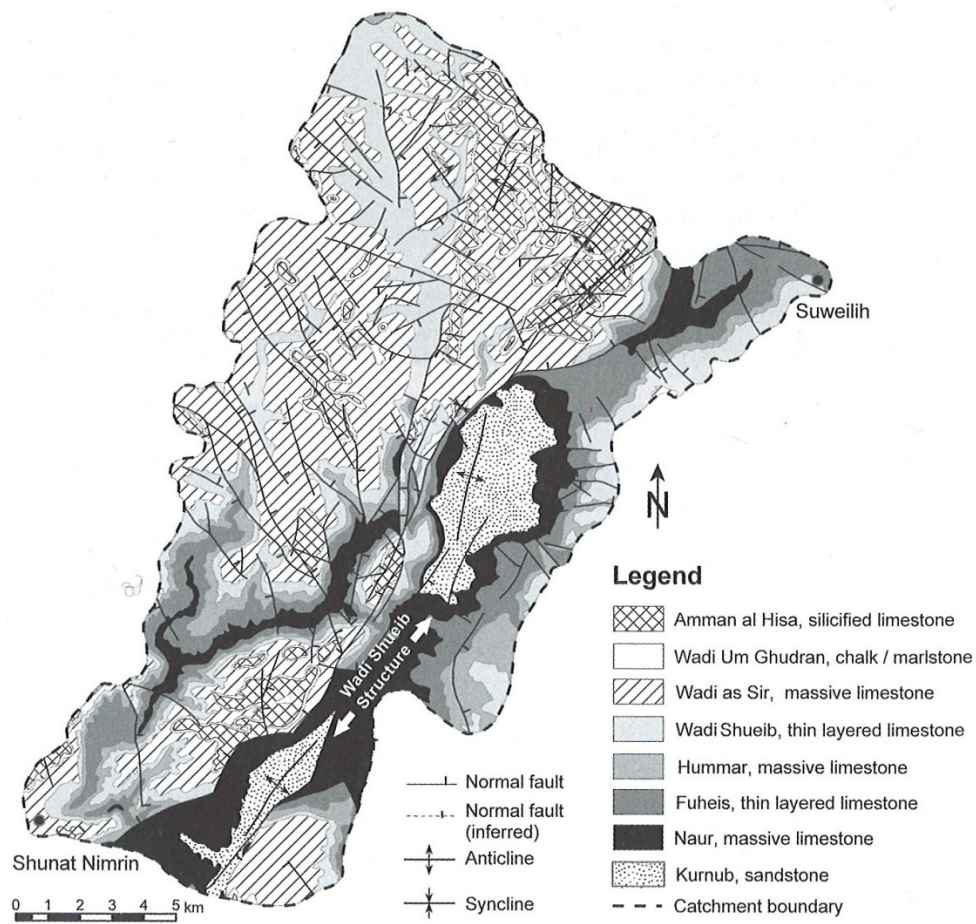


Figure 6: Geological Map (WERZ & HÖTZL 2007)

2.3. Hydrogeology

In the study area the near-surface formations consist of sedimentary carbonate rocks and therefore are mainly karst aquifers with differing hydraulic conductivities (Table 1). The Ajlun Group is divided into sub-unit aquifer complexes with a lower aquifer complex in the lower part (Cenomanian) of the Ajlun Group in the Hummar Fm. (A4) and Naur Fm. (A1/2). The uppermost unit of the Ajlun Group and the lower part of Belqa Group (Upper Turonian to the Campanian-Maastrichtian) makes the aquifer complex (A7/B2), which forms in general the most important aquifer in Jordan because of its vast extent and its relatively high permeability (MARGANE et al. 2002). The Shueib Formation (A 5/6) is composed of calcareous siltstone, mudstones and shales which act as main aquicludes separating between the two sub-aquifer complexes (GUTTMAN 2009).

Table 1: Hydraulic classification of the geological formations in the Wadi Shueib (modified after MARGANE et al. 2002)

Geological formation	Aquifer characteristic	Hydraulic conductivity* [m/s]	Lithology (thickness in Wadi Shueib)*
Amman Fm. (B2) Wadi Ghudran Fm. (B1) Wadi as Sir Fm. (A7)	Aquifer (A7/B2)	2.0 E-05	limestone marl, limestone limestone [total 140-265 m]
Shueib Fm. (A 5/6) Hummar Fm. (A4) Fuheis Fm. (A3) Naur (A 1/2) [average]	Aquitard Aquifer Aquitard Aquifer	1.0 E-09 2.0 E-05 1.0 E-09 1.0 E-05 [7.0 E-06]	marl (50-60 m) limestone (40-65 m) marl (50-80 m) marl, limestone (86-200 m) [total ~240-400 m]
Kurnub	Aquifer	3.0 E-05	sandstone (150-350 m)

*after MARGANE et al. (2009)

In the upper part of Wadi Shueib several springs are draining the Upper Cretaceous limestone aquifer complex with the Amman/Wadi as Sir Aquifer (A7/B2) as local most important sequence. The discharge of these springs has been rather constant over time, which indicates on the one hand the large extent of the catchments and large reserves of groundwater, but it must be taken into account on the other hand, that they do not form continuous water bodies but perched water lenses with extension into the eastward highlands (GUTTMAN 2009). Four main springs provide basis of the water supply of the cities Salt, Fuheis and Mahis in the upper Wadi Shueib (cf. chap. 5.). The springs of the A7/B2 aquifer are generally karst springs with appreciable discharges and show typically an immediate reaction to heavy rainfall events.

Through the compressive tectonic setting within the study area the sub-unit aquifers are connected with each other by fractures, main faults and fault zones (WERZ et al. 2009) that makes them difficult to be hydrogeologically fully defined, which is important e.g. for protection measures. The Figure 7, Figure 8 and Figure 9 show a clip of the geological setting in the upper Wadi Shueib and additionally a cross-section by HAHNE et al. 2008 that demonstrates how the local tectonic setting interferes with the complex hydrogeological conditions of the karst springs.

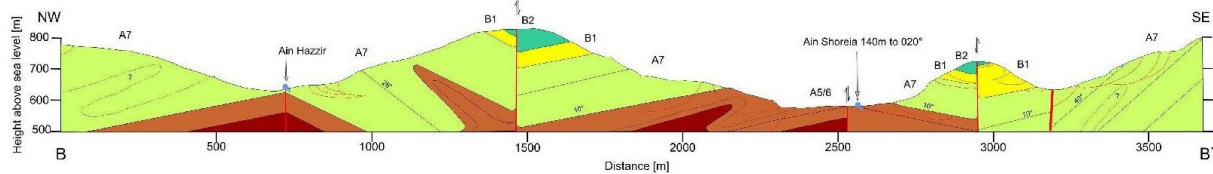


Figure 7: Crossection (B-B', red ellipse in b,) showing geological situation of Hazzir and Shoreia springs (modified after HAHNE et al. 2008).

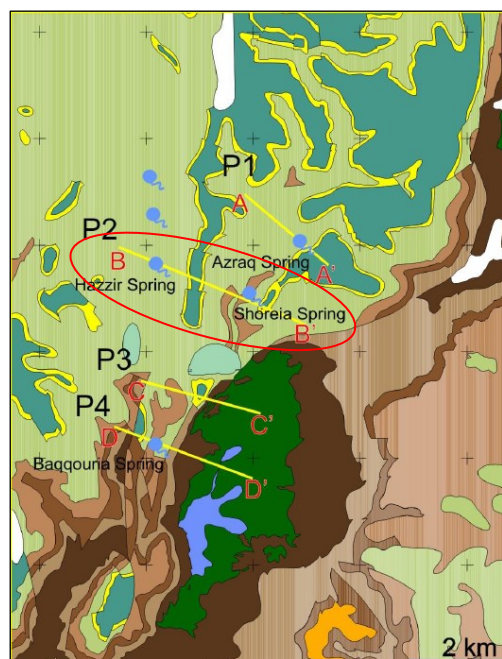


Figure 8: Geological map (clips of Map sheets No. 3154 II/III & No. 3153 I/IV) showing cross section B-B' (modified after Hahne et al. 2008).

Formation	Group
40	Belqa
20-50	
80-150	Ajlun
60	
50	
80	
200	Kurnub Sandstone
250-300	
420-450	Azab (undifferentiated)

Figure 9: Stratigraphic stack of geological units included a, and b,. (modified after Hahne et al. 2008)

2.4. Climate

The climate in the region is semi-arid to arid and strongly influenced by the Mediterranean circulation with dry summers without precipitation and winters with quite few relatively heavy rainfall events usually in the months from October to March. Annual precipitation varies from 800 mm/yr in the higher altitudes and below 200 mm in the Jordan Valley. Figure 10 characterizes the extremely varying climate conditions depending on the altitude within the Wadi by considerably decreasing annual precipitation rates towards the Jordan Valley. Temperatures range from around 12°C average daily minimum in January up to above 40°C average daily maximum in July and show a contrary trend towards the Jordan Valley compared to annual precipitation (RIEPL 2013, WERZ et al. 2009).

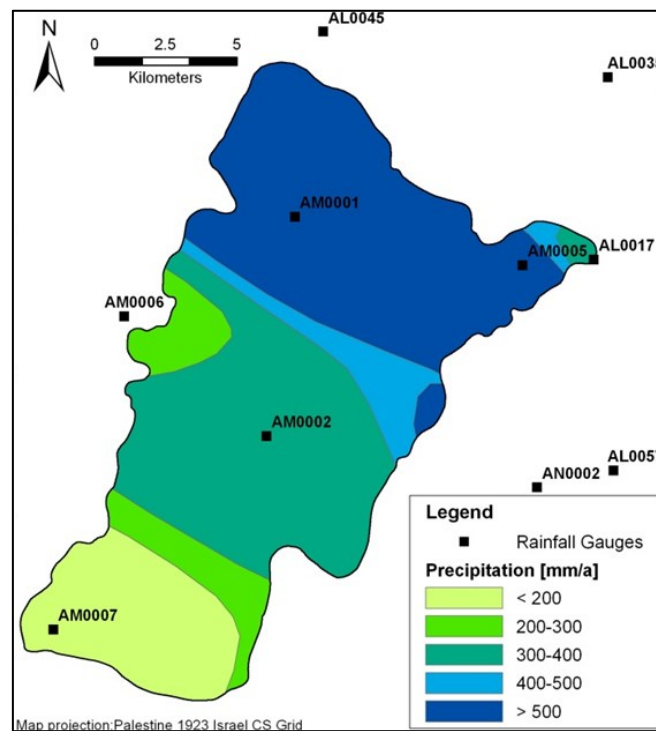


Figure 10: Long term average annual precipitation in the Wadi Shueib catchment area. Rainfall Gauge AM0001 is located in the city Salt (RIEPL 2013).

2.5. Landuse

Wadi Shueib belongs to the Balqia Governorate with five distinct municipalities (As-Salt, Fuheis, Ira, Yarka, Mahis). Its total area is 198 km². The total population is 131 000 (DOS 2011). The population density as well as most agricultural activities is concentrated in the higher parts (Dropedia, 2013). Due to the climatic conditions, the land use in Wadi Shueib is characterized by a distinct separation of the vegetated and populated north-eastern part from the scarcely used, dry and rocky south-western part. Agricultural activity in the Wadi Shueib is not extensive, due to the steep topography and the shallow soils (Dropedia, 2013). The actual shares of land use (see Figure 11 &

Table 2) can be divided following a remote sensing classification from Werz (2006) improved by Dropedia (2013):

Table 2: Landuse in the Wadi Shueib

Werz (2006):	Dropedia (2013):
- Urban area: 13 km² - Crops area: 25 km² - Orchards area: 12 km² - Forrest area: 12 km² - Bare soil & rock area: 136 km²	- Urban area: 17.6 km² - Dense vegetation area: 5.9 km² - Loose vegetation area: 59.1 km² - Bare soil & rock area: 115.1 km²

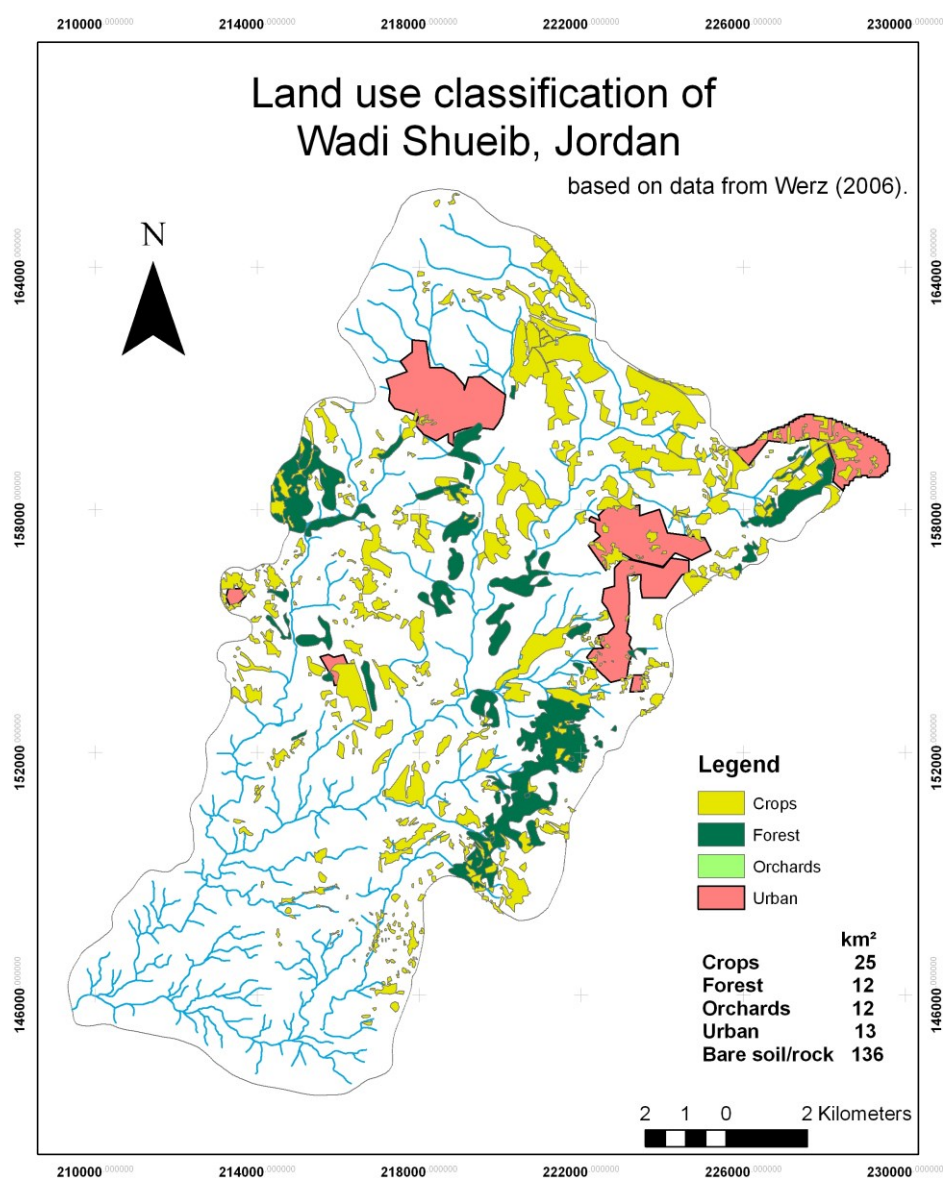


Figure 11: Land use in the Wadi Shueib (Dropedia, 2013).

2.6. Local Water Resources

The water supply system in the Wadi Shueib including all sources and the treatment facilities is shown schematic in Figure 12. The springs, wells and treatment plants are described in detail in the following chapters 2.6.1, 2.6.2 & 2.6.3.

The four main springs Azzraq, Baqquriah, Hazzir and Shoreia provide the basis for the water supply for the city Salt. The Azzraq spring is used for the water supply of Fuheis. The water of all five springs is purified at the Shoreia spring treatment plant before supplied to the customers (Margane et al., 2009).

The investigated area is drained by a dense wadi stream net whereas the Wadi Shueib course acts as a receiving stream for the entire area, and discharges in the Wadi Shueib dam reservoir in the southwestern part of the area (Werz, 2006).

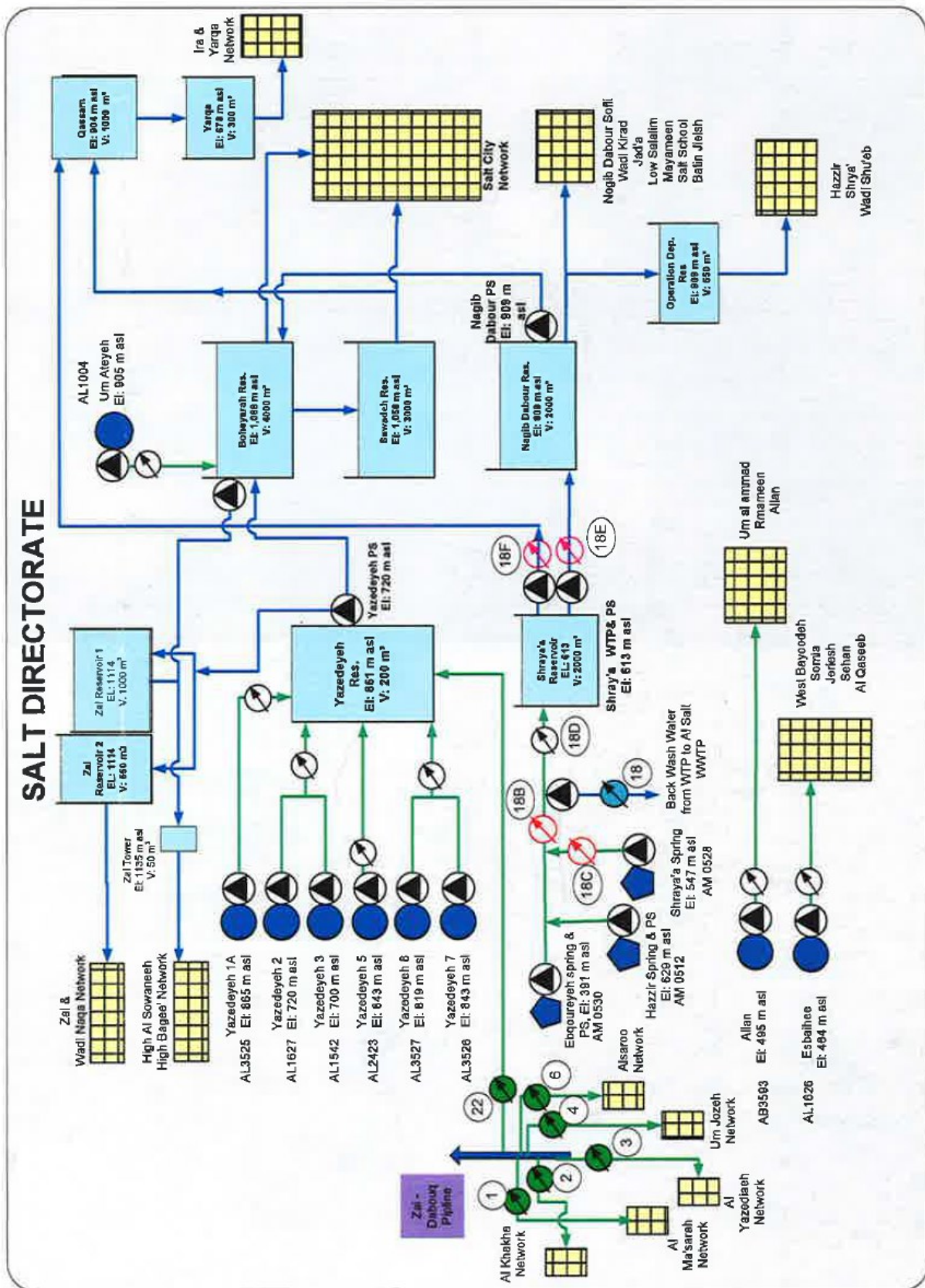


Figure 12: Water sources, treatment and distribution in the Salt directorate (MWI, unknown)

2.6.1. Springs in the Wadi Shueib

Hazzir spring

The Hazzir (Figure 14) spring is a fault spring discharging within the Shueib Formation. The spring is fed by water ascending at a fault zone from the Hummar Formation (A4). The spring shows a relatively constant discharge amount and is not affected directly by heavy rainfall. It is assumed that the spring water originates deep in the aquifer since the discharging spring water is relatively cool during summer and relatively warm during winter (Werz, 2006). The average discharge is around 101.5 m³/h with a total of 0.89 MCM per year (Margane et al., 2009).

Baqquriah spring

The Baqquriah spring is located in a highly fractured faulted area within the Wadi as Sir Formation discharging at the contact to the lower permeable Shueib Formation (A5/6) from enlarged cavities. The groundwater flow is directed from the outcropping recharge zone of the Wadi as Sir Formation north and northeast of the spring. The spring shows turbidity six hours to one day after heavy rainfall events. The average discharge of Baqquriah is 383 m³/h and a total of 3.36 MCM per year (Margane et al., 2009).

Azzraq spring

This spring flows between the contact of massive limestone and a thin marl layer within the Wadi as Sir formation (Werz, 2006). The water is pumped to the Shoreia treatment plant and pumped back after the treatment first to Azzraq spring and then to Fuhheis. It is used for the drinking water supply of Fuheis. The average discharge is 235 m³/h with means a total flow of 2.06 MCM per year (Margane et al., 2009).

Shoreja Quelle

Shoreja spring is located 5 km lying 595 m above the sea level, southern to the city Salt,. It is flows from the Wadi as Sir formation (A7). The spring is a contact spring appearing at the edge of Wadi as Sir formation and the underlying Wadi Shueib formation (A5/6). The discharge of Shoreja spring indicates heavy variations between a minimum of 45 m³/h and a maximum of 325 m³/h between 1995 and 2005. The mean discharge is about 143,8 m³/h (Dropedia, 2013). The water is pumped to the Shoraja treatment plant and supplied to the local drinking water system.

Farkha spring

This spring is located several hundred meters upstream to Hazzir spring next to the Wadi stream. Its average discharge is 8.0 m³/h (Margane et al., 2009) mounting to 70 000 m³/a. The spring is not connected to the drinking water supply system and therefore discharged unused into the wadi stream.



