A step towards decentralized wastewater management in the Lower Jordan Rift Valley

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ABSTRACT

In order to address serious concerns over public health, water scarcity and groundwater pollution in Jordan, the expansion of decentralized wastewater treatment and reuse (DWWT&R) systems to small communities is one of the goals defined by the Jordan government in the "Water Strategy 2009–2022". This paper evaluates the general potential of decentralized wastewater system solutions to be applied in a selected area of the Lower Jordan Rift Valley in Jordan. For the study area, the connection degree to sewer systems was calculated as 67% (5% in the rural sector and 75% in the urban sector). The annual wastewater production available for DWWT&R in the rural sector of the investigation area was calculated to be nearly 3.8 million m^3 at the end of 2007. The future need of wastewater treatment and reuse facilities of the rural sector was estimated to be increasing by 0.11 million $m^3\,year^{-1}$, with an overall potential of new treatment capacity of nearly 15,500 population equivalents (pe) $year^{-1}$. The overall potential for implementing DWWT&R systems in the urban sector was estimated as nearly 25 million m^3 of wastewater in 2007. The future need of wastewater treatment and reuse facilities required for the urban sector was estimated to be increasing at a rate of 0.12 million pe $year^{-1}$. Together with the decision makers and the stakeholders, a potential map with three regions has been defined: Region 1 with existing central wastewater infrastructure, Region 2 with already planned central infrastructure and Region 3 with the highest potential for implementing DWWT&R systems.

Key words | decentralized wastewater management, Jordan, rural sector, treatment potential, urban sector

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INTRODUCTION

Jordan has one of the lowest per capita water availabilities worldwide ($<200\,m^3\,capita^{-1}\,year^{-1}$). In the year 2005, the country's total water demand was in the range of $1,560 \times 10^6\,m^3\,year^{-1}$, of which $461 \times 10^6\,m^3\,year^{-1}$ were supplied from non-renewable water resources, such as fossil groundwater resources. It is expected that the Jordanian demand will reach $1,686 \times 10^6\,m^3\,year^{-1}$ by the year 2020, from which only $792 \times 10^6\,m^3\,year^{-1}$ can be covered by renewable resources (MWI & GTZ 2004).

In the long run, the main means of providing the additional water necessary to satisfy this increasing demand will be made through the importation or creation of new

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water resources, e.g. through the desalinization of brackish groundwater resources (Gikas & Tchobanoglous 2009*a*; Rosenberg & Lund 2009).

This has to go along with the development of technologies and management options for a more effective and sustainable use of existing water resources, such as the treatment and reuse of wastewater. Therefore, in Jordan, treated wastewater is considered as a valuable water resource for irrigation and currently the Jordanian Government has imposed that all new wastewater treatment projects must include feasibility and design aspects for treated wastewater reuse (MWI 2009). In the Jordan National Water Master Plan, it is planned that the amount of treated wastewater for reuse will be increased from $34 \times 10^6\,m^3\,year^{-1}$ in 2005 to $101 \times 10^6\,m^3\,year^{-1}$ in 2020. This accounts for nearly 15% of the total renewable water resources available (MWI & GTZ 2004).

Many experts share the traditional viewpoint that centralized wastewater treatment and reuse systems provide the best technical and cheapest solution to overcome these problems as they are most reliable and easiest to operate, maintain and monitoring. However, the introduction of centralized wastewater technologies is often impeded by several factors. In fast growing conurbations, urban planning over several decades is almost impossible, meaning that investments in a centralized sewage disposal infrastructure will involve large uncertainties (Tjandraatmadja *et al.* 2005; Gikas & Tchobanoglous 2009*b*). In remote rural areas with a low population density, the implementation of centralized wastewater treatment facilities is difficult due to high investment costs for development and infrastructure but also deficient management and operation schemes often hinder a successful implementation. These problems might be overcome by implementing decentralized wastewater treatment facilities that have shorter depreciation times and often lower investment costs because a costly sewerage network is often not or only partly necessary (Werner *et al.* 2005; Maurer *et al.* 2005; Engin & Demir 2006). Decentralized systems also have the advantage that they are highly flexible and can easily be adapted to changing conditions and demands in both conurbations and rural areas (Orth 2007; Kamal *et al.* 2008). For successful decentralized wastewater treatment systems, centralized management is proposed to ensure a regularly inspection and maintenance. This management should also consider site specific accounting for social, cultural, environmental and economic conditions in the target area (Bakir 2001; Massoud *et al.* 2009; Al-Omari *et al.* 2009).