Figure 13: Maturation pond of As Salt WWTP (Zemann, 2012)



Figure 14: Hazzir spring (Zemann, 2011)



Figure 15: Yesidia wells pumping station (Zemann, 2012)



Figure 16: Wadi Shueib dam and reservoir (Zemann, 2012)

2.6.2. Wells in the Wadi Shueib

Yesidia wells

The annual 1.21 MCM produced from the Yesidia well field (Figure 15) are primarily allocated for supplying the rural communities in the Zai area to the north. But in high demand times the system allows this water to be pumped to the Salt network (Riepl, 2012).

Um Attija:

Um Attija well is located in the middle of Salt protected by a several hundred square meter wide, fenced and undeveloped protection zone. It is the only well that is used directly for water supply. Its average production yield is about 0.33 MCM per year (Riepl, 2012).

2.6.3. Water Uses and Demand

The majority of the households rely on municipal water supply. Although the water amount would be sufficient to cover the local demand if the quality was acceptable, the municipal water supply was intermittent during the last decades, often providing water only once per week (Riepl, 2012). The water consumption in the Al Balqa Governorate is estimated around 86 l/capita for domestic uses. However, there are high infrastructure losses. The average Unaccounted for Water (UFW) between 1997 – 2004 was estimated for the area by the WAJ with around 57.2 % of the annual network supply (Riepl, 2012).

2.7. Wastewater

2.7.1. Occurrence & Treatment

There are two wastewater treatment plants in the study area. One for the city of Fuheis and the other for Salt. The Salt WWTP (Figure 13) offers a treatment capacity of 7 700 m³/d and serves a population of 49 950 which means a connection degree of 66,6 %. The Fuheis treatment plant has a total capacity of 2 400 m³/d and treats the wastewater of 17 350 people, which is equal to a connection degree of 69,4 %. However, it must be mentioned that the MWI has undertaken considerable efforts to increase the sewer connectivity in the last years (Riepl, 2012).

The sewer network inside the city as Salt is in good conditions with few breakages and leakages. However, a lot of people still use septic tanks to avoid paying the costs of a sewage connection. All smaller villages in the Wadi are not connected to one of the plants and therefore rely solely on septic tanks which need to be emptied by trucks regular. This is due to the high costs and the difficult topography conditions (Margane et al., 2009).

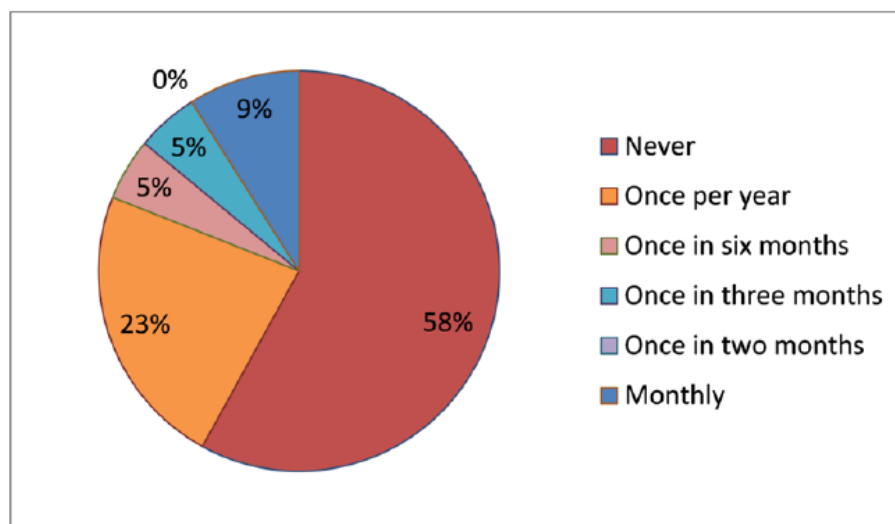


Figure 17: Frequency of wastewater tank emptying in As Salt according to a household survey (taken from Riepl 2012 after Borgstedt and Subah 2008)

Three different types of cesspits are available on the Jordanian market ranging from complete sealed ones (which require a regular emptying) to permeable chambers, where the entire content infiltrates into the groundwater. Suction truck drivers charge around 6 JOD/m³. Families which cannot afford

the money often dig new cesspits next to full ones and therefore endangering the environment. A questionnaire done by the GIZ in cooperation with the MWI indicated that a significant number of households never pump sewage sludge from their cesspools (Figure 17). There are also reports of leaking or overflowing cesspits. The whole fact has as well large implications on the health and hygiene situation (Margane et al., 2009).

2.7.2. Wastewater Related Problems

The main share of Hazzir and Shoreja spring groundwater contribution zone lies within the urban areas of As Salt. The catchment zone for Baqquria is located downstream to the city (Figure 19). Due to the geological conditions (compare chapter 2.2) with outcropping karstified limestone, the groundwater in the whole area is highly vulnerable to anthropogenic hazards which is as well the result of a remote sensing analyze done in Wadi Shueib (Figure 18) by Werz (2006).

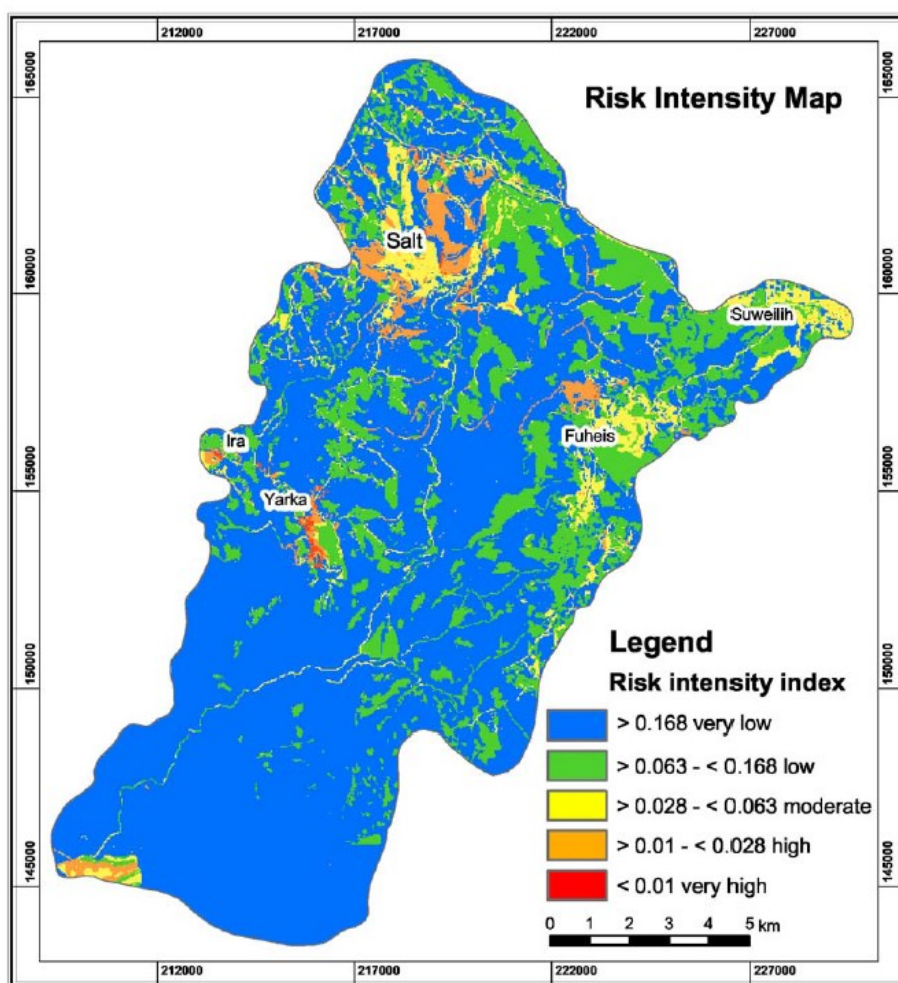


Figure 18: Risk intensity map in the Wadi Shueib (Werz, 2006)

All springs and wells in the Wadi Shueib are sampled on a monthly base by the local water authority (WAJ). Especially Hazzir and Baqquria spring hereby sometimes exceed the Jordanian drinking water standard for nitrate with an increasing trend from 2002 – 2006. A special focus on the contamination of Hazzir spring is put in chapter 5. A bacteriological impact was measurable at both springs as well. However a single day sampling campaign in 2007 indicated no problems with heavy metals (Margane

et al., 2009). As major parts of the groundwater contribution zones of those springs are covered by urban areas of the city Salt, leaking sewage and cesspits are assumed to be a main source for contaminations

Other groundwater hazardous activities like disposals from slaughterhouses and careless oil spills have been reported as well (Riepl, 2012).

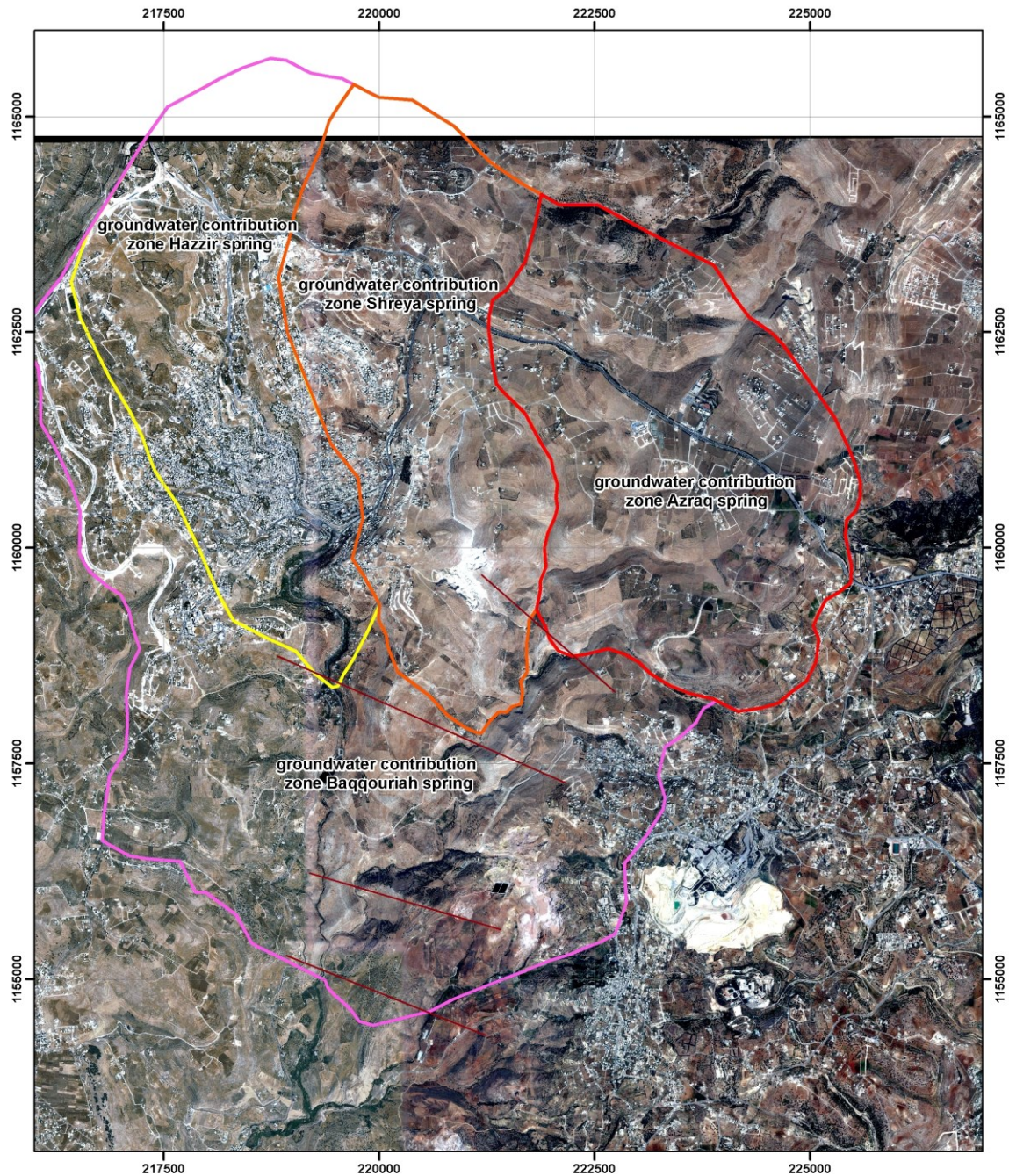


Figure 19: Groundwater protection zones of the four main drinking water springs in the Wadi Shueib catchment (Margane et al., 2009).

3. Monitoring of the Water Quality in the Wadi Shueib

Authors: Moritz Zemmann (KIT), Leif Wolf (KIT), Ali Sawarieh (KIT), Nayef Seder (MWI), Natalie Schmidt (TZW), Andreas Thiem (TZW)

3.1. Water Sampling Campaigns between 2008 and 2012

Between autumn 2008 and spring 2012, overall 4 sampling campaigns took place in the Wadi Shueib/Kafrein to assess the water quality of the groundwater, the surface water and the wastewater treatment plants. Beside the typical water chemistry and bacterial contamination, a focus was laid on emerging pollutants, especially pharmaceuticals and x-ray contrast media. The results for these substances are presented in chapter 4.

Samples were taken from the main springs (Hazzir, Farkha, Azzraq, Baqquria, Shoreja, Tujabyl) and wells (Um Attija, Yesidia) which almost all were used for drinking water supply in the area as well as from the local WWTP (Fuheis, Salt, Es Sir) and the dams (Shueib and Kafrein reservoirs), collecting the streams at the outlet of the Wadis for further use in agriculture in the Jordan Valley. The two wells AN1025 and AN1026 are located downstream to the Kafrein dam within several 100 m distance.

At each location, samples were taken for pharmaceuticals and major cations and anions. For groundwater in the Wadi Shueib, additional samples for *E. coli* and the total coliform contamination were taken as well. Bottles for sampling were rinsed three times with the sampled water before taking the sample, except for the coliforms, which were not rinsed due to the standard operation procedures (SOP) of the local laboratory. Additional to the water chemistry, physio-chemical parameters (pH, oxygen, temperature, redox, conductivity) were measured in situ.

3.2. Investigated Substances

3.2.1. Major Ions

In addition to the pharmaceuticals, cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+ , NH_4^+) and anions (hydrocarbonate, sulfate, phosphate, nitrate, nitrite, borate) were analyzed. Therefore, all samples were filtered with cellulose mixed ester (CME) filters (Roth, screen width: 0.45 μm). Cations samples were acidified with concentrated nitric acid (60%) using 1 ml per 100 ml of sample and shipped to Germany for analysis in the KIT (Karlsruhe Institute for Technology) laboratories by ion chromatography following DIN 38406. Cations analyses were conducted at the laboratories of the Water Authority of Jordan (WAJ) following their standard operation procedure (SOP) concerning storage and analysis. Hydrocarbon analyses took place within 24 hours after sampling.

3.2.2. Coliforms

Sampling and analysis for *E. coli* and total coliforms was conducted following the SOP of the WAJ laboratories.

3.2.3. Physio-Chemical Parameters

During the whole sampling campaign, physio-chemical parameters were measured in situ. Where possible the measurement took place directly in the water. If not directly accessible (like WWTP

effluents), the measurement took place inside a bucket, used for sampling. The listed parameters were conducted with a WTW Multi 3430 measurement device using the probes as followed:

Electric conductivity, Temperature	TetraCon 925
Redox, Temperature	SentTix OPR 900
Dissolved Oxygen, Temperature	FDO 925 IDS
pH, Temperature	SenTix 980

3.2.4. BOD, COD, TOC, DOC

Selected sites as well as the WWTP effluents were chosen to be analysed for the biological oxygen demand (BOD₅), the chemical oxygen demand (COD₅) the total organic carbon (TOC) and the dissolved organic carbon (DOC). The analyses were conducted in the WAJ laboratories according to the SOP. Overall water quality by analysis of chemical parameters

3.3. Local Regulations

As most wells and springs are used for drinking water purposes, their quality was assessed due to the Jordanian Standard for drinking water – JS 286 (see table 1).

Table 3: Threshold values for some drinking water quality parameter in Jordan (JISM, 2001)

Substances and Properties That Affect the Taste of Drinking Water			
Properties	Symbol	Permissible Level mg/liter	Maximum Level* mg/liter
Hydroxide	pH	6.5-8.5	-
Total Dissolved Solids	TDS	500	1500
Total Hardness	TH	300	500
Chemical Detergents	LAS (MBAS)	0.2	0.5
Ammonium	NH ₄	0.5	0.5
Aluminum	Al	0.1	0.2
Manganese	Mn	0.1	0.2
Iron	Fe	0.3	1.0
Copper	Cu	1.0	1.5
Zinc	Zn	3.0	5.0
Sodium	Na	200	400
Chloride	Cl	200	500
Sulfates	SO ₄	200500	
* In the absence of a public water source of better quality			

The limit for nitrate is 50 mg/l in drinking water whilst the allowable number for total coliforms is 1.1/100 ml and for *E. coli* is 0/100 ml using the MPN method (JISM, 2001).

The effluent quality of the WWTP's was compared to the Jordanian Standard for reclaimed domestic water JS 893. This again is divided by the different reuse options, with increasing restrictions from discharge into streams to reuse for artificial aquifer recharge and reuse in agriculture (JISM, 2002).

3.4.Status Quo February 2012

Taken the hydro-chemical measurements for all sampled locations for February 2012 a map has been provided (figure 1) to give a general overview on major ions, mineralization, EC and pH.

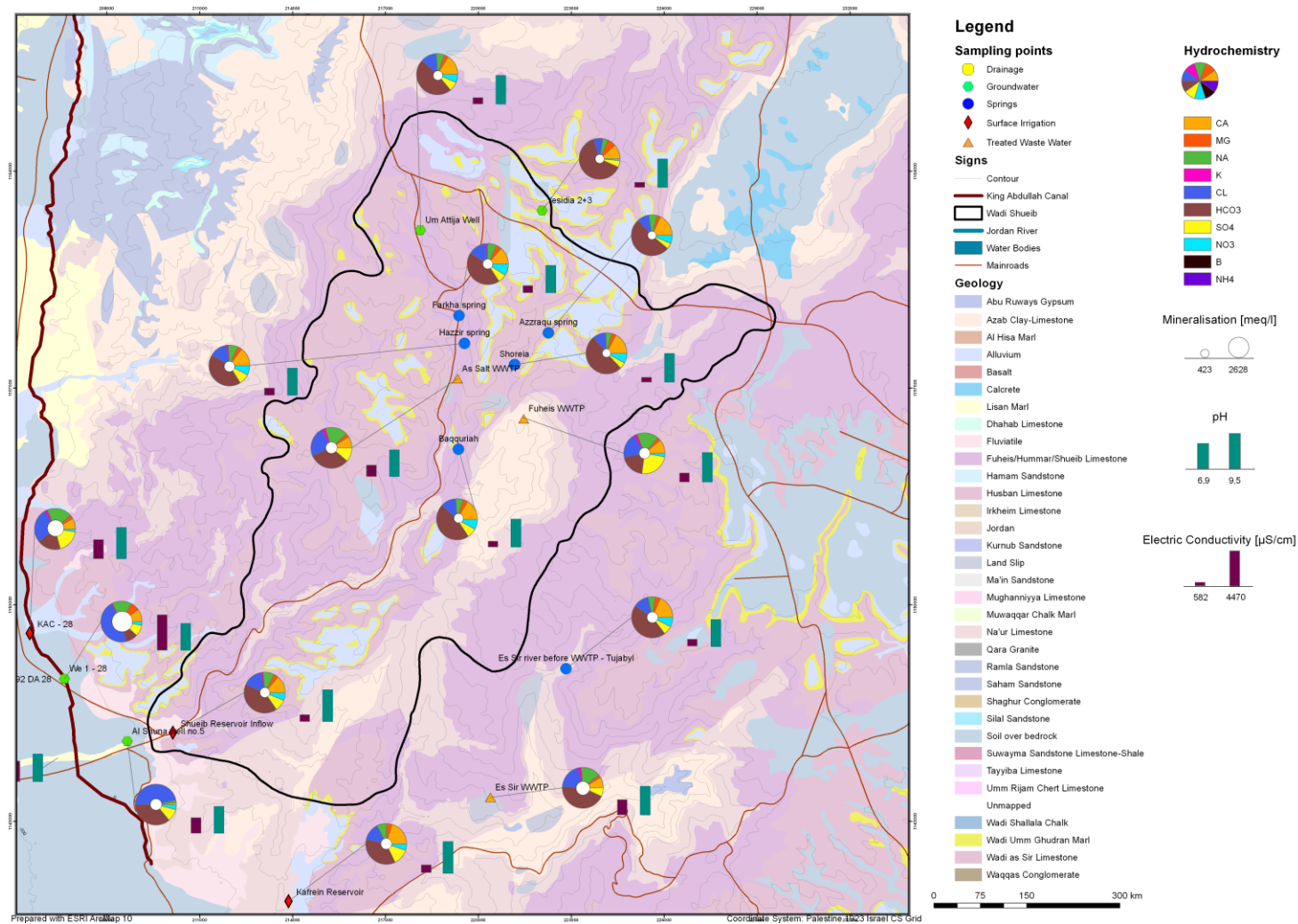


Figure 20: Hydro-chemical map of Wadi Shueib/Kafrein February 2012 (modified after Huttenlocher, 2012).

3.5. Historical Data and Recent Trends

Exposing the history of ion concentrations in Wadi Shueib wells and springs since the early 70s until today (see Figure 21 & Figure 22) indicates no distinct trend towards any increasing pollutions or improvement of water quality. Anyhow, time series indicates the origin of the water source (compare Figure 21 & Figure 22). Baqquriah, Hazzir, Shoreja, Farkha spring and Um Attija well are all located inside or downstream to the city with continuous high nitrate (30 – 60 mg/l) concentrations and significant *E. coli* detection (compare Table 7chapter 4.5). In contrast, Azzraq spring located sideways to the city of Fuheis and the Yesidia wells upstream to Salt show only minor impact of nitrate (< 30 mg) and no or low *E. coli* pollution. Increasing trends like the EC at Baqquriah (see Figure 22) rising 500 $\mu\text{S}/\text{cm}$ in the early 90s up to around 700 $\mu\text{S}/\text{cm}$ in 2012 seems not to reach a hazardous level within the next decades.

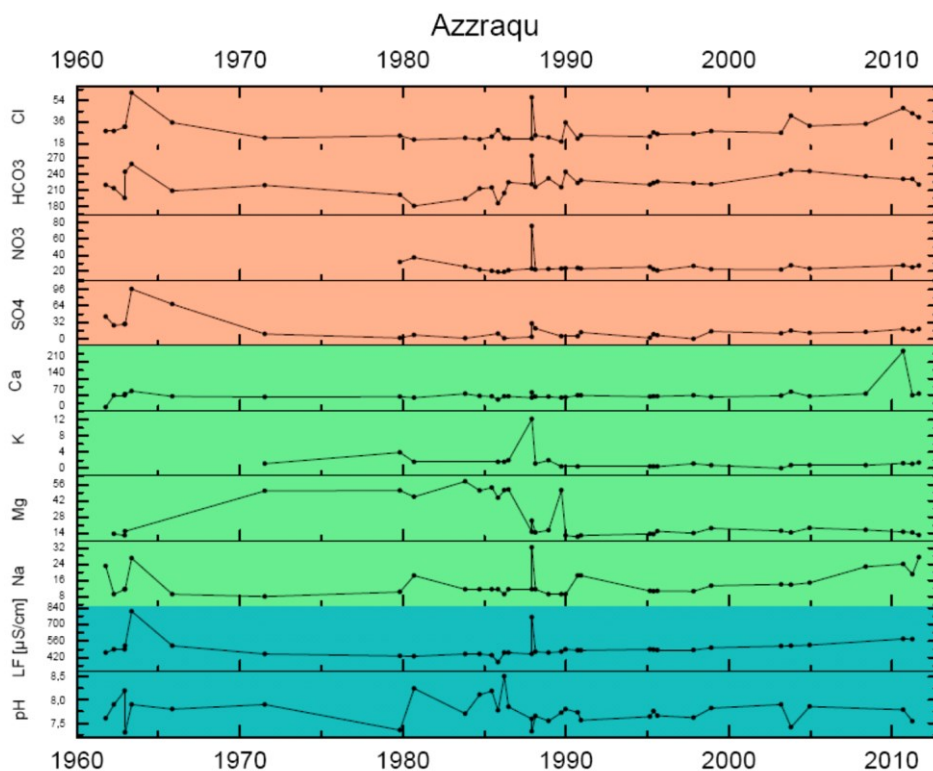


Figure 21: Time series of major ions, EC and pH at Azzraq spring between 1960 – 2012 (Huttenlocher, 2012).

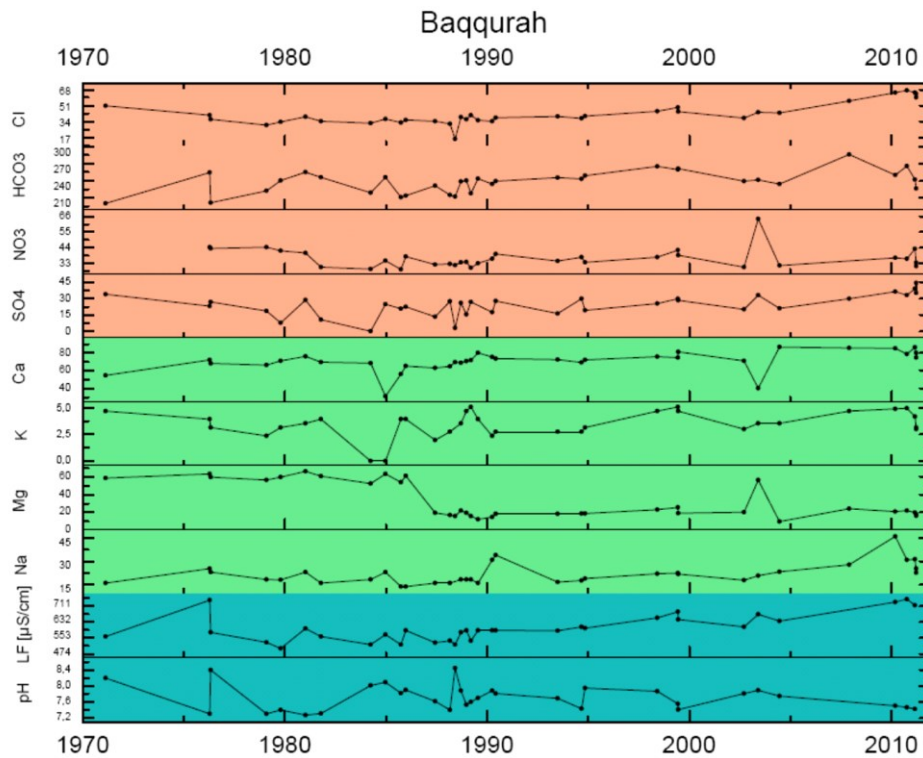


Figure 22: Time series of major ions, EC and pH at Baqqurah spring between 1960 – 2012 (Huttenlocher, 2012).

3.6. Conclusions

Concerning the overall water quality, all water samples are below the governmental limits for drinking water. Single events exceeded this limits (like nitrate at Farkha spring) but never for the drinking water sources. This applies as well to the effluent quality of the WWTP.

Though, it must be stated that most springs indicate nitrate concentrations on a constant high level, even if this is not outrunning the threshold. As well, almost all groundwater sources have positive detections for *E. coli*. Since the water is treated before supplied to the houses this should not cause any problems, but as *E. coli* typically originates from human feces the impact is obvious. Nitrate may origin from leaking sewers or broken cesspits as well as from agriculture. While both, nitrate and *E. coli* are indicators for the anthropogenic influence it therefore should be considered to take measures for any further reduction.

Regarding to the Jordanian standards for drinking water, the water resources in the Wadi Shueib and Kafrein all fit to the local limits. Some places like Farkha and Tujabyl springs may exceed them for single events but as they are not used for drinking water supply, they remain nonhazardous. Anyhow, the pollution with *E. coli* seems to be an omnipresent problem, but as long as sufficient treatment is provided, this is will not be harmful to the customers.

4. Assessment and Temporal Evolution of Pharmaceutical Concentrations

Authors Moritz Zemmann (KIT), Leif Wolf (KIT), Ali Sawarieh (KIT), Nayef Seder (MWI), Natalie Schmidt (TZW), Andreas Thiem (TZW)

4.1. Use of Pharmaceutical Substances as Quality Indicator

The occurrence of organic trace substances like emerging pollutants or pharmaceuticals in the local water sources is a well-known fact and already described for the Lower Jordan Valley by different authors like Wolf (2009) or Tiehm et al. (2012). The early sampling result of this study was part of their publications as well. Pharmaceutical concentrations (diclofenac, ibuprofene and others) at the µg level were detected for wastewater and hospital effluents in Amman using UV-Vis spectrometry (Alahmad et al., 2010).

Mostly pharmaceuticals are consumed by people and later released into the sewer system or into septic tanks after excretion. As a lot of those substances are rather persistent to microbiological degradation, they are not reduced during the passage of a WWTP and therefore released into streams and consequently reaching the groundwater. Leaking sewers might as well introduce them directly into the groundwater (Wolf, 2006; Klinger, 2007). Independent to their entry pathway, all those substances have the same characteristic of not occurring natural. So any detection of a single substance can be directly related to an anthropogenic impact. Due to this uniqueness and the special entry pathways into the aquatic environment, they can be used both, as tracer as well as indicators for water quality.

4.2. Sampling of Pharmaceutical Substances

Samples for pharmaceuticals were acidified with 1,5 ml of hydrochloric acid (HCl, 33%) per liter sample and stored cool and dark until their shipping to Germany. The analyses took place at the Water Technology Centre (TZW) in Karlsruhe (Germany), using a HPLC – ESI - MS – MS. The exact method is described in Sacher et al. (2008).

The main focus of the field investigations was put on a selection of X-ray contrast media and pharmaceuticals (see Table 4) which already could be detected during a first screening at selected locations in the Jordan Valley in 2007 or which are quite known to occur in the aquatic environment worldwide (Zemann et al. under preparation).

Table 4: Application of the investigated pharmaceuticals

Analgetics / Antiphlogistics	X-ray contrast media	Lipid lowering agent
Pentoxifylline (PEN)	Diatrizoic Acid (DIA)	Bezafibrate (BEZ)
Diclofenac (DIC)	Iodipamid (IOD)	Chlofibric acid (CHL)
Ibuprofen (IBU)	Iohexol (IOH)	Etofibrate (ETO)
Indomethacin (IND)	Iomeprol (IOM)	Fenofibrate (FEN)
Naproxen (NAP)	Iopamidol (IPA)	Gemfibrozil (GEM)
Phenacetin (PHE)	Iopromide (IPR)	Antipsychotic drugs
Anti-inflammatory drug	Iotalamic acid (ITA)	Diazepam (DZP)
Fenoprofen (FEN)	Ioxaglic acid (IXG)	Antiepileptic
Ketoprofen (KET)	Ioxithalamic acid (IXT)	Carbamazepine (CAR)

4.3. Results for Pharmaceuticals in the Urban Catchment of the Wadi Shueib

The detections for diatrizoic acid and iopamidol are given in Table 5. Diatrizoic acid remained almost stable over the whole data collection. It was found every time in the Hazzir, Shoreja, Baqquriah and Farkha springs and in the Um Attija well, whereas it was never found at Azzraqu spring, in the Yesidia well, in the WWTP of Salt and only once in March 2011 at Fuheis WWTP. In addition it was found in the Shueib reservoir in 2011 (March & September) and 2012. The spatial distribution is shown in Figure 23.

Iopamidol was detected 2008 and March 2011 only at Hazzir spring. Later in September 2011, it was also found as well in Baqquriah and Farkha spring. In 2012, iopamidol was found at the same locations as diatrizoic acid (Figure 24). It was as well present in every sample from the WWTPs and in the Shueib dam with very high concentrations.

Above the mentioned several single substances were found at different places mostly in the dams and the WWTPs:

- Iohexol was found two times in March 2011 at Hazzir and Baqquriah spring
- Ibuprofen was found as well two times in 2012 at Azzraqu and Farkha spring
- Bezafibrate, carbamazepine, chlofibric acid, diazepam, diclofenac, fenofibric acid, gemfibrozil, ibuprofen, ketoprofene, naproxen, iohexol, iomeprol, iopromide could be detected several times over the whole investigation period in the Shueib dam and the Salt and Fuheis WWTP

Table 5: Detections for diatrizoic acid and iopamidol for all sampling points in the Wadi Shueib. Red boxes mark the positive detections. Limit of detection (LOD) was 10 ng/l.

	Diatrizoic acid					Iopamidol GW			
	2008 Nov	2011 Mar	2011 Sep	2012 Feb		2008 Nov	2011 Mar	2011 Sep	2012 Feb
Springs & wells									
<i>Azzraq spring</i>	> LOD	> LOD	> LOD	> LOD		> LOD	> LOD	> LOD	> LOD
<i>Baqquriah</i>	x	x	x	x		> LOD	> LOD	x	x
<i>Farkha spring</i>	x	x	x	x		> LOD	> LOD	x	x
<i>Hazzir spring</i>	x	x	x	x		x	x	x	x
<i>Shoreja spring</i>	x	x	x	x		> LOD	> LOD	> LOD	x
<i>Um Attija Well</i>	x	x	x	x		> LOD	> LOD	> LOD	x
<i>Yesidia well</i>	> LOD	> LOD	> LOD	> LOD		> LOD	> LOD	> LOD	> LOD
Mean concentration [ng/l]	88	46	41	41		69	11	200	40
Detections	5 out 7	5 out 7	5 out 7	5 out 7		1 out 7	1 out 7	3 out 7	5 out 7
WWTP & dam									
<i>As Salt WWTP Effluent</i>	> LOD	> LOD	> LOD	> LOD		x	x	x	x
<i>Fuheis WWTP</i>	> LOD	x	> LOD	> LOD		x	x	x	x
<i>Shueib Reservoir Inflow</i>	> LOD	x	x	x		x	x	x	x

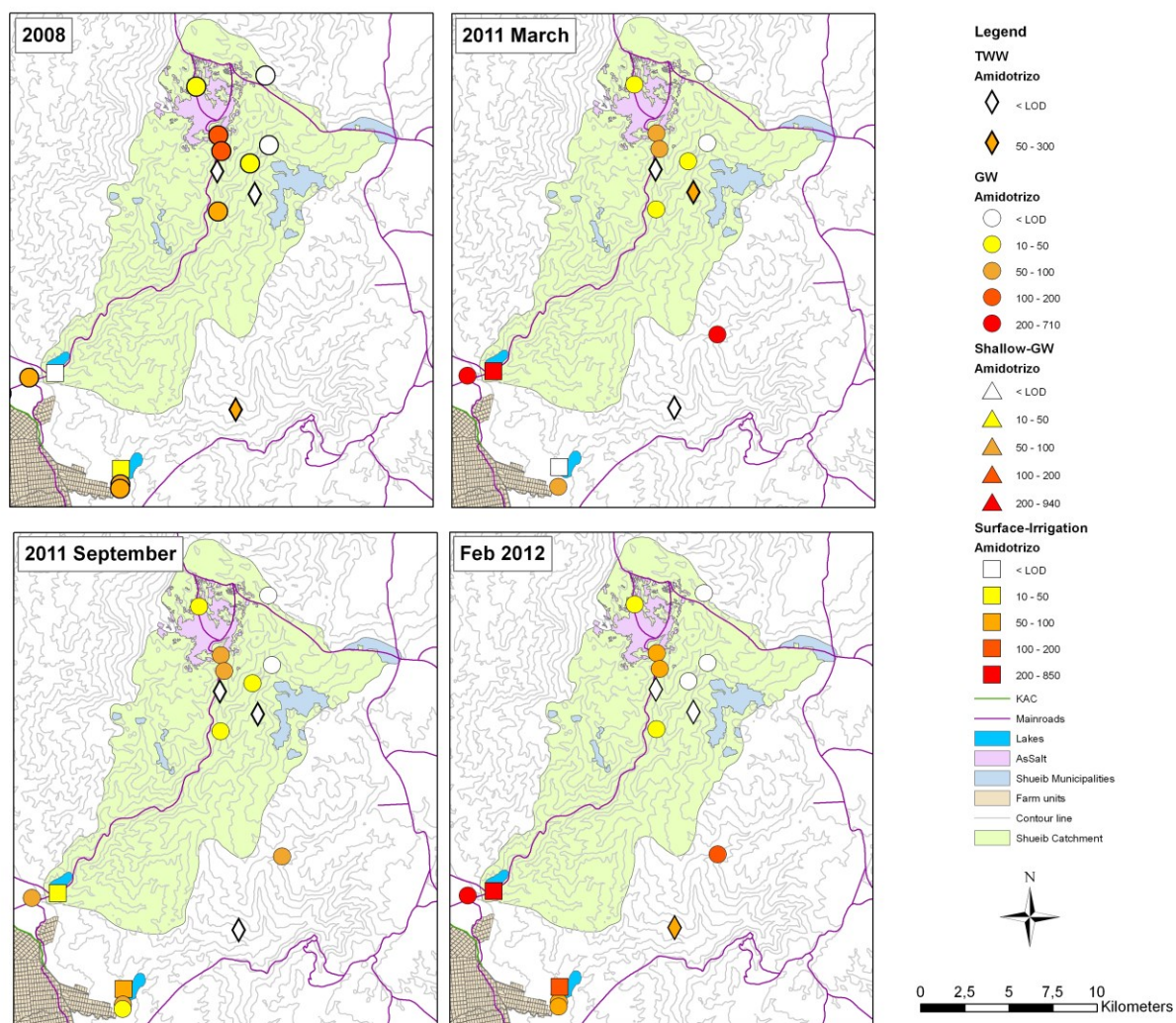


Figure 23: Spatial distribution of diatrizoic acid concentrations from 2008 – 2012

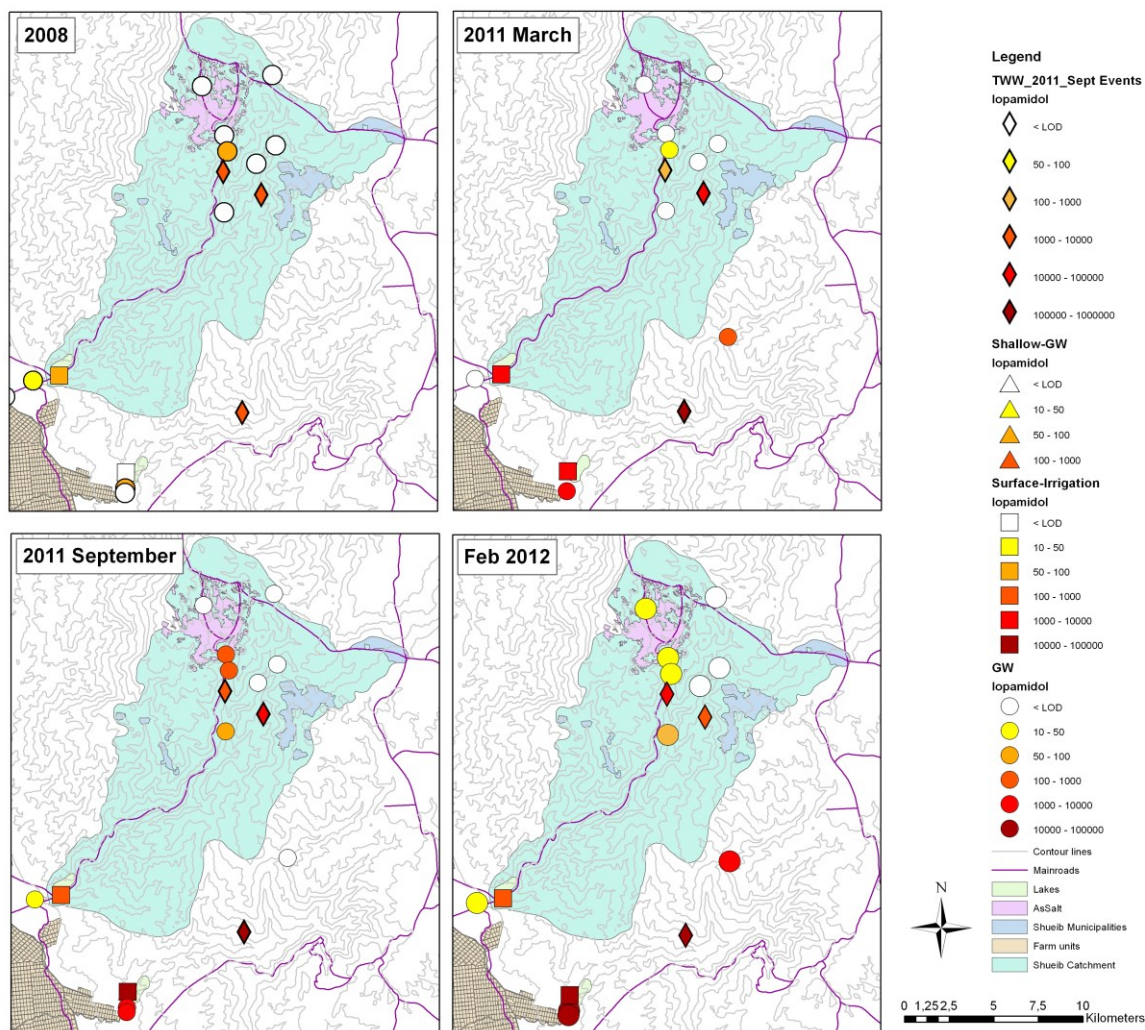


Figure 24: Spatial distribution of iopamidol concentrations from 2008 – 2012

4.4. Results for Pharmaceuticals in the Urban Catchment of the Wadi Kafrein

The detections in the Wadi Kafrein are listed in Table 6. Most occur in the effluent of the Es Sir WWTP and also can be detected in the Kafrein reservoir. Tujabyl spring indicates detections in the same range than the springs in Wadi Shueib. The two wells AN 1025 and AN 1026 are both located downstream to Kafrein reservoir outside the Wadi. This reservoir is infiltrating massively into the underground acting nowadays as local managed aquifer recharge (MAR) scheme (Sawarieh et al., 2009). A tracer test in 1999 indicated a direct connection from the reservoir to AN 1025 with a flow velocity of approximately 70 – 90 days flow time (Lenz, 1999). Therefore it is likely that the polluted water in that wells originate from the dam while it offers a similar set of substances.

Table 6: Pharmaceutical detections in the Wadi Kafrein

	Feb 12	Sep 11	Mar 11	Nov 08
Es Sir WWTP effluent	IPA, IPR, IOM, IOH, DIA, IBU, CAR, BEZ	IPA, IPR, IOH, IBU, GEM, CAR, BEZ	IPA, IPR, IOM IOH, IBU, GEM, CAR, BEZ	IPA, IPR, IOM, DIA, GEM, DIC, CAR, BEZ
Kafrein reservoir	DIA, IPA, IPR, GEM, IBU, CAR	DIA, IPA, IPR, IOH, GEM, CAR	IPA, IPR, IOM, IOH, GEM, CAR	DIA, IPR, IOM, IOH, GEM, CAR
River before Es Sir WWTP - Tujabyl	DIA, IPA, IBU	DIA	DIA, IPA	
AN 1025	IPA, IPR, DIA, IBU, CAR	IPA, DIA		IPA, IOH, DIA
AN 1026	DIA, IPR, IPA, IBU, CAR	DIA, IPA	DIA, IPR, IPA, IOH	DIA, IPR, IOH, CAR

4.5. Suitability of Pharmaceuticals as Contamination Indicator

If pharmaceuticals are useful for contamination indication, their occurrence should strongly correlate with other typical and well known indicators for wastewater influence like *E. coli*, nitrate or borate. *E. coli* is present in any human or animal feces. It is found in sewage water, treated waters, natural water and soils subject to recent fecal contaminations (WHO, 1996). Table 5. gives an overview on the detections for pharmaceuticals, combined with the nitrate and *E. coli* findings in the water samples. The colour index is following the local standard of 50 mg/l in Jordan according to the Jordanian standard for drinking water. The limit for any *E. coli* is 0 per 100 ml (JISM, 2001). Therefore the classification was done by the detection limit.

Up to now, the detections for most pharmaceuticals (beside diatrizoic acid and iopamidol) occurred only as singularity in the springs and wells. Therefore they are not objected to any spatial analysis, but may be helpful to indicate contamination as sum of detected substances. As the composition of TWW is highly exposed to as well seasonal and daily changes can detections should only indicate the bunch of substances released into the environment.

Concerning the detections for pharmaceutical substances in groundwater, they rose from 6 in 2008 up to 16 in February 2012. Table 7 clearly indicates a direct correlation of *E. coli* and nitrate contamination with the occurrence of multiple pharmaceuticals (2-3 substances). Whilst Hazzir and Farhka or Tujabyl springs show values above the permission limits (see chapter 3.3)for drinking water for all three parameters, Azzraq spring and Yesidia well both proof good water quality with minor detections of pharmaceuticals (0-1 substance).

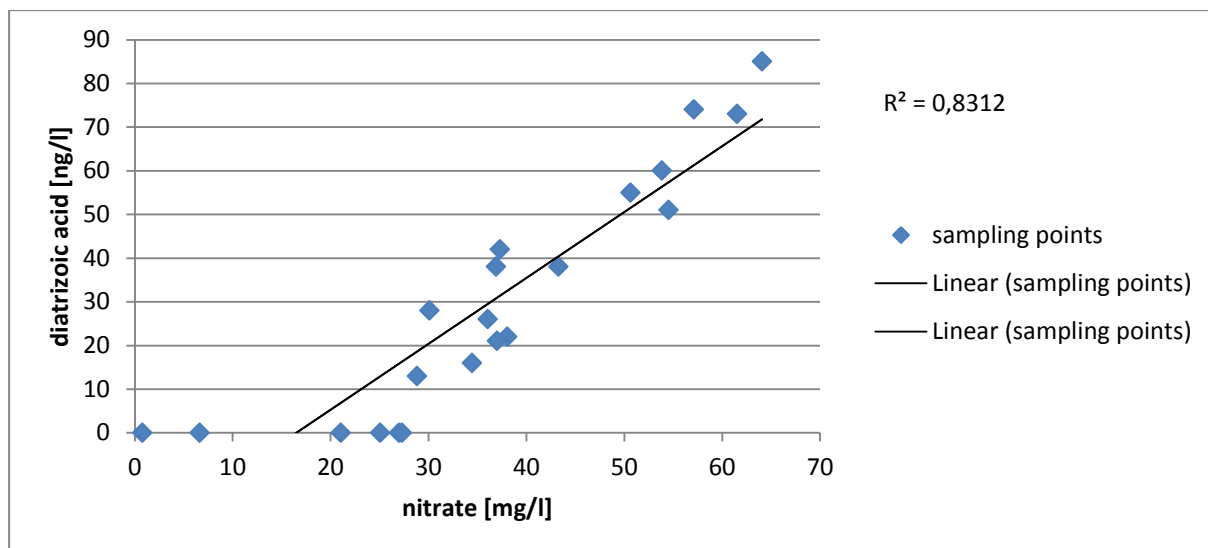


Figure 25: Correlation of diatrizoic acid and nitrate for measurements from 2011 – 2012.

Table 7: Juxtaposition of pharmaceutical detections, *E. coli* and nitrate concentration at different groundwater resources in Wadi Shueib and Wadi Kafrein

	Feb 12			Sep 11			Mar 11			Nov 08		
	detections	<i>E. Coli</i>	Nitrate	detections	<i>E. Coli</i>	Nitrate	detections	<i>E. Coli</i>	Nitrate	detections	<i>E. Coli</i>	Nitrate
	[Number of substances]	[MPN/100 ml]	[mg/l]	[Number of substances]	[MPN/100 ml]	[mg/l]	[Number of substances]	[MPN/100 ml]	[mg/l]	[Number of substances]	[MPN/100 ml]	[mg/l]
Azzraq spring	1	17	27.02	0	33	25.1	0	< 1.8	27.31	0	< 1.8	n.a.
Baqquriah spring	3	5	43.28	2	170	36.1	2	33	36.92	1	79	n.a.
Farkha spring	3	920	57.13	2	23	64.1	1	6.8	61.55	1	49	n.a.
Hazzir spring	2	110	50.63	2	490	53.9	3	1600	54.53	2	130	n.a.
Shoreia spring	2	13	34.47	1	33	28.8	1	n.a.	30.10	1	8	n.a.
Tujabil spring	3	1600	49.88	1	920	56.6	2	n.a.	50.83	n.a.	n.a.	n.a.
Um Attija well	2	n.a.	38.04	1	< 1.8	37.0	1	n.a.	37.31	1	2	n.a.
Yesidia well	0	2	6.63	0	n.a.	21.0	0	n.a.	0.77	0	< 1.8	n.a.
total detections	16 out 8	7 out 7		9 out 8	6 out 7		10 out 8	3 out 4		6 out 7	5 out 7	
Mean concentration			38.4			40.3			34.6			
<i>E. coli</i>	< 1.8	> 1.8	Nitrate [mg/l]:			< 50	> 50	n.a. = not analysed				

Plotting all results for diatrizoic acid against the nitrate concentrations as well indicates a clear dependency of those two substances (see Figure 25).

Showing those strong connections between the occurrence of pharmaceuticals and other typical indicators for anthropogenic influence to a water body, they seem to work rather well to trace human pollution. As shown before, they can be used on both qualitative (Table 7) and quantitative (Figure 25) levels, as long as there is a sufficient data base available.

4.6. Conclusions

Evaluating the water resources pollution on the base of pharmaceutical occurrence and their concentrations pictures a high degree of anthropogenic influence to Wadi Shueib and Kafrein.

- All springs and wells downstream or inside the city area of Salt are contaminated with pharmaceuticals
- No or minor detections in the wells (Yesidia) and springs (Azzraq) sideways and upstream to the cities Salt and Fuheis.
- Pharmaceutical contamination (or absence) is always linked to high (or low) nitrate and *E. coli* concentrations in both directions
- Absolute detections of pharmaceutical substances are rising since 2008, while the nitrate remains on a stable level

Therefore it must be stated, that the whole groundwater resource in the area seems to be influenced by anthropogenic waste like sewage or TWW. In addition, the numbers of positive detections are rising, which means that the pollution is increasing within the last years.

However, it must be said, that any kind of trend and projections are based on the results of 4 sampling campaigns. A better data base could therefore provide much more reliable predictions. Concerning any imminence for the local population it need to be stated, that those substances up to now only occur in concentrations around ng/l which is far away from any harmful concentration for humans. Though, it is not much known about long term dosage of small concentrations for humans but fist studies on fish populations seems to indicate possible cocktail effects (Brodin et al 2013). Today, not many countries (Australia) do have thresholds for emerging pollutants in drinking water or TWW, but the topic is growing bigger and of raising awareness within the last years. Actually the EU has a legal framework to implement thresholds for several single substances within the near future (Focus online 2012). But still there is the problem of a removal technology. Reverse osmosis, nano-filtration and granular activated carbon filtration are both, sufficient and expensive (Jekel et al., 2006) and not very common in wastewater treatment.

5. Focus Monitoring Site Hazzir Spring

Authors: Felix Grimmeisen (KIT), Ali Sawarieh (KIT), Moritz Zemann (KIT), Leif Wolf (KIT)

5.1. Pollutant Content Variations of Nitrate and Bacteria at Hazzir spring

Within the study area substantial amounts of raw sewage are discharged into the Wadis. This sewage often pollutes the groundwater resources, introducing high concentration of nitrate, organic matter and bacteria. The investigations were performed in the upper part of Wadi Shueib, about 20 km west of Amman, Jordan.

Four main springs in the upper Wadi Shueib provide basis of water supply of the cities Salt, Fuheis and Mahis with a total population of about 110 000 (see Figure 26). Salt is located in the middle of the springs' catchment area and thus indicates the central problem and main objective of the investigations. In order to protect the 4 Wadi Shueib springs (Baqquriah, Hazzir, Shoreia and Azraq) from pollution in 2009 protection zones have been delineated by the Jordanian Ministry of Water and Irrigation (MWI) in cooperation with German Federal Institute for Geoscience (BGR; MARGANE et al. 2009).

In this context special interests have been focused on the Hazzir Spring, due to its important role within the water supply of the area on the one hand and its persisting pollution problems on the other. As mentioned above the main aquifer of the Wadi Shueib springs is the Amman - Wadi Sir Aquifer (A7/B2), from which groundwater is discharged also to Hazzir spring. Continuous flow measurements at Hazzir Spring from May 2011 till September 2012 have been showing a mean discharge of 40 L/s.

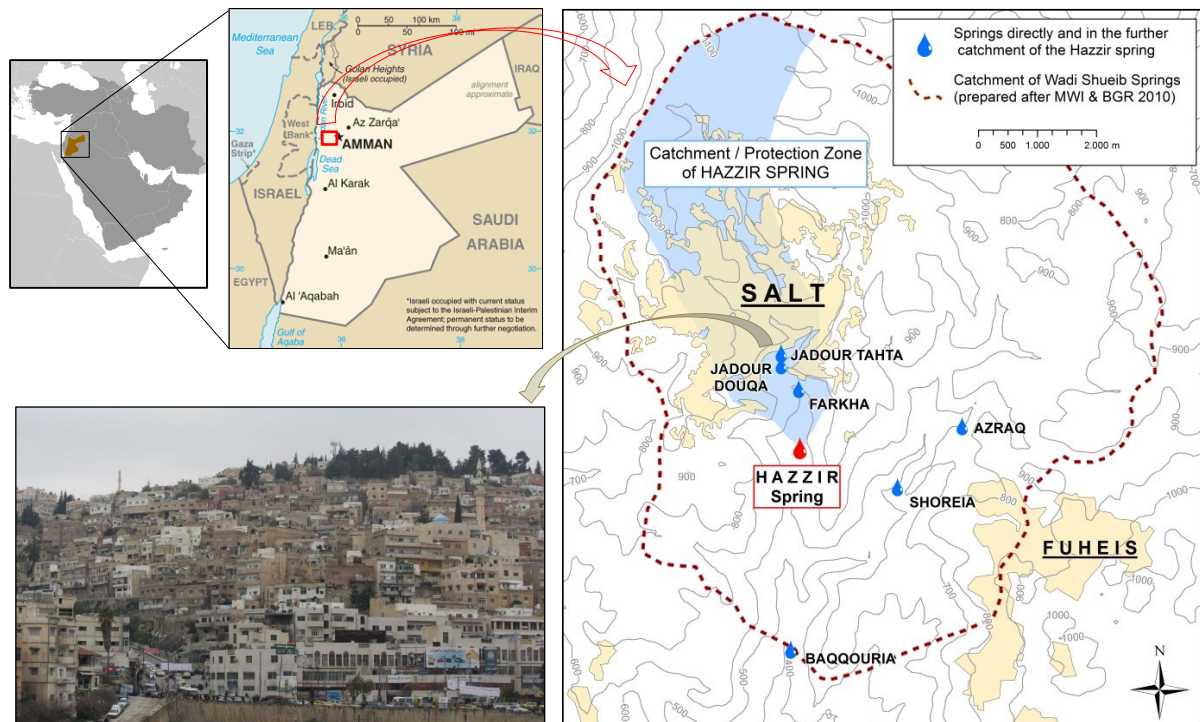


Figure 26: Topographical overview on Wadi Shueib springs catchment with special focus on Hazzir Spring

5.2. Historical Review

MARGANE et al. (2009) note in the Technical Report Delineation of Groundwater Protection Zones for the Springs in Wadi Shuayb' that not the full available amount at Wadi Shueib springs is abstracted "[...] but only some part of it and this only if its quality was suitable". In this context especially Hazzir Spring is mentioned of being frequently switched off because of bacteriological contamination. As illustrated in figure 26 the catchment of Hazzir Spring as part of Wadi Shueib springs catchment is urbanized most by the city Salt. Analysis of spring water quality such as nitrate concentrations of mostly more than 60 mg/L or the frequent presence of *E. coli* have been showing contamination problems and the anthropogenic influence of urbanization already in the past (see Figure 27). Due to the contamination problems a continuous supply from the Hazzir spring could not be provided till today.

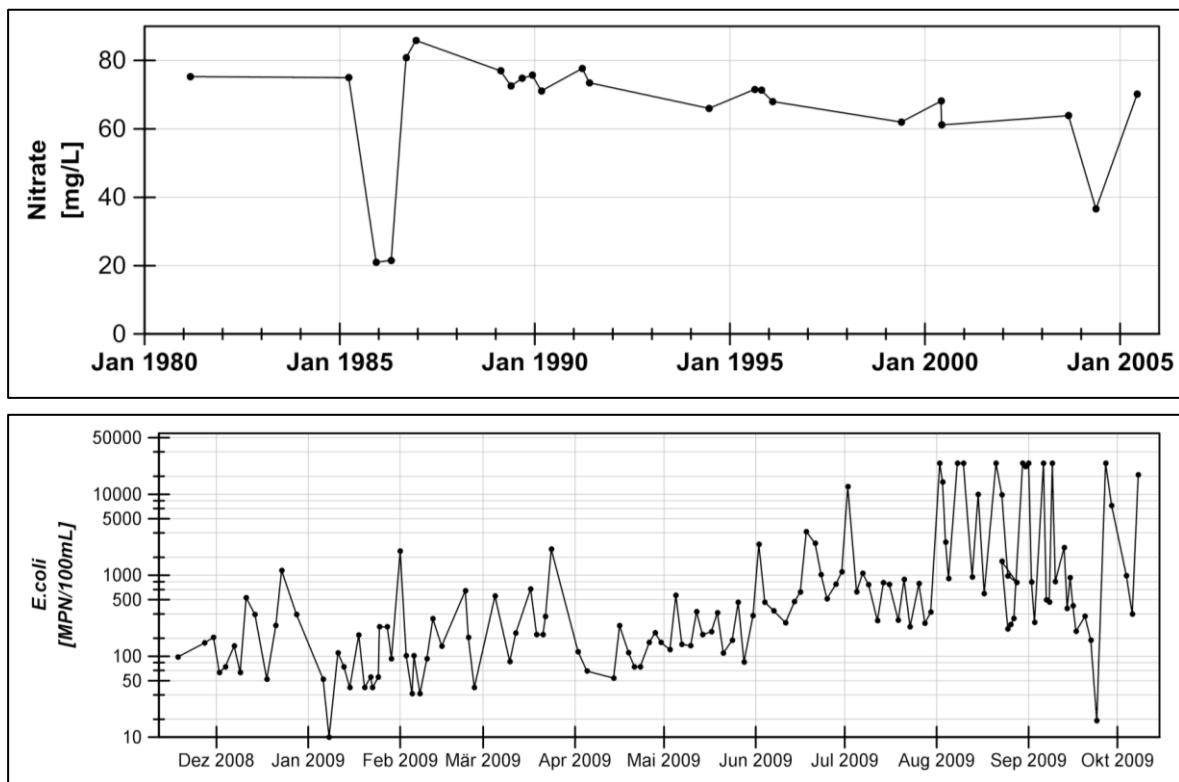


Figure 27: Historical data of nitrate concentration and bacteriological impacts (*E. coli*) of Hazzir Spring water. (Source: data provided by MWI, preparation by Grimmeisen)

5.3. Present Spring Water Monitoring and Sampling Analysis

Because of the constantly high nitrate concentrations and the frequency of bacteriological impacts these two parameters amongst others have been focused in the investigations about indicators for anthropogenic influences on the water resource.

In May 2011 an UV-Vis spectrometer probe has been installed in the Hazzir spring tub to measure continuously N-NO₃ beside turbidity, TOC and DOC at a 15 minute time interval (see Figure 28). Additionally from May 2011 till September 2012 more than 60 water samples have been taken on a

weekly basis to be analyzed for nitrate, total coliforms and *E. coli* at the laboratory of Water Authority of Jordan (WAJ).

Beside the high resolution monitoring by probe and the weekly sampling further 3 sampling campaigns of each about 2-3 weeks (Sept. 2011, March 2012 and Sept. 2012) have been accomplished to obtain a detailed study on bacteriological contaminations. By rapid testing using Idexx Colilert® tests fecal coliforms and *E. coli* could be analyzed daily, e.g. during a rainfall event (March 2012; see Figure 32).



Figure 28: Fotos of Hazzir Spring (left) and monitoring devices. Box with monitoring devices (middle) and UV-Vis probe (right).

5.4.Results

With the spectrometer probe it could be achieved to obtain an almost complete time series of nitrate concentration at Hazzir spring of about 1 year at 15 minutes time interval (see Figure 30). The analysis of water samples taken weekly have been showing their importance by its establishment of still high nitrate values (50-70 mg/L) and persisting presence of *E. coli* (see Figure 29) on the one hand and the use for the calibration of the UV-Vis probe on the other.

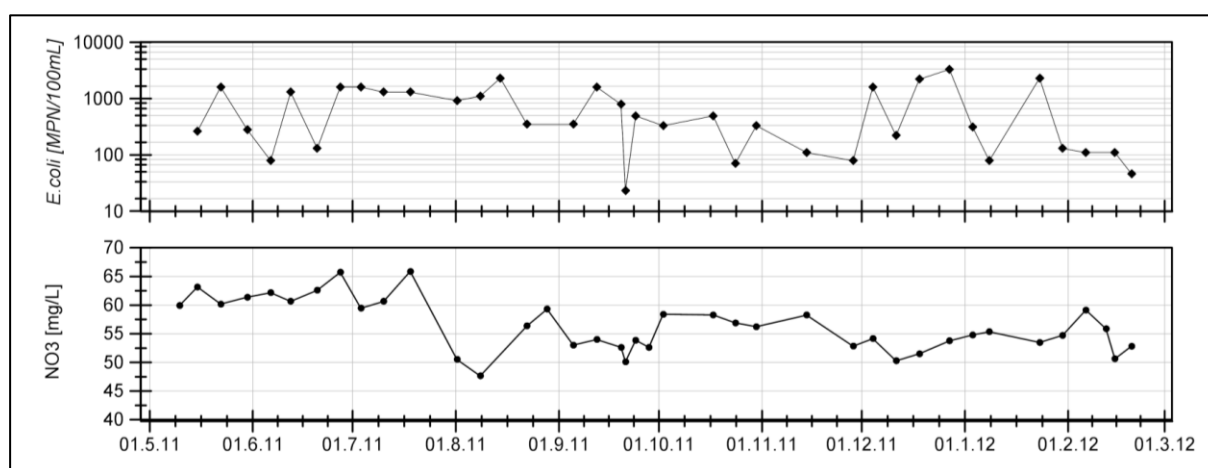


Figure 29: Nitrate concentrations and *E. coli* findings of water samples taken weekly at Hazzir spring.

As one of the important major result at the samples analyzed in laboratory of WAJ it must be regarded that no negative findings at fecal coliforms and *E. coli* have been obtained.

As mentioned before the nitrate results of the weekly water samples have been used as calibration values for the UV-Vis probe on the one hand but provide also basis of a continuous reference at the N-NO₃ measurements. In figure 40 the nitrate time series is partly illustrated beside the nitrate concentrations of lab analyzes as reference and spring discharge as well as precipitation of winter season 2011-12. The nitrate curve marks a constant level of about 60 mg/L with variations rarely above 10 mg/L while small rainfall events do not show a significant effect. By trend the nitrate curve values are little too high compared to laboratory results. Spring discharge of about 40 L/s with noticeable fluctuations of 10 L/s almost weekly doesn't show clear correlations or impacts on nitrate concentrations at this scale. Still at small variations but obviously the nitrate curve follows quite clearly a weekly fluctuation.

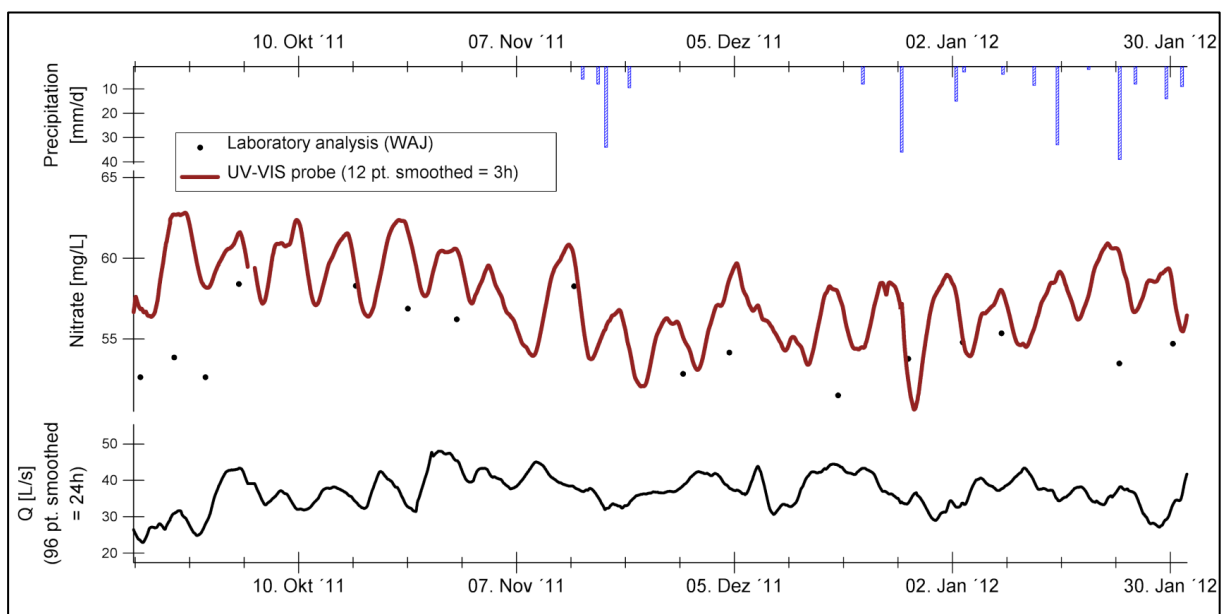


Figure 30: Large scale analysis of nitrate time series of UV-Vis measurements at Hazzir spring.

To demonstrate the importance of studying time series at different scales Figure 31 is to illustrate the proof of correlation and its interpretation. Hazzir spring time series abnormally show variations and a correlation of discharge, nitrate concentration and electric conductivity at a daily basis by absence of rainfall. In this context mainly a discharge variation of about 10 L/s indicates the direct impact of the urban area on the spring water quality (Grimmeisen et. al 2012). Besides the daily discharge variations positive correlations with nitrate and EC shown in figure 31 underline this fact clearly.

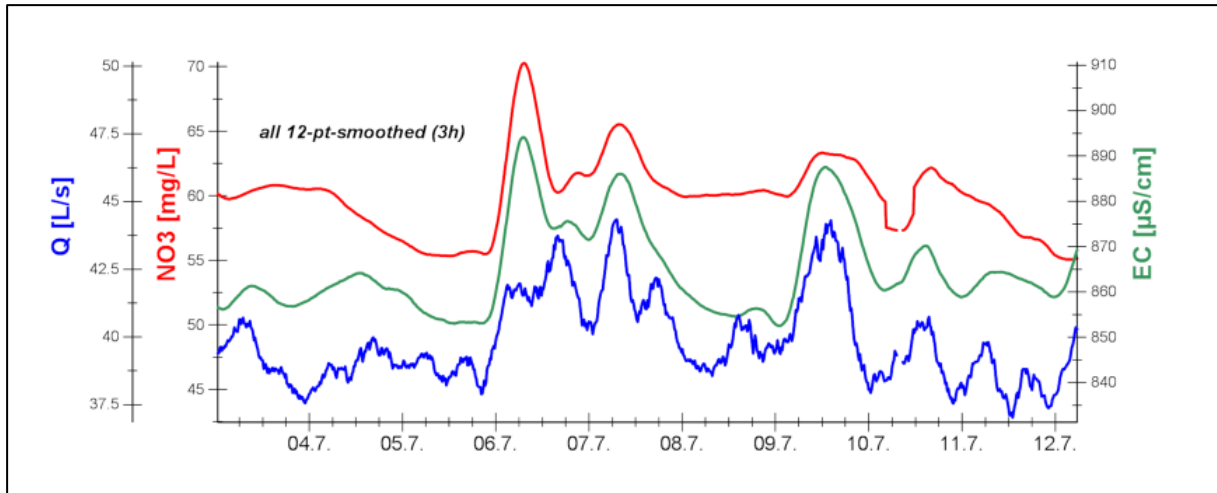


Figure 31: Small scale analysis of Hazzir Spring time series indicating the direct impact of anthropogenic contamination (Grimmeisen, 2014 in preparation).

On the basis of the analysis of Hazzir spring time series, two main sampling campaigns during rainy season (February/March 2012) and summer time (September 2012) have been performed to proof the nitrate variations by *E. coli* testing during different climate conditions.

During a rainfall event in March 2012 *E. coli* testing show a typical quick reply by an increase of discharge accompanied with a strong bacteriological impact (see Figure 32, Figure 33). The event shows that less than 18 hours after starting of the rain event a strong impact of *E. coli* arrives the spring pointing up the characteristic vulnerability of the karst spring, while the water supply wasn't stopped early enough. Therefore the spring monitoring helps to understand flow mechanisms under high and low flow conditions to improve the water supply management.

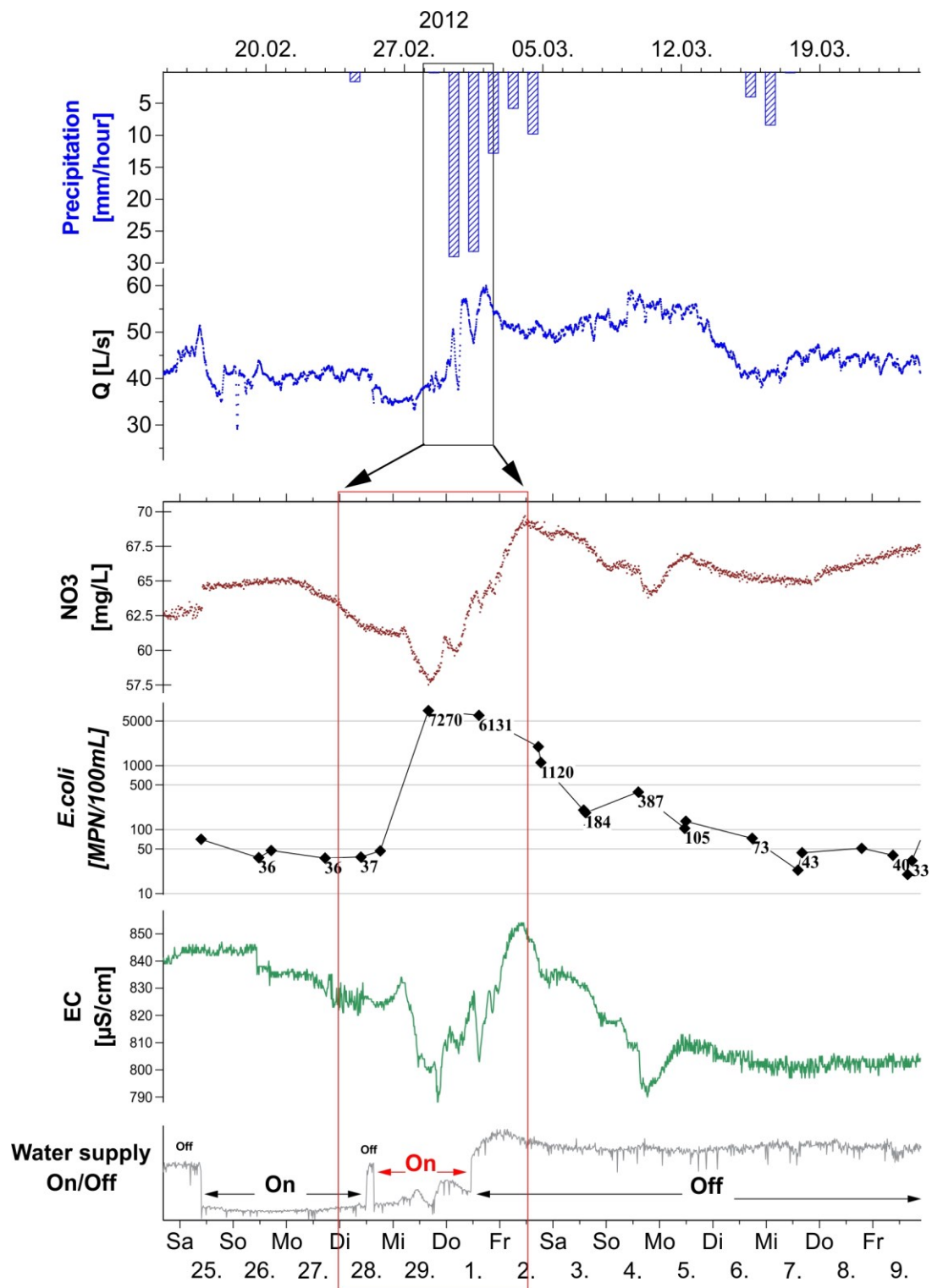


Figure 32: Hazzir spring monitoring during a rainfall event in March 2012 (modified after Grimmeisen, 2014 in preparation).



Figure 33: Foto of a small brook in the central area of Salt city after a rainfall event in March 2012 (Grimmeisen, 2012).

The second sampling campaign took place in September 2012 at the end of the summer season to prove any possible correlation between the weekly nitrate fluctuations (see Figure 33) with *E. coli* impact. Figure 34 illustrates the result of a daily sampling for *E. coli* tests (Colilert®) during one week. By background colors the regularity of weekly nitrate minima at Wednesday and maxima at weekends (in Jordan, being an Islamic country, this is from Friday to Saturday) is shown. By the Colilert tests it could be demonstrated quite clearly that the *E. coli* values are correlating to the weekly nitrate variation although an always constantly high level.

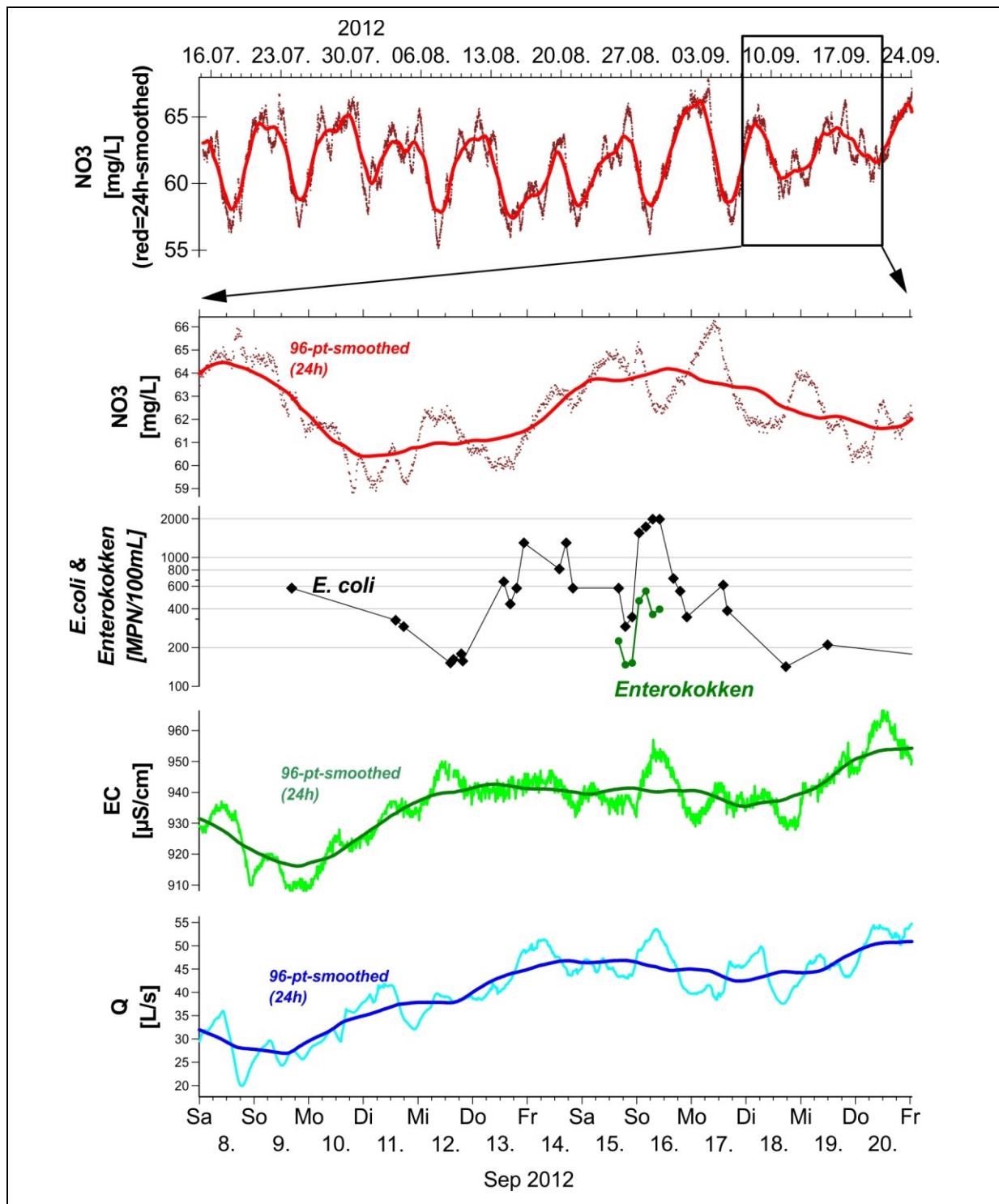


Figure 34: Hazzir Spring monitoring during summer season in September 2012 (modified after Grimmeisen 2014 in preparation).

5.5. Conclusions

Nationwide, the water supply in Jordan for public households is organized on a weekly basis. Different zones were supplied for about 1-1.5 days with fresh water to fill the private water tanks. As well the high nitrate concentrations and the consistent bacteriological impacts at Hazzir spring are majorly influenced by the weekly water supply system accordingly to the leaking sewer system. As advanced study in the Hazzir spring catchment will be to define the origin of main waste water producing water supply zone within the spring's catchment (see Figure 35). But at the same time this case study exemplary demonstrates the value and necessity of high resolution monitoring and its advantages with regard to the abilities of single target day analysis. The understanding of linkage between water supply system, water supply zones, sewage mobilization, sewer leakages and spring water quality was only possible to be derived by the time series analysis of continuous nitrate measurements.

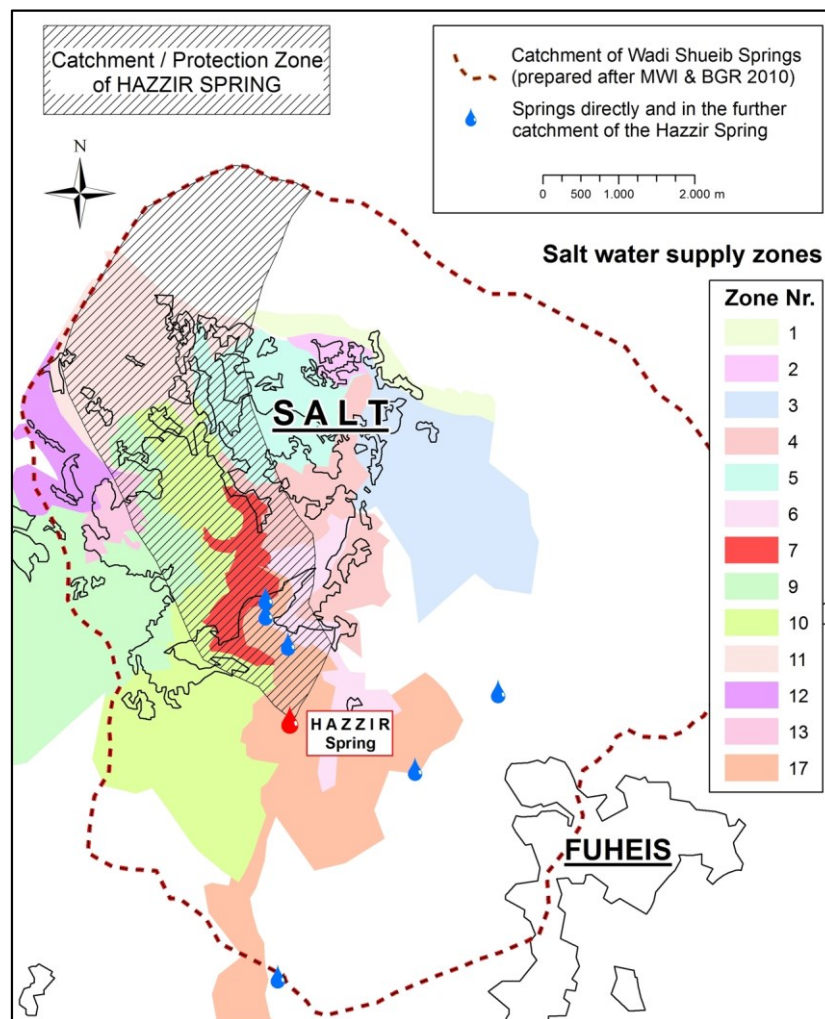


Figure 35: Salt water supply zones (Source: data provided by MWI, preparation by Grimmeisen).

6. Macro Fauna and Flora as Indicators of Water Quality

Authors: Ikhlas Alhejoj (KIT, JUA), Elias Salameh (JUA)

6.1.Plants and Animals used as Indicators to determine the Quality of Water – a Historical Overview

Many different species of the aquatic fauna and flora found in Jordan were encountered which can be utilized in characterizing the quality of the water. Animals and plants in springs, creeks/rivers and ponds were studied as indicators of water quality. The aquatic biota (fauna and flora) can be used effectively as bioindicators of water health (Rosenburg & Resh 1993), especially, in a semi- arid country, such as Jordan with unpredictable seasonal rainfall, subject to the great scarcity of water and an ever- increasing demand from the rising human population presents a great problem. Chemicals such as especially used in gardens and in agriculture can pollute the water, and sewage enters the creeks. So it is important to protect Jordan surface water resources in order to keep these aquatic systems healthy and protect them.

The aim of the present research is to study the occurrence of aquatic organisms in running surface water springs, creeks, rivers and stream. Water covers extending from the Zerqa River in the North to Mujib River in the South were sampled for animals and plants alongside, the quality of the water is characterized, regarding its temperature, conductivity, biological dissolved oxygen, and dissolved chemicals. The selected size of organisms used as bio-indicators is larger than about 0.5 mm, so that they can be seen with the naked eye (macro-organisms). The smallest animals considered in the study belong to the Ostracoda, representing tiny crustaceans. The largest are frogs and crabs. The animals chosen for the analysis belong predominantly to the macro invertebrates such as worms, insects, arachnids (spiders), mollusks and crustaceans and the plants are predominantly flowering seed plants. Other species of biota, such as sponges, fish, and algae can also be used as biological indicators in the present study.

All those species and groups which are utilized in this study are described in some detail during this study. Included are also plants, some of which very common and characteristic of specific environments, others less so. Especially their tolerance to dissolve minerals in the water is useful as bioindicators.

In this study, the species or groups of species that are characteristic to a certain environment of the water and its degree of pollution will be characterized. Here the specific communities for specific environments such as clean water of different type, weakly to strongly polluted water and water affected by different degrees of salinity are described and characterized. Examples will be specific places in Jordan.

Historically, the use of aquatic organisms as indicators of water quality start in the beginning of the twentieth century by using macro-invertebrates to assess water quality and degrees of pollution in rivers subject to sewage contamination. This can be traced back to the pioneering work of two German scientists, R. Kolkwitz and M. Marsson, in the early 1900s. Their publication on saprobity (degree of pollution) led to the development of indicator organisms. Kolkwitz and Marsson (1908) were the first or among the first to exploit these effects and present a practical system for water quality assessment using biota. Their system, known as the Saprobic system, has been used mainly in Central Europe. In the beginning bio monitoring was applied to microorganisms but after that the

macro-invertebrates as bio-indicators rapidly gained on importance (cf. Bartsch and Ingram, 1966; Mackenthun, 1969; Sladeczek, 1973; Rosenberg and Resh, 1993; Hering et al., 2004). Biomonitoring technique was the object of interest of many authors around the world.

Several studies have been performed in Europe, USA, Australia and other countries by using aquatic biota as bio-indicators in order to monitor the water quality of surface Water. These model studies are available and the way in which they have been carried out can also be utilized in Jordan. In Jordan only one study in the early eighties (Bandel and Salameh, 1981) has been carried out the status of the water resources in the Amman Zarqa area by correlating the hydrochemistry of a water source to its hydrobiology, those authors were able to assign grades of pollution to the different sources ranging from 1 for the best water quality to 10 for heavily polluted water and this study that can be utilized and improved.

Classification of water quality by using macroinvertebrates technique started in Europe in 1902 with the development of the saprobic system, developed originated by Kolkwitz and Marsson, is based on the principle that different aquatic invertebrates species from all components of the aquatic fauna have different tolerances to pollutants. For example the presence of mayflies or stoneflies for instance indicates that the water is clean. Biological indicators can be useful for waters polluted with organic matter, particularly sewage, especially; the indicator organisms are usually sensitive to depletion in oxygen concentrations.

In Jordan where water sources are small and rivers in international considerations, except the Jordan River are not found, only small surface water flows of generally ten to few hundreds of liters per second are found. Such small discharges are vulnerable to small amount of pollutants. Hence, the fast recognition of changes in their quality is very essential for water users, especially, when that water is used as a source of drinking water. As an example on that is the water of King Abdullah canal and its feeding sources, which is used after purification for the drinking water supply of Amman. Pollution events along KAC have taken place more than one time a year since the operation of the drinking water supply from KAC. The pollution events were not detected before the polluted water reached the inhabitants and caused sickness and public unrest and interruptions in the water supply. The problem was that the water samples collected for quality checks require transportation to the laboratories and rigorous chemical and physical time-consuming analyses. Biological indicators disappearance or appearance can easily show that something happened to the water quality. It needs only a trained person controlling the canal water. Such application of bioindicator results can save time, health detriments, trouble in purification plants and social unrest.

6.2. Methodology

The method applied here is to use aquatic fauna and flora in evaluating the quality of the water. It is mainly done by assessing selected physical features characters such as water temperature, pH, acidity and conductivity. The parameters were measured in the field and chemical features data (nitrate, phosphate, hardness (calcium, magnesium and total hardness), BOD (Biochemical oxygen demand) and trace elements (e.g. copper, iron, zinc, boron), analyzed in the laboratory, have been collected along the water courses in the study area (sampling and analysis in the laboratory is displayed in **Fehler! Verweisquelle konnte nicht gefunden werden.** and

Figure 36). Data were assembled from each site from which also the fauna and flora had been collected and determined. Also additionally to identifying and specify their wealthier communities.

The aim is to use that information to evaluate the water status in Jordan and to enable future comparison to shed light on effects of development on these water resources and organic community samples of living organisms were collected from 24 sites in 7 localities, mostly running water, in the area from north to the central part of Jordan (see).

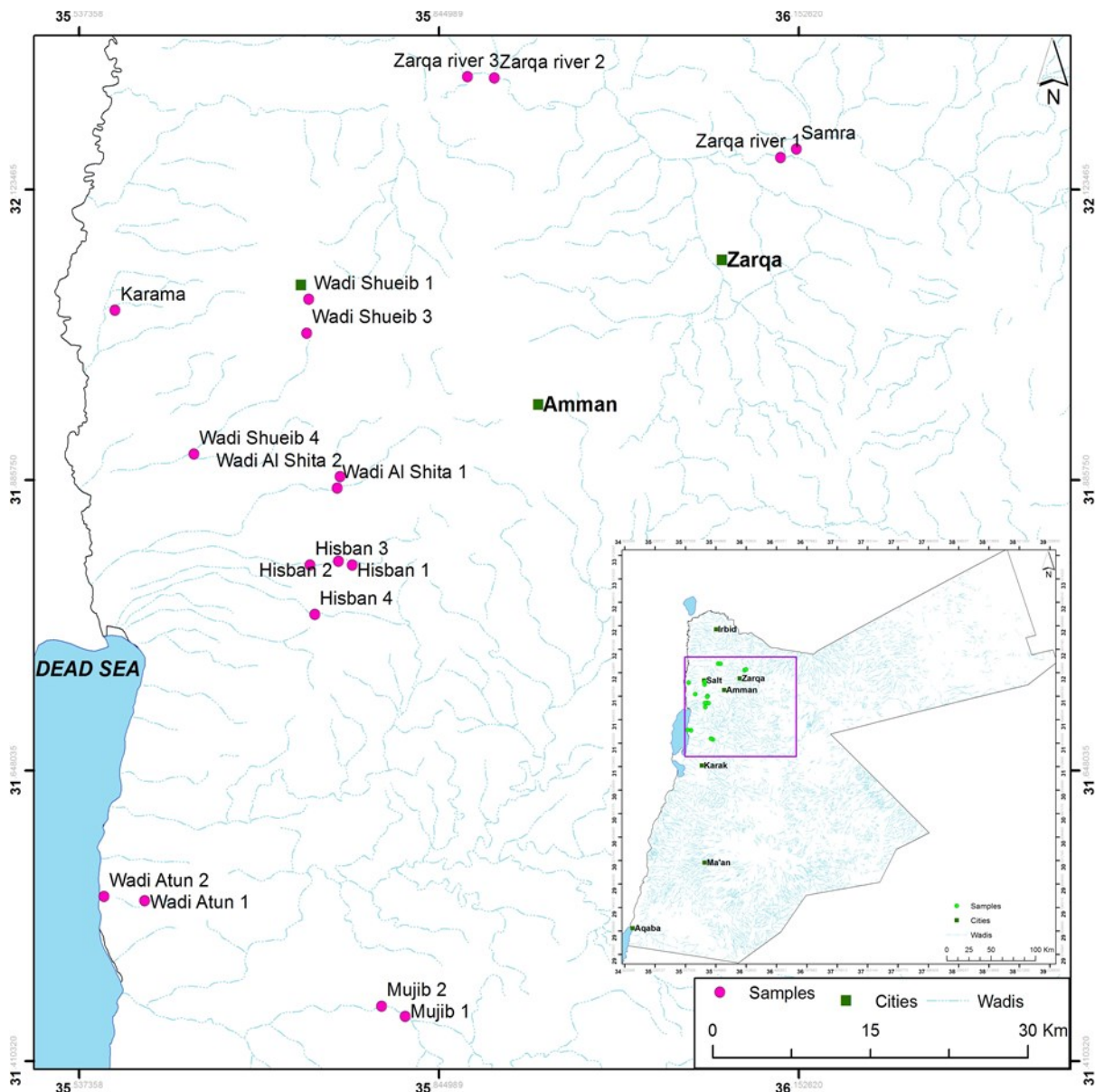


Figure 37).

Organism samples were collected during the late winter to early spring time, from December to April (2011-2013) from chosen localities. The collected organisms were isolated and determined according to their place in the taxonomic system as far as possible based on literature and was in the case of the molluscs checked by Klaus Bandel and based on palynological studies regarding the diatoms while ostracod samples were determined by Steffen Mischke, Free Berlin University and mayfly samples were determined by Gattolliat (2013), Museum of Zoology, Switzerland.

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Figure 36: Collection of macroorganisms at different locations.

Sampling of macro organism is summarized in Fehler! Verweisquelle konnte nicht gefunden werden.. In the laboratory the material was searched for aquatic organisms which were placed in dishes containing water from the same sampled site and later 70% alcohol was added for later identification. Identification and documentation of those organisms using an S6 D Leica stereomicroscope with magnification of 6.3x - 40x with connected digital camera. The fresh collected organisms were documented in the laboratory of the University of Jordan.

6.3.Study Locations

Organisms and water samples were collected and studied in a region stretching from the north to the central part of Jordan from 22 sites along different aquatic systems include: Zarqa River, Wadi Hisban, Wadi Shueib, Wadi Shita, Karama reservoir-area, Wadi Mujib and Wadi Atunon ().

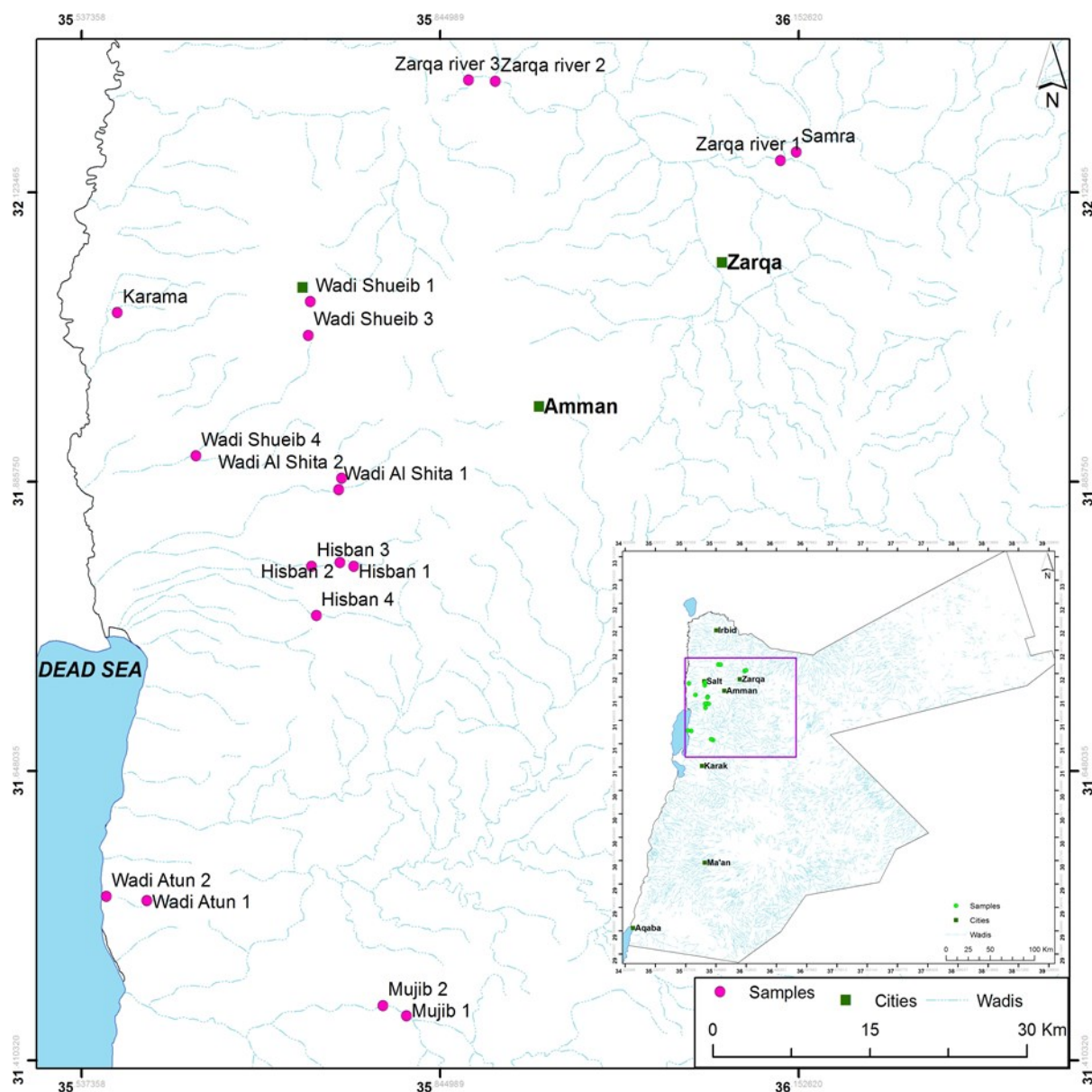


Figure 37).

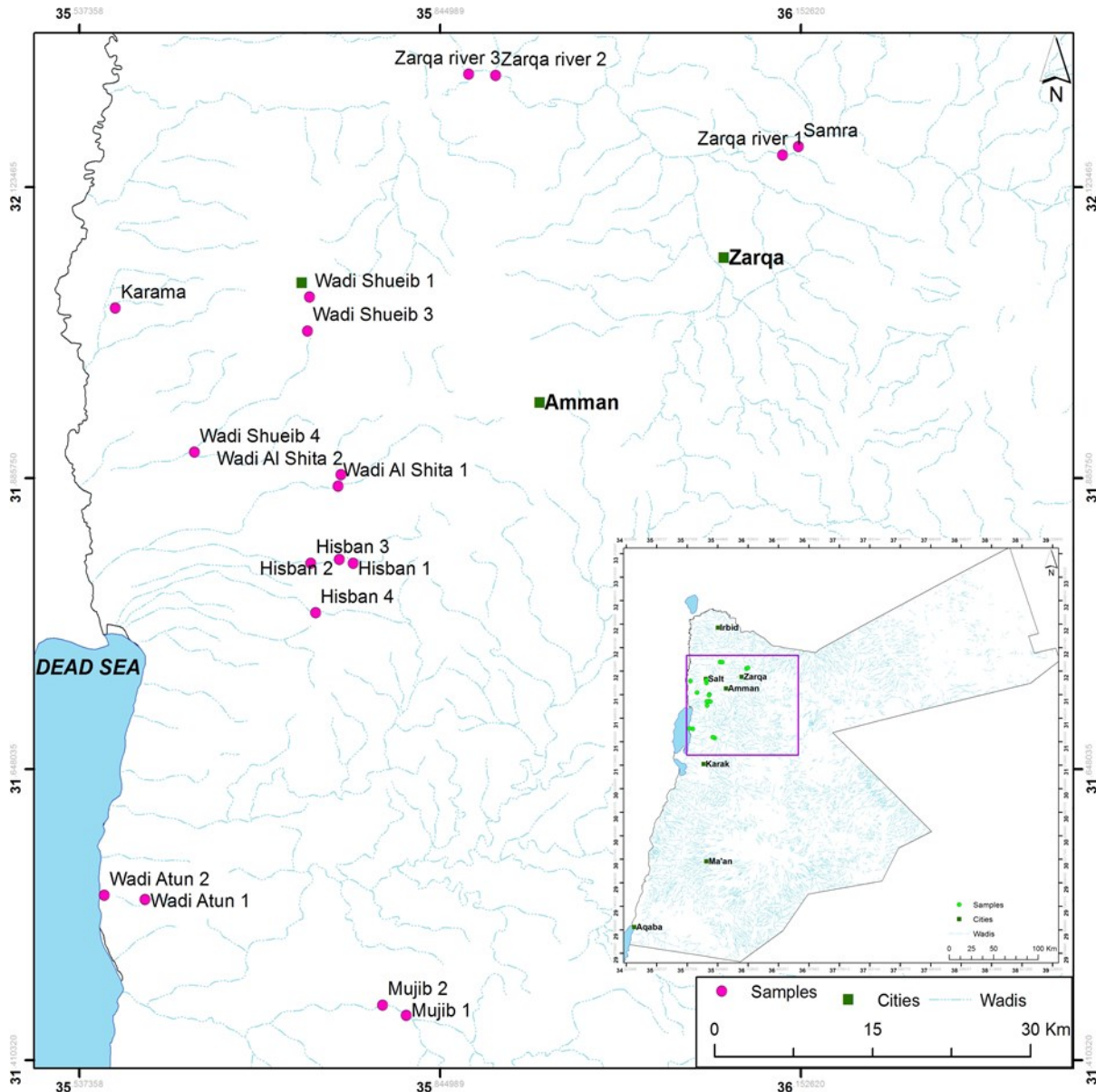


Figure 37: The study area covers wadis pouring into the Jordan Valley and the Dead Sea, extending from Zarqa River in the north through Karama reservoir-area, Wadi Shueib, Wadi Hbsan, Wadi Shita, and Wadi Atun to Wadi Mujib in the south.

6.4. Macro Organisms in Jordan

Animals and plants as aquatic bioindicators are found in various aquatic systems, where they are present on the water's surface or swimming in the water itself and others which live on the bottom of water bodies on rocks, logs, in the sediment, on debris and on aquatic plants. Aquatic ecosystems differ regarding their different chemical, biological and physical parameters. Those organisms are strongly influenced by water chemistry and habitat quality e.g., dissolved oxygen, bacteria, nitrate or phosphorous concentrations, pH, and others. Their reaction and the responding of these living organisms can be used in environmental quality assessment and environmental pollution analysis (Peck et al. 1998). The distribution of various aquatic organisms depends on particular ecological preferences, such as habitat structure (e. g. Food viability, water flow rate, temperature and

substrate) and pollution. Such effects may be misunderstood, for example, as being caused by environmental pollution. Water bodies in our study are classified on the presence or absence of certain biota groups which occur in the study area. In general the organisms which tend to go extinct respectively by increasing pollution are Plecoptera, Ephemeroptera, Trichoptera, Gammarus, Asellus, red Chironomidae and Tubificidae fauna with increasing pollution (Persoone and DePauw 1979). Pollution tolerant species such as tubificid worms and red Chironomid larvae inhabit in polluted waters and can survive under low dissolved oxygen levels and high organic enrichment (Peckarsky et al. 1990) can also be used as excellent water bioindicators. Many groups of aquatic macro organisms have been used and proposed as indicators of water quality. Insect group, Crustaceans group, Annelid group, Mollusca group, fish group and plant groups were observed and discussed in this study as given in Table 8 and Table 9.

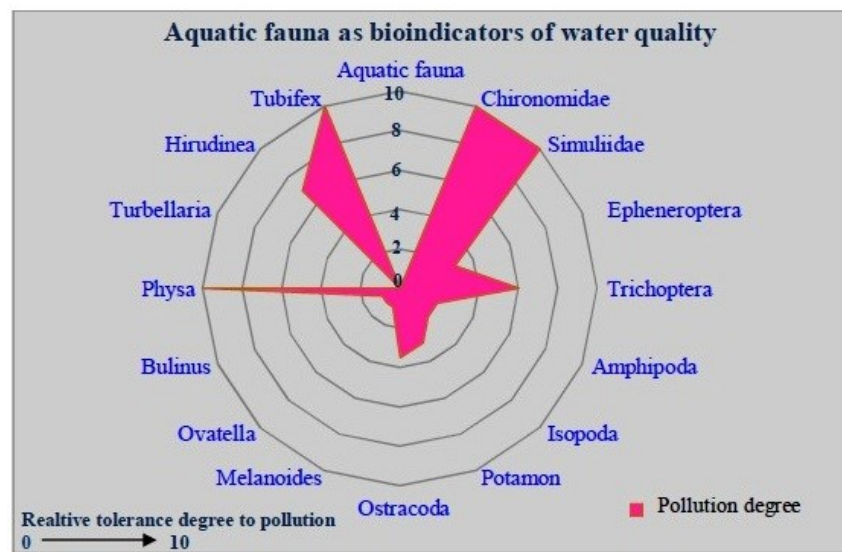


Figure 38: Different groups of aquatic fauna show different level of tolerance to pollution in Jordan. based on biological, physical and chemical parameters

The identification of the studied organism groups was not always possible at the species level for all samples. Based on chemical, physical and biological analyses in the present study, aquatic fauna have different levels of tolerance to pollution and generally fall into two categories; Pollution tolerant organisms (including: tubifex, chironomids, and Physa) (**Fehler! Verweisquelle konnte nicht gefunden werden.**) and pollution intolerant organisms: they are only observed in unpolluted water systems in Jordan such as *Turbellarian*, *Theodoxus*, *Melanopsis*, *Galba*, *Amphipoda*, *Isopoda* and Mayfly larvae.

Table 8: Macrobioindicators groups taxonomy (table part 1 of 2)

Taxonomy group	Order	Family	Genus	Species
Insecta	Diptera	Chironomidae	Chironomus	
		Simuliidae (black fly)		

		Culicidae (Mosquitoes)		
		<i>Ephydriidae</i> (shore or brine fly)		
	<i>Ephemeroptera</i>			
	<i>Trichoptera</i>			
	<i>Placoptera</i>			
	<i>Odonata</i>			
	<i>Coleoptera</i>			
	<i>Hemiptera</i>	<i>Veliidae</i>		
Crustaceans <i>Ostracoda (class)</i>	<i>Amphipoda</i>	<i>Gammaridae</i>	<i>Gammarus</i>	<i>Gammarus. lacustris</i>
				<i>Gammarus pulex</i>
	<i>Isopoda</i>	<i>Asellidae</i>	<i>Asellus</i>	<i>Asellus aquaticus</i>
	<i>Crabs</i>			<i>Potamon potamios</i> Olivier
	<i>Podocopida</i>	<i>Cyprididae</i>	<i>Heterocypris</i>	<i>Heterocypris reptans</i> (Kaufmann 1900)
	<i>Podocopida</i>	<i>Limnocytheridae</i>	<i>Limnocythere</i>	<i>Limnocythere inopinata</i> (Baird, 1843)
			<i>Humphcypris</i>	<i>Humphcypris subterranean</i> (
			<i>Candona</i>	<i>Candona sp</i>

Table 9: Macrobioindicators groups taxonomy (table part 2 of 2)

Taxonomy group	Order	Family	Genus	Species
Aquatic worms Annelid : Phylum <i>Oligochaeta</i> : class <i>Hirudinea</i> : class Platyhelminthes: Phylum <i>Turbellaria</i> : class	<i>Oligochatea</i>	<i>Tubificidae</i>	<i>T. ubifex</i>	<i>T. tubifex</i>
	<i>Hirudinida</i> (leechs)			
Mollusca <i>Gastropoda</i> : Class	<i>Neritopsina</i>	<i>Neritidae</i>	Theodoxus	<i>Theodoxus (Neritaea) jordani</i> (Sowerby, 1832)
	<i>Neotaenioglossa</i>	<i>Thiaridae</i>	<i>Melanoides</i>	<i>Melanoides tuberculata</i> (Müller, 1774)
	<i>Neotaenioglossa</i>	<i>Melanopsidae</i>	<i>Melanopsis</i>	<i>Melanopsis praemorsa ferussac</i> ,
				<i>bulinus truncatus</i>
				<i>Hydropia musaensis</i>
				<i>Hydropia contempta</i>
	<i>Gastropoda</i>	<i>Physidae</i>	<i>Physella</i>	<i>Physella acuta</i> (Draparnaud, 1805)
		<i>Pulmonata</i>		
Plants <i>Magnoliophyta</i> : phylum	<i>Juncales</i>	<i>Junceaceae</i>	<i>Juncus</i>	<i>Juncus rigidus</i>
	<i>Caryophyllales</i>	<i>Chenopodiaceae</i>	<i>Arthrocnemum</i>	<i>Arthrocnemum macrostachyum</i>

6.5. Detected Bio-Indicators

6.5.1. Insects

Water insects belong to the arthropods phylum that live or spend part of their life cycle in water bodies. This group of organisms is commonly occurring in almost all freshwater habitats, as well as some brackish ones. Insect group is diverse and play a great role in aquatic ecosystems, which are an important biotic component of food webs for fishes and other invertebrates. Aquatic insects are found in vary wide variety of aquatic environments and represent various environmental disturbances tolerant grade. For this reason insect are considered a very good water quality indicator (Arimoro and Ikomi, 2008). Since each species has different environmental requirements and response to changes in environmental factors (e.g. temperature, dissolved oxygen, alkalinity, phosphates, nitrates and metal concentrations, salinity, etc.), however for example, some insects are very vulnerable and sensitive to pollution such as plecoptera (stonefly) and some species of ephemeroptera (mayfly) insects that are considered water quality indicator species and generally regarded as the most sensitive to ecological disturbance (Hynes, 1960). These insects are the most sensitive group to organic pollution such as sewage effluent and are then the first to disappear, because they require clean water condition and an abundant supply of oxygen to survive (Matagi, 1996 and Dohet, 2002), while some other insect species can live and survive in extremely polluted waters (Merritt and Cummins, 1996). Diptera insect has variable tolerance to pollution, but is usually considered to inhabit organic polluted waters, such as Chironomus genus which are notable as being excellent indicators of organic pollution and of the amount of eutrophication (phosphorus). Those insect species capable of surviving and thriving under low dissolved oxygen or highly turbid conditions inhabit polluted waters (Kolkwitz & Marsson, 1908, Chutter, 1972). Pinder (1995) also confirmed that Red midge larvae (Chironomids) are very tolerant to low levels of dissolved oxygen.

Some insect organisms may be found in a variety of environments, mayflies are present in clean water with good oxygen levels but some species can live with low oxygen supply (e.g. Callibaetis spp.) (Peckarsky et al. 1990). Mayfly insects are also used as a good indicator of water acidification (Soldan and Landa, 1989). The insect larvae are also useful as biological indicator organisms for assessing water salinity degrees for example Ephydriidae family of the order Dipetra usually inhabit saline habitats. It represents a highly tolerant bioindicator organism for highly salty water with low oxygenated or nutrient-rich environments.

Biological technique by using aquatic insects is based on their diversity, abundance and distribution in relation to the physical and chemical conditions of the habitats. Then the information which is given by indicator organisms can be used to estimate the level of environmental impact and its potential dangers for other living organisms (Kovacs, 1992).

Studies of aquatic insects as biological monitoring techniques have been widely examined and described the relationship between the water quality and the insect communities (e.g., Compin & Céréghino, 2003; Azrina et al. 2005). Some studies focused on the effects of anthropogenic activities, for example, Rao and Reddy (1991) studied dye factory effluent impacts on the insect organism and they found that mayflies, dragonflies and a member of Hemiptera larva were killed as a result of man-made pollution. Organic and metal contaminations were also studied by using insect fauna (Grumiaux et al., 1998).

Identification of insect organisms in Jordan is difficult and not well documented. To identify the collected specimens to species level was not possible for all our samples so the identification of insect samples to higher taxonomic level was possible.

Related to the field observation and laboratory work showed that aquatic insects species are found with different population densities. Epheneroptera, Trichoptera, Diptera, Placoptera, Odonata and Hemiptera fauna. Which are the most dominant aquatic insect orders in our organism samples. For example, large numbers of Ephydriidae larvae (Figure 39) are present in Karama brackish water so it can be used as saline water indicators. Red Chironomidae larvae are also observed and documented in different study sites which are found with high densities at Wadi Shueib reservoir sites (Figure 40). Various Epheneroptera larvae species are present in the most of the study sites with different water conditions (Figure 41).



Figure 39: Ephydriidae larvae, brine flies larvae from Karama area



Figure 40: Red Chironomidae larvae in Wadi Shueib reservoir site



Figure 41: Mayfly larvae (Epheneroptera larvae) from Wadi Shueib location.

6.5.2. Crustaceans

The crustaceans are arthropod phylum. This is a large and diverse group, including freshwater crabs, ostracods, crayfish, amphipods and isopods. Collected samples range in size from approximately 100 microns up to several centimeters. In our samples ostracods are smallest crustaceans, their size ranges from about 0.05 to 2mm in length. The biggest Crustaceans fauna are crabs with a range in size below 10 centimeters. Crustaceans inhabit a wide range of habitats, they are mainly found in freshwater, marine and brackish environments. Crustaceans live in a great number of different habitats, which are often used as bioindicator organisms especially in freshwater studies (DIN, 1991, Borgmann and Norwood 1995, Birk and Hering, 2009).

These organisms have different tolerance degrees to pollution, for example; most amphipods species are sensitive to contaminants so they can only live in clean water or low-polluted water (Pennak 1989, Pratiwi et.al 2004). Crustacea Isopoda are moderately intolerant bioindicator type and can be found in streams, ponds, or shallow areas of lakes (Peckarsky et al. 1990).

According to Dahl and Greenberg (1996) and many others, some of amphipod species are able to evaluate difference in habitat quality and confirmed that *Gammarus pulex* is a freshwater species that can tolerate pollution with low oxygen and low pH levels. Crayfish fauna are an example of pollution-tolerant indicator organisms. They can survive in relatively polluted water, which may be found in standing or flowing water ecosystems (Pennak 1989). Ostracods are small crustaceans, their size ranges from about 0.05 to 2mm in length and they are found in all water types, including salt water.

Generally, the crustaceans group has relatively slight tolerance to changes in salinity (Gruner, 1993) although the Crustacea ostracods species are often found to be relatively high tolerant to salinity.

Freshwaters bodies in Jordan are clearly dominated by crabs (Figure 42), amphipods, ostracodes and isopods (Figure 43), commonly seen swimming or hidden under vegetation, stones, rocks and debris on river, stream and lake bottoms. Those organisms are benthic, although planktonic or swim freely. The amphipod organisms are characteristic of spring water, and only clean freshwater quality for example in wadi Hisban springs large numbers of the yellowish colored amphipod organisms are present (Figure 44).



Figure 42: Potamon freshwater crab from Wadi Hisban location.



Figure 43: Isopod fauna from Wadi Shueib location.



Figure 44: Freshwater amphipod fauna from Wadi Hisban location.

6.5.3. Molluscs Group as Bioindicators

The molluscs organisms are represented by gastropods, which are found on rocks, logs, or dead leaves in spring, brooks, ditches, streams, and lakes, with different water qualities including fresh water and brackish water bodies. Gastropods fauna feed on dead organic matter, detritus, algae, and diatoms in the substrate. Gastropoda snails are generally pollution intolerant, however, some species of gastropods are much less polluting tolerant than others and are often used as well bioindicators organisms. Gastropoda (Snails) with gills are sensitive to pollution and prefer clean water with high oxygen level, for example, *Theodoxus (Neritaea) jordani* species (Figure 45) show high sensitivity to pollution in the different study areas and reflect very good water quality conditions. Although some species of Gastropoda (Snails) with lungs, e.g. *Physa* snail (

Figure 46) can tolerate polluted water and can even survive where the water is very low in oxygen saturation (Pennak 1989). They usually indicate nutrient enriched conditions and poor water quality (McDonald, et.al 1990). On the other hand some other species of gastropods can be an indicator of

good water quality and can survive with low amount of pollutants, such as *Melanopsis praemorsa ferussac*.



Figure 45: *Theodoxus (Neritaea) jordani* species with eggs in Hisban location.



Figure 46: *Physa* snail from Wadi Mujib dam location

6.5.4. Worms

Aquatic worms which are observed and studied during this research include: Tubifex worms (Oligochaeta), Leeches worms (Hirudimea) and Turbellaria worms. These worms range in length from 1-30 mm and are mainly found in different water quality with different ecological conditions. Some of the aquatic worms are highly sensitive to pollution while others are somewhat tolerant or completely tolerant to pollution.

Tubifex worms or sewage worms are of the class oligochaeta (aquatic earth worm) and are generally, organic pollution tolerant worms. Tubifex worms live in soft sediments rich in organic matter with low dissolved oxygen and are often present in very large numbers feeding on decaying organic matter in streams badly polluted with sewage materials (Peckarsky et al. 1990). For this reason the occurrence of this worm in a stream is a very good indication of organic water contamination (Wright and Todd , 1933: Brinkhurst , 1966). Thomas (1972) reported that Tubifex worms are useful bioindicators to assess the functional efficiency of water treatment plants. Plenty of sewage worms are present at the Wadi Shueib site and Wadi Mujib pond below the dam (Figure 47).

Leeches (Hirudimea) or more commonly recognized as bloodsucker worms. This worm species are mainly found attached to stones or other objects in shallow standing streams and feeding on worms, snails, and insect larvae (Davies, 1991) Leeches have variable tolerance to pollution, but are usually considered to inhabit polluted water (Peckarsky et al. 1990).

Freshwater turbellaria worms are known as flatworms from oval to elongate in shape and they are free-living animals. These organisms live in various aquatic systems such as ponds, lakes, streams, ditches, and temporary puddles and eat bacteria, protozoa, algae, and invertebrates. Flatworms are characteristic of spring water and only very clean creeks and streams because they need high dissolved oxygen supply in water and prefer cold water. This worm was found in the Wadi Shita site with clean cold water conditions (Figure 48)



Figure 47: Tubifex worms dwelling in muddy substrate (Wadi Mujib site).



Figure 48: Freshwater turbellaria worm (Shita spring site)

6.5.5. Plants

The water quality of a creek also influences the plants which grow on its margins or within its bed. Macro organisms are influenced by the quality of the water and therefore reflect that quality. Water does not have stress but it may produce stress to organisms living in or near it.

This research also highlighted the impact of water quality on plants. In addition, Macro bioindicators (flora and fauna) were used to gather to examine the effect of water stress on biota to provide a complete picture about the water quality and health in the study localities. Also water may be polluted, and in that case organisms living in or near it may not be healthy.

The aquatic flora which are living in water or near to water bodies and can be used as indicator of aquatic ecosystem health,. The plant indicator method is similar to animal indicators which is based on the principle that each aquatic plant species have different sensitivity to pollutants and the tolerance is usually limited so if the flora are known, the water quality can be predicted.

Aquatic plants reflect the quality of the water and can be used in addition to the animals which live in the water in the determination of degrees of pollution. Responses of plant organisms, e.g. Trees, shrubs, grasses and mosses, to the presence of pollutants are also observed in this study. Plants are used also to give a good indication of saline water quality. Where water salinity is higher, salt water plant species are observed.

As an example, The Chenopodiaceae family has species such as: (*Arthrocnemum macrostachyum*) which they present in Karama creek (Figure 49) which is usually an indicator of salt in the water and the ground in which it grows. *Juncus rigidus* species (Figure 50) is also a member of plants that lives in salt water and can be used as salty water indicators, commonly found in spring in Jordan such as Karama area.



Figure 49: *Arthrocnemum macrostachyum* species from Karama creek, location

Figure 50: *Juncus rigidus* species from Karama area.

6.6. Results and Discussion

The quality of running and standing water in Jordan can be defined by means of the biological indicator method which is based on organisms having high indicator of water quality. Here animals which can be used as bioindicators have successfully been recognized, belonging especially to the gastropods, aquatic worms and insect larvae. The results of the present study suggest a “Jordanian Biomonitor System for Watercourses (JBSW)” which can be classified with water qualities of 12 categories as shown in Table 10.

Table 10: Jordanian Biomonitor System for Watercourses (JBSW), categories, organisms, tolerance degree, water body type, Chemical indicators and some example locations for the bio indicators of water quality in Jordan.

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
1	High water quality (very clean/ non-polluted)	Theodoxus, Turbellarian (flat worm), and Mayfly larvae (<i>Caenis antoninae</i>)	Organisms highly sensitive to pollution	Rocks and gravels, clear shallow water from still to slow running water	Low COD and BOD values and main ions Ca^{2+} and Mg^{2+}	Hisban, and Shita Spring.

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
2	Very good water quality by self purification	No Turbellarian (flat worm). Theodoxus, Melanopsis, Mayfly larvae, (<i>Baetis monnerati</i>) and sponges.	Organisms highly sensitive pollution and not sensitive to strong growth of phytoplankton (no nitrate)	<i>Exposed</i> riverbed rocks but with darker mud deposits than normal due to additional nitrate. Shallow water from moderate to swift current.	COD value is around 15 mg/L and BOD 0 mg/L. High occurrence values of SO ₄ (>7 meq/l), NO ₃ (about 0.2 meq/l), and Na (5 meq/l)	Mujib River a few km below dam site and KAC during spring 2013.

Continued from Table 10

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
3	Good water quality	Gastropods (Melanopsis, Galba and Bulinus). Crustacea (Amphipoda) and mayfly larvae such as <i>Baetis monnerati</i>	Organisms sensitive to pollution, clean water to slightly polluted water.	Gravel bottom stream with moderate running water and springs issuing from carbonate rocks.	Normal freshwater chemistry but small increase in NO ₃ and PO ₄ values	W. Hisban below spring area, Wadi Sir, small spring creek in upper Wadi Zarqa.
4	Fairly good water quality	Melanopsis coming from continuous sources, Physa, Mayfly larvae (Caenis sp), and leeches.	Semi tolerant organisms that tolerate some degree of house sewage added to streams.	Rock and gravel, less sand occurs in the relatively turbid running water from moderate to swift current with high occurrences of aquatic vegetation.	NO ₃ concentration up to 1.0 meq/l and low concentration of Na dissolved ions	W. Shueib and Wadi Sir upstream of the treatment plant.
5	Moderate water quality	Chironomidae (blood worms), Physa, Mayfly larvae, and Caddisflies larvae.	Tolerant organisms which survive with moderately polluted water	Bottom surface between stones with organic mud and sand below surface black.	COD value reach to 50 mg/L and BOD 22mg/L. The concentration of SO ₄ ²⁻ around 6meq/l, NO ₃ ⁻ 1.5 meq/l, and PO ₄ 0.3 mg/l.	Periodically in lower Zarqa River
6	Slightly bad water quality	Low densities of Physa and leeches or disappearance and well present Simuliidae (Black fly larvae) and tube-building animals such as Chironomid (blood worms), and Tubifex (Sludge worms)	Pollution tolerant organisms but still with well aerated water	Rocks with muddy organic rich deposits in interspaces. Brown, turbid water with moderate to swift current.	Relatively high values of COD with 60 mg/L and BOD reach 35 mg/L. concentration of SO ₄ ²⁻ about 1,5 meq/l, NO ₃ ⁻ 1.0 meq/l, and PO ₄ 1.0 mg/l	Wadi Shueib downstream of the treatment plant and periodically parts of Zarqa River

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
7	Bad (Eutrophic) water quality	High occurrence of Chironomidae (blood worms), Tubifex and Physa with their eggs.	Tolerant to eutrophication organisms.	Fine sediment below surface and lower side of rocks black with still greenish turbid water and high growth of algae and Cyanobacteria.	The value of COD is 35.0 mg/L and BOD is measured 5.0 mg/L. characteristic compounds including SO_4^{2-} (4.5 meq/l) , NO_3^- (0.20 meq/l) , and PO_4 (0.30 mg/l)	Wadi Mujib Lake directly below dam

Continued from Table 10

Category	Water quality	Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
8	Very bad water quality	Red Chironomid worms, frogs and fish.	Organisms not sensitive to pollution.	Muddy sediment between rocks, black below surface, rocks covered with bacterial slime.	COD has high value of >70 mg/L and BOD >10 mg/L. Main ionic compounds such as NO_3^- (1.50 meq/l) , PO_4 (0.30 mg/l), HCO_3^- (8.0 meq/l), and CL (11.98 meq/l)	Periodically Zarqa River especially upstream of King Talal Reservoir.
9	Poor water quality (Heavily polluted water) (smelly and colored water.	No insect larvae only bacterial slimes. In Kafraïn lake fish periodically killed.	Organisms highly tolerant to pollution.	Muddy with high sludge content. Turbid - gray color in creeks brown in lake.	COD value reaches to 83.0 mg/L and BOD 40.0 mg/L. high concentration of PO_4 and NO_3	Wadi Sir after and below treatment plant and lake of Kafraïn dam
10	Mineral water	Large numbers of Pseudamicola (snail), Simuliidae (Black fly larvae), Chironomid worms. Larvae of mayflies such as <i>Nigrobaetis vuatazi</i> and caddisflies are present here. Springs with mosses and ferns	Organisms tolerant to mineral water and slightly salty water.	Springs with Gravel and silty ground in creeks.	Relatively high concentrations of Sr (reaches 37.0 mg/L) Br 10.0 mg/L, and Zn 0.02 mg/L	Wadi Atun stream
11	Warm water	No macroaquatic animals only dense crust of Cyanobacteria and springs with reeds (Phragmites)	Organisms are able to survive high temperatures.	Warm springs issuing from basalt and sandstone as warm as 60°C.	Relatively high concentration of trace elements such as Mn 5.0 mg/L, Cu 0.2 mg/L, Ba 700mg/L	Zara and ZarqaMa'in springs

Continued from Table 10

Category	Water quality		Aquatic organisms bioindicators	Tolerance degree	Environments description including; Substrates, water body type, and color.	Chemical indicator	Locations (examples)
12	Brackish water	Class 1	Pseudamnicola(snail), Ostracods (e.g., <i>Heterocypris salina</i> , <i>Cyprideis torosa</i> , and <i>Heterocypris reptans</i>) and Insect larvae such as Ephydriidae (shore fly), Chironomidae, mayfly (<i>Cloeon sp.</i>).	Salt tolerant organisms which survive with salinity of 16000 - 21000 $\mu\text{S/cm}$	Creek on gravel with algae and aquatic plants and pools surrounded by salt tolerant plants with ostracodes.	Relatively high concentrations of dissolved salts such as sodium chloride. Br and Sr concentrations are high	Karama area
		Class 2	Periodically with ostracods (e.g., <i>Heterocypris reptans</i> and <i>Cyprideis torosa</i>) up to 2011 with <i>Melanoides</i> but from 2012 including 2013 without <i>Melanoides</i> -surrounded by salt tolerant plants	Up to 2011 with salinity about 23600 $\mu\text{S/cm}$. In 2012 and 2013 the salinity level reaches to 26100 $\mu\text{S/cm}$	Standing water with muddy ground	Higher salt concentrations and Br concentration reaches to 16 mg/L and Sr with 50 mg/L.	Karama Reservoir lake.

This report deals with the living organisms as bioindicators of water quality from selected localities at Wadi Shueib, River Muib, and Zarqa River. In addition, several other water bodies such as Zarqa River, Wadi Hisban, Wadi Sir, Wadi Shita, Wadi Atun, Wadi Mujib and the area around Karama Reservoir were also studied and included in the overall work. The transition from clean water to polluted water within the course of a single creek can well be exemplified on Wadi Shueib case. The disturbance of intolerant organisms (*Theodoxus*, and *Melanopsis*) falls out and disappears with pollution increases along the creek of Wadi Shueib. Four sites were chosen along Shueib creek, the first at the Jadoor spring site, the second is creek near Alfrkhah and Deak spring, Third site after the Salt sewage treatment plant and final site is represent pond located near Shueib dam.

Molluscs organisms were abundant and represented by gastropods species (*Melanopsis praemorsa ferussac* and *Theodoxus jordani*) associated with freshwater crustaceans (amphipods and isopods) at Jadoor spring (site. 1, Figure 51).

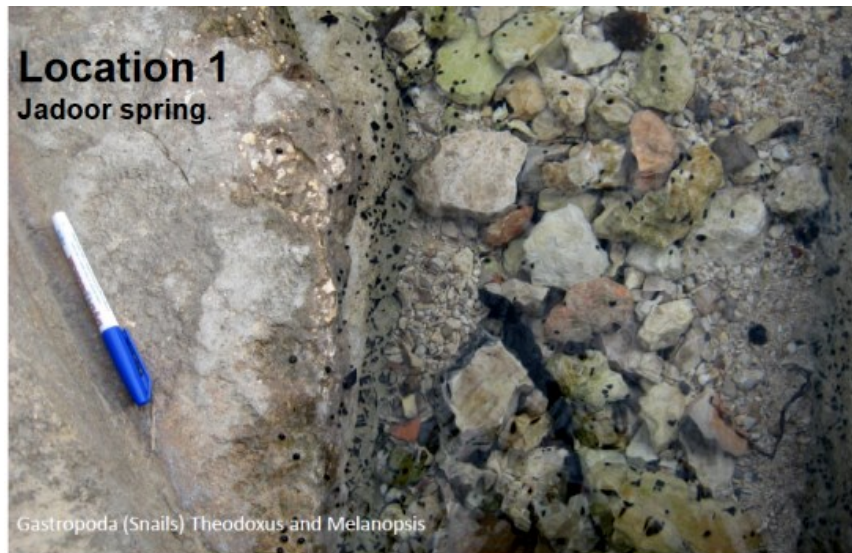


Figure 51: Plenty of *Melanopsis praemorsa ferussac* and *Theodoxus jordani* species were present in Jadoor spring.

The number of gills snails (*Melanopsis* spp.) was higher at the first site (Jadoor spring) and the *Theodoxus jordani* species were completely disappeared. In contrast, *Physa* snails the (lungs snails) were present with high density at the same site (Figure 52).



Figure 52: *Physa* snails associated with gelatin eggs, mayfly, isopoda macro-bioindicators are also present in site. 2.

At this site the water quality is weakly polluted and affected by the human activities (urbanization and agriculture) (Figure 53) but is still a good water quality.



Figure 53: Weakly water polluted in the site 2 caused by human activities.

At site 3 located after a Salt sewage treatment plant (Figure 54), the water was colored, turbid, smelly, dirty, and highly abundant of tubifex worms were obvious seen on sand polluted area with high population density.



Figure 54: Tubifex worms which are found in polluted water (site 3).

At the last sites which are located near Wadi Shueib dam, Abundant of Diptera order (red Chironomus sp.) coexisting with plenty of cylinder tube eggs shape (Figure 55) were observed and documented in this site.

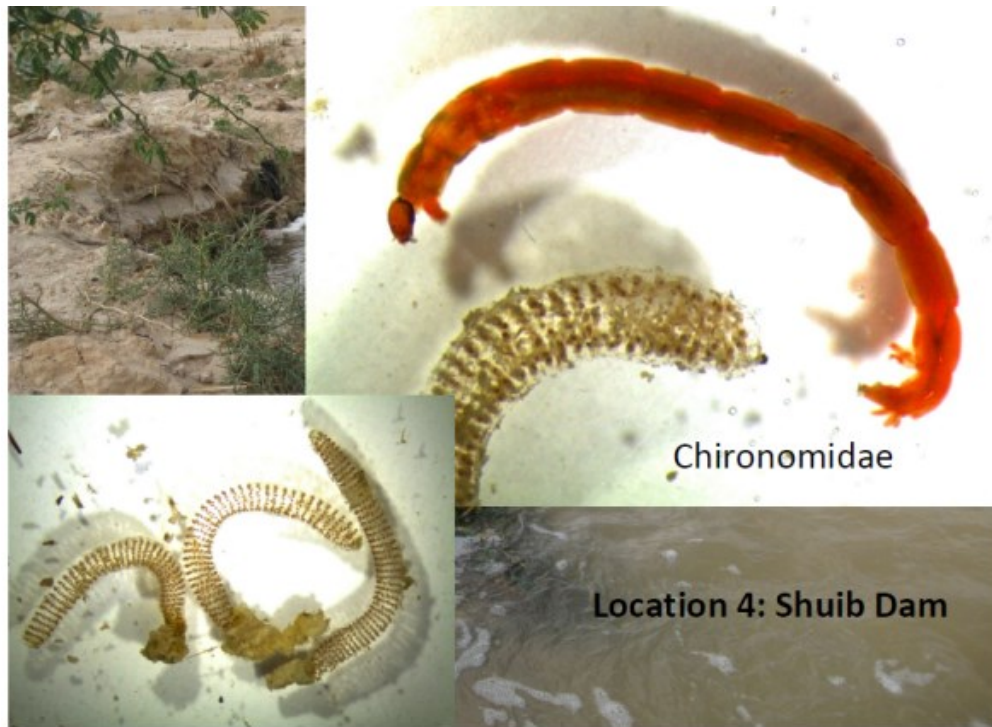


Figure 55: High densities of Chironomus Sp. Coexisting with eggs at the site.

From the field observations and related results we can summarize our work in the Figure 56. This figure shows four bars represent the relative abundance of disturbance aquatic macrofauna (intolerant and tolerant) species in the four sites were located in the Wadi Shueib creek from up to downstream around 100 Km² long distance. The presence or absence of these species mainly depends on physical and chemical properties changes of the wadi Shueib creek. Disturbance Intolerant organisms (Theodoxus, Melanopsis and Mayfly) are declining with pollution increase along this wadi. On the other hand the disturbance tolerant (Tubifex and Chironomidae) species are rapidly increasing and the intolerant organisms are totally disappeared under stressed conditions.

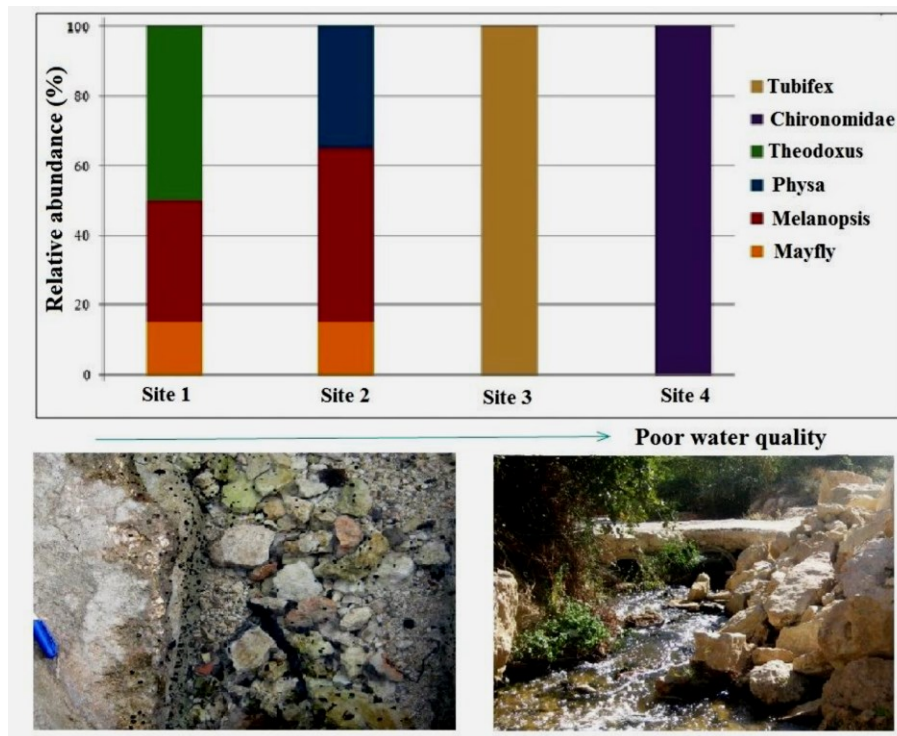


Figure 56: In Wadi Shueib stream, aquatic macrobioindicators document a shift in community composition related to human activity (Site 1: Jadoor spring; Site 2: creek near Alfrkhah and Deak spring; Site 3: creek after the Salt sewage treatment plant; Site 4: pond located near Shueib dam).

6.7. Conclusions

The presences or absences of certain aquatic organism's species or other plant life in an ecosystem can provide important clues about the health of the water quality.

Bioindicators are a useful tool to assess the functional efficiency of water treatment plants like Salt water treatment plants.

Related to these results and organisms occurrence in the Wadi Shueib creek we can conclude that the water qualities of those sites are represent different water qualities as following:

- The first site at the Wadi Shueib location (Jadoor spring) is still a clean water quality with a very good condition where sensitive organism's species (*Melanopsis praemorsa ferussac* and *Theodoxus jordani*) are clearly observed.
- Second sites represent midway of the Wadi Shueib creek were the characteristic species showing some degree of change in the quality of water , the very sensitive organisms (*Theodoxus jordani*) are eliminated and the tolerant organism's species (*Physa Sp*) are increased.
- Third site, from the present study showed the organic pollution are the major problems in Wadi Shueib water which receives pollutants from the Salt municipal sewage system and basically started after the Salt sewage treatment plant where the population of the pollution tolerant bioindicator species like (*Tubifex* worms and *Chironomus midge*) are present and increases rapidly with pollution. The degradation in water quality continues along the Wadi Shueib downstream to the dam.

7. Biological Methods for Water Quality Determination

Authors: Miriam Leicht (KIT), Stefan Fuchs (KIT)

7.1. Methods

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 (Friedrich et al, 1996).

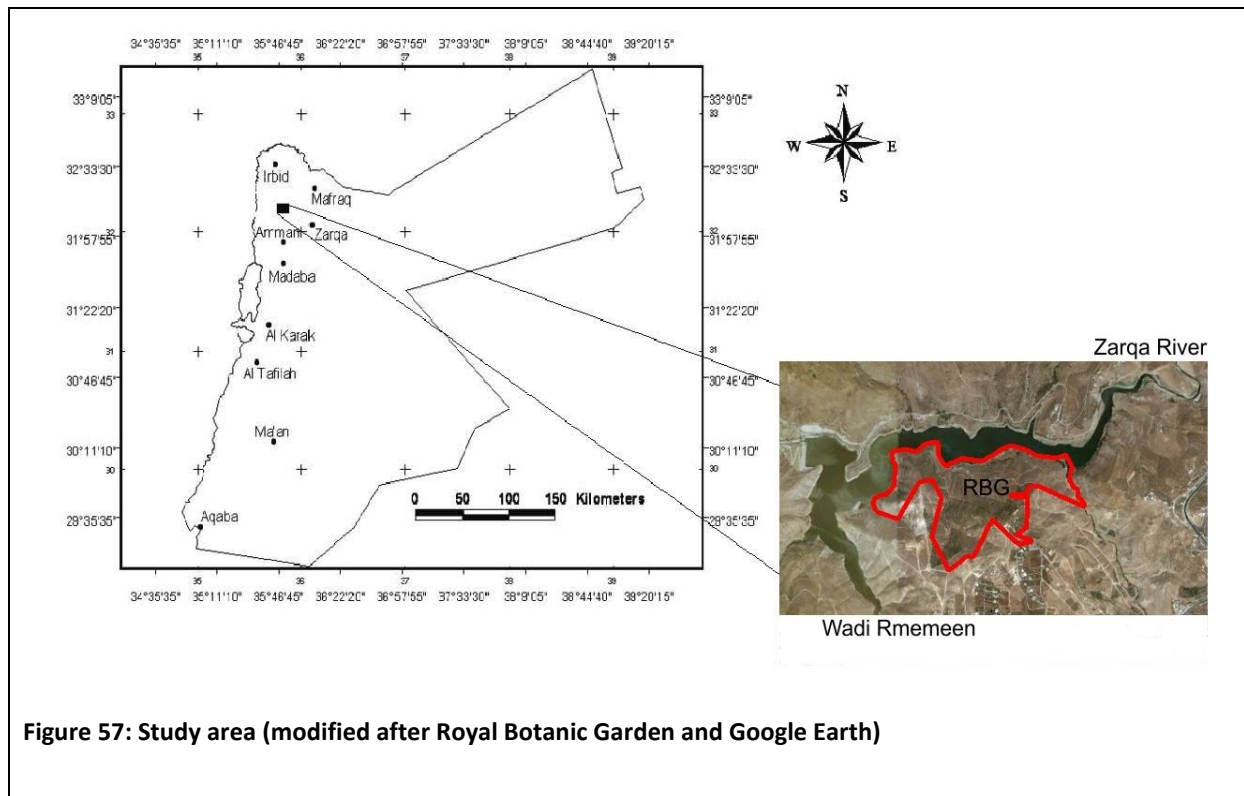


Figure 57: Study area (modified after Royal Botanic Garden and Google Earth)

Within the scope of the SMART II project, WP 5 – 502, a feasibility study focusing on monitoring of surface water quality based on biological indicators is being developed. Therefore two biological methods will be tested and applied in Jordan Rivers and Wadis around the King Talal Dam, Jordan (Figure 57):

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

This chapter will give a short introduction about the used methods to determine the water quality. A detailed description can be found in WP 5 – 502.

7.2. 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). They are, according to their structure, able to incorporate contaminants, to grow rapidly and they also offer an easy sampling possibility (Fuchs, 1996). 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.

The biofilm samplers (see Figure 58) which are used have a total surface area of 1 m² and are exposed at different sites within the surface water system for about 14 days (Figure 59), depending on the organic load of the water. During this time a biofilm grows on the surface of the collector and incorporates any particulate and dissolved pollution passing through. Afterwards the biofilm can be harvested easily and transferred to a lab for the subsequent analysis of specific pollutants (e.g. heavy metals, organic volatile compounds etc...as necessary).

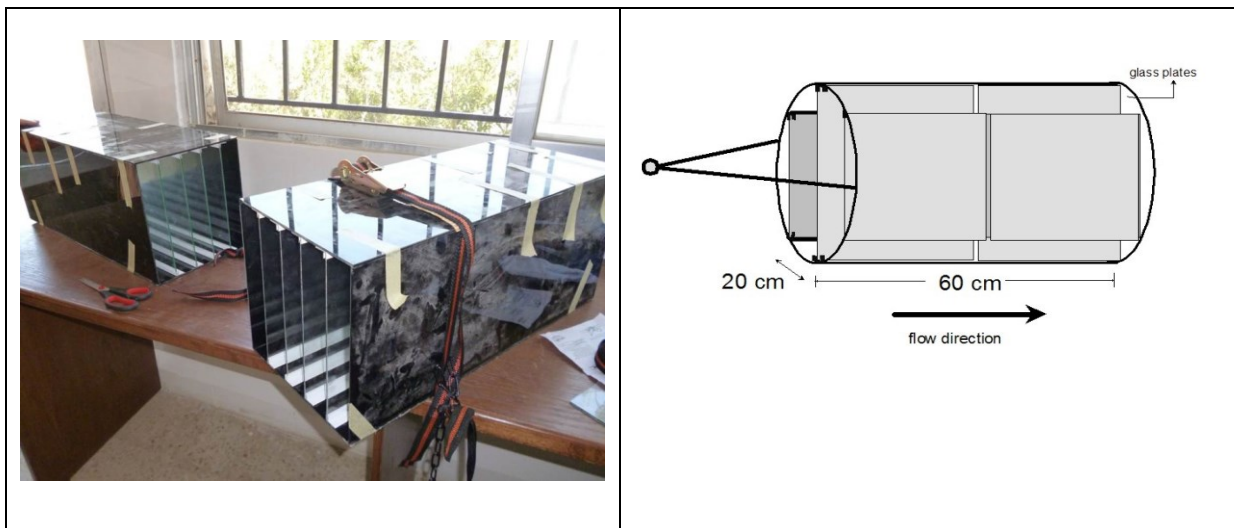


Figure 58: Biofilm sampler as used in the project area

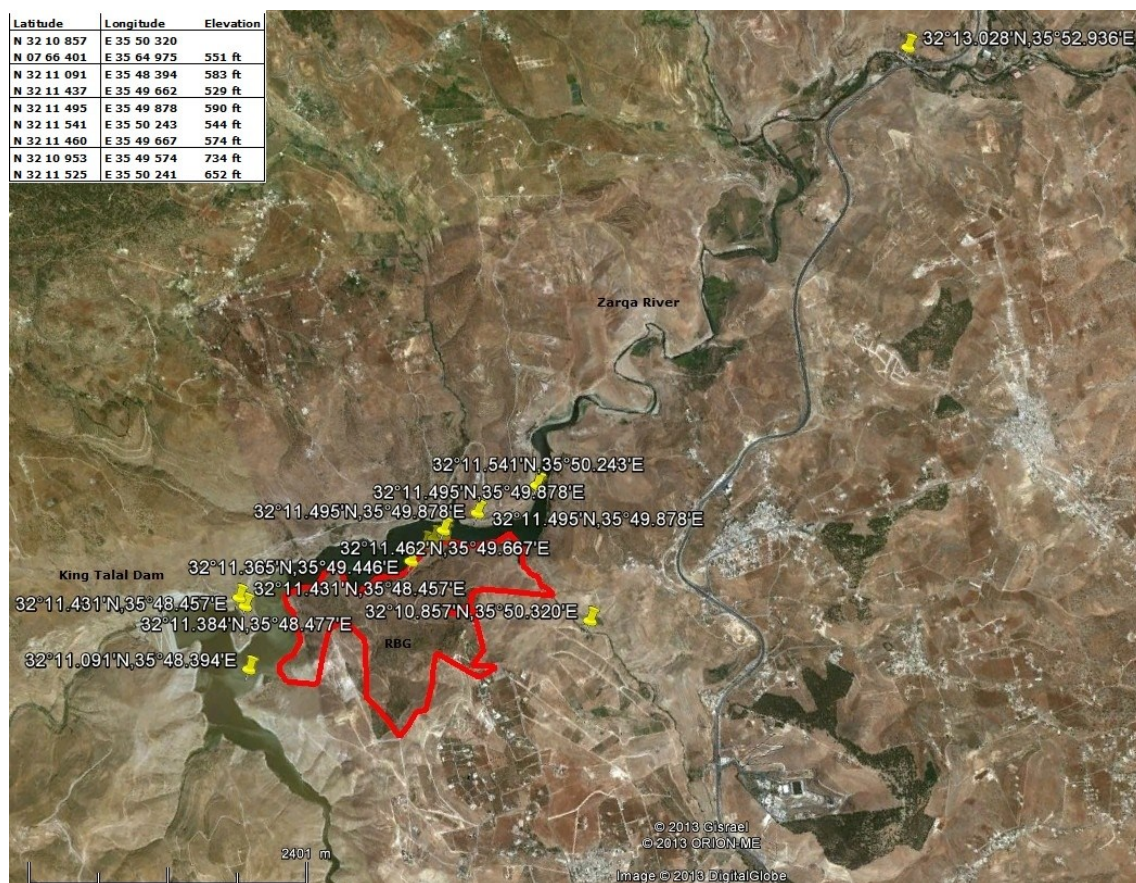


Figure 59: Location of the biofilm samplers

7.3.Macro-Invertebrate Survey

A further biological method, which has not been applied up to now but will allow completing the chemical monitoring, will be tested.

Thus Macro-invertebrates are being collected at several Wadis in Jordan up- and downstream of a point of waste water discharge (Table 11). After determining the most important indicator organisms, the composition of the macro invertebrate community will be compared to the findings of investigations in the Mediterranean Region.

Table 11: Main macroinvertebrate sample locations

Latitude	Longitude	Sample number
N 32 11 07,0	E 35 50 08,1	1
N 32 11 09,1	E 35 50 08,6	2
N 32 11 17,3	E 35 50 04,4	3
N 32 11 20,0	E 35 50 04,2	4

In addition, chemical and physical parameters like oxygen, temperature, conductivity, COD, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and Total Phosphorus will be analyzed to support the biological findings.

One method to utilize the data of the macro invertebrates is the Saprobic Index by Kolkwitz and Marsson (1908). It is based on the fact that downstream the source of pollution a significant change in the macro invertebrate's community is observable.

Figure 60 shows the principle of the Saprobic system. All organisms have specific environmental demands and only if a spot meets all the demands of a certain organism, it will settle down. The classification was developed to indicate heavy pollution caused by the discharge of e.g. untreated wastewater in the surface water body. Directly after the inlet point a rapid decay of organic material occurs. The decay will consume all oxygen that is available in the water which will lead to a significant change in the freshwater community. Class V thus shows only organisms which can stand very low oxygen concentration or very high organic pollution. In the following, until arriving at Class II due to self-purification, the community will recover.

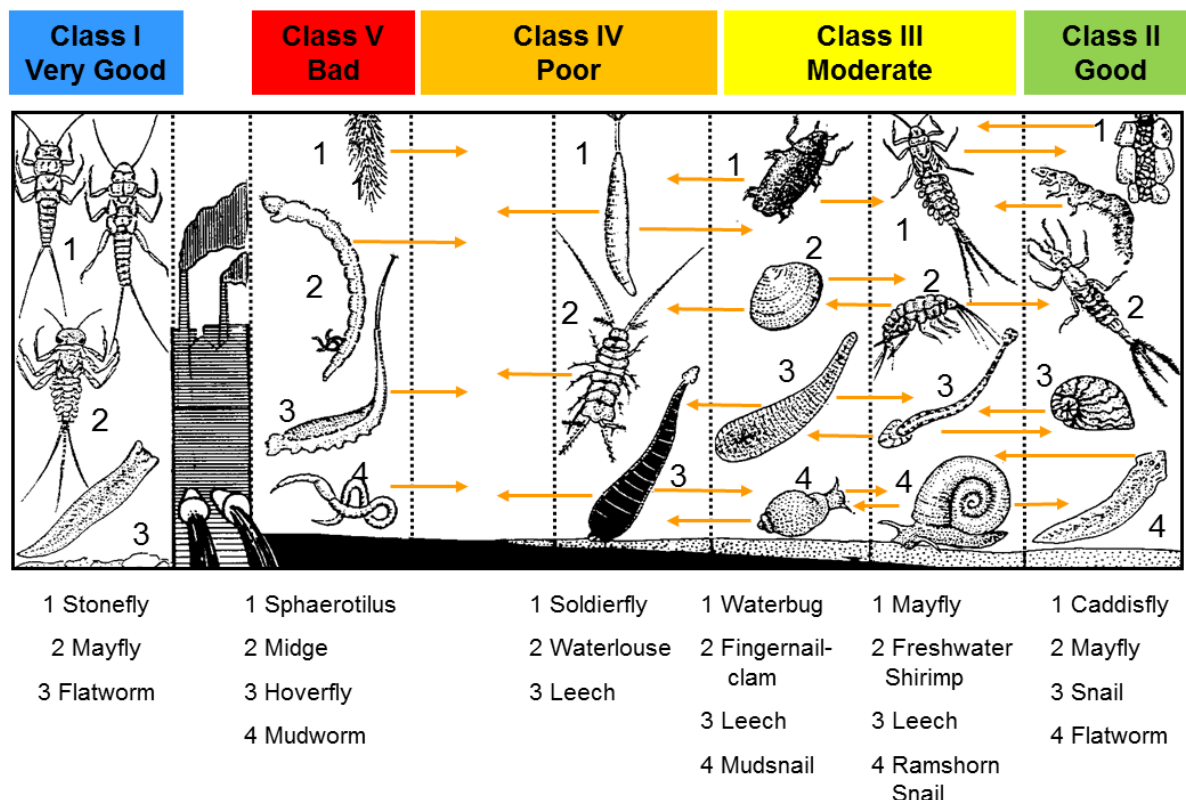


Figure 60: Classification based on changes in invertebrate community (modified after Barndt, Bohn, Köhler, 1996)

The Saprobic Index is based on four zones of gradual self-purification (Kumar, 2003):

Class I: unpolluted

Class II: the oligosaprobic zone, scarcely contaminated

Class III: the β -mesosaprobic zone, moderately contaminated

Class IV: the α -mesosaprobic zone, heavily contaminated

Class V: the polysaprobic zone, very heavily contaminated

7.4. Results

Based on the samples of Wadi Ar Rumman, biofilm monitoring shows almost no pollution with heavy metals. The Macro-Invertebrate survey in the Wadi Ar Rumman result is based on indicator organisms. No biological indicators for organic pollution have been identified. Al Zarqa River shows a reduced invertebrate community indicating the organic loading of the water. Detailed description of the measurements and results can be found in in WP 5 – 502 (Monitoring of surface water pollution based on biological indicators).

8. Conclusions and Recommendations

Authors: Felix Grimmeisen (KIT) & Moritz Zemmann (KIT)

8.1. Common Conclusions

Water resources pollution from urban areas must be understood in general as complex and diverse as the natural character of water resources already are. Against this background the fact of increasing groundwaters contamination due to high urbanization in the Lower Jordan Valley and its contributing Wadies became a main aspect within the SMART-project. Therefore it was primarily and exemplary worked out in the Wadi Shueib to assess the qualitative and quantitative impact of human activity. This report gives an overview on the different applied methods, showing diverse perspectives on urban pollution and shows the qualitative and quantitative results. Thereby, two main approaches were applied methods: the use of bioindicators such as macro-organisms or biofilm-monitoring, and water quality analysis of organic and inorganic substituents in combination with physicochemical measurements and microbiological monitoring. Thereby, specific attention was put on the detection of pharmaceutical substances in groundwaters and the installation of high resolution online monitoring system at a contaminated spring.

Concerning this report it must be stated that none of the observed drinking water exceeded the governmental limits for water supply, which is as well valid for the effluent quality of the WWTPs. Though, this qualitative perspective changes considering the results on raw waters such as groundwater and surface water due to both approaches on biological methods or microbiological and physicochemical analysis. It turned out that most critical to urban impact were fecal contamination of groundwaters, indicated by *E. coli* with detections varying from fairly low (1-10 findings) up to surface water conditions (> 1000) in most sampling points. The evidence of an urban impact e.g. by sewer leakages is marked additionally by the occurrence of pharmaceuticals in all springs and wells downstream and inside the Salt city area. Although they are far away from harmful concentrations for humans these tracers show always the linkage to increased nitrate concentrations and *E. coli* findings. The use of bioindicators like macro-invertebrates show a similar result, but with higher dependency on the distance to the urban area. Whereas e.g. macro-organisms at springs in the city center still indicate very good conditions beside various increased inorganic parameters (e.g. EC, nitrate or pharmaceuticals), contamination tolerant organisms rapidly increase in the creeks downstream to the city indicating increasing pollution of the water along the Wadi Shueib. Therefore it is necessary for the assessment of water quality to conduct as well physical and chemical measurements in addition to biological parameters.

Within a case study, the impact on the local water resource from the urban area was shown exemplary at Hazzir spring by high resolution monitoring. Derived from one and a half year of continuous nitrate measurements combined with further testings for *E. coli*, time series analysis come up with clear weekly signal in spring water quality caused by the local water supply and waste water production of the inhabitants. Nationwide in Jordan, but also common in other Arabic countries, the water supply of public households is organized on a weekly basis delivering different supply zones for about 1-1.5 days per week with fresh tub water to fill the private water tanks. Leaking drinking water pipes as well as leaking sewers both recharging the local aquifer and thereby affect the local groundwater quality on a weekly basis. These signals exemplary give proof of the anthropogenic impact to the urban water cycle.

However, fecal contamination remains as one of the most critical urban pollutant due to *E. coli* and therefore must be primarily taken into consideration to provide sufficient treatment. Besides this fact, the whole area seems to be more and more influenced by anthropogenic wastes. Increasing pharmaceutical detections and concentrations propose a rising level which might give a forecast of future amounts of pollution in the groundwater.

8.2. Further Work for the SMART Follow-up Project

Wadi Shueib remains one of the focus investigation areas for the SMART project. Extension of monitoring stations and wells used for drinking water or water from the reservoir used in agriculture is crucial to improve the common welfare and make safe use of those resources. Effects of further implementation measures like sewer rehabilitation or decentralized wastewater treatment could be measured thereby as well.

Results from Hazzir spring monitoring reveal the need for contamination specific online monitoring systems to react directly to the impact of anthropogenic influences to the local water resources. Therefore adverse effects to the local population could be avoided and up to now unused spring discharges could be utilized.

Concerning the overall water quality in the area, only minor exceedings of relevant thresholds could be observed. However, they bear no threat as the water is treated and further diluted in the Shoreija treatment plant.

Pharmaceutical residues could be detected in the whole area with increasing rates and concentrations over 5 years. Until now, they are logs scales below any application dosages but knowledge is growing about such substances, so more and more countries define allowable limits for effluent concentrations for treated wastewater. Therefore, it is highly advised to monitor them in all aquatic environments as well for the future.

Different bio-monitoring techniques showed similar results to the physio-chemical investigations, therefore acting as a good supplement to existing monitoring systems and techniques.

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 upset optimized solutions.

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