A recent example for a central management strategy for the implementation of DWWT&R systems is Jordan. The "Royal Commission on Water" of Jordan prepared the new Water Strategy entitled as "Water for Life. Jordan's Water Strategy 2009–2022" (MWI 2009). This new strategy reflects the Jordanian policy for the whole water sector and with respect to wastewater it sets the goal to provide adequate wastewater collection and treatment facilities for all major cities and small towns by 2022. The strategy explicitly specifies that decentralized treatment plants shall be built to serve semi-urban and rural communities and that decentralized treatment plants shall also be explored for new urban settlements.

These implementation aims should be specified by a Wastewater Master Plan that shall establish targets for providing collection and treatment systems throughout the country and to prioritize situations and locations. Such guiding Wastewater Master Plan should include investigations on the most suitable financing and operation systems, treatment technology, wastewater collection and reuse/discharge systems. But before starting defining these parameters, a first chapter of the master plan will be the quantification of the general potential of DWWT&R systems in the region and the selection of areas where the implementation is most useful. This allows generating an overview of the amount of wastewater to be treated and reused and also deducing a first estimation of future investments in decentralized wastewater infrastructure.

Therefore, the objective of this publication is to generate the first key parameters that characterize the general potential of a decentralized wastewater sector in the selected area in the Jordan part of the Lower Jordan Rift Valley. Based upon recent literature findings, assumptions of a few data were made and also estimated (or generated) due to non-availability of contemporary data on certain parameters that have been used in this paper in particular.

Overview of the study area

There are three neighbouring countries that share the Lower Jordan River Basin and its margins: Jordan, Palestine and Israel. The basin stretches along the Jordan River from Lake Tiberias in the north to the Dead Sea in the south and comprises an area of about 8,000 km^2. At the northern shores of the Dead Sea, the valley floor is at −425 m below sea level, whereas the surrounding highlands reach up to 1,200 m above sea level. The investigation area is located in Jordan at 31°45′–32°45′ N and 35°32′–36°15′ E, within the jurisdiction of 8 Jordanian governorates. They are: Irbid, Ajloun, Jarash, Al Balqa, Amman, Al Mafraq, Az Zarqa and Madaba.

In the Jordanian part of the Basin, the main wadis (ephemeral streams) that drain into the Jordan River are Wadi Al Arab in its northern end, followed by the wadis Al Rian, Shueib, Kafrein and Wadi Hisban in the South.

METHODOLOGY

Data collection and assumptions

A database was built in order to provide a current demographic view of the population in the study area. For this purpose, the Population and Housing Censuses from 2004 were provided by the Jordanian Department of Statistics. The population data from 2004 have been extrapolated to the end of 2007 to give a more actual picture of the situation and to allow a comparison of different sources of information.

For this extrapolation, the population growth for the rural and urban level was defined to be uniform. This assumption is based on real data of the Population Census of 1994 and 2004 that was provided by the Jordanian Department of Statistics. An analysis of these data showed that in the investigation area the mean population growth rate during this time period was 3.1% for both the rural and the urban sector. The finding that the population growth in recent years is fairly uniform across Jordan is supported by CDM (2005). They observed that the rural-to-city migration is nearing its end, which is attributed to improvements in the road network, so that more people are staying in small towns and commuting to work in the urban centres (CDM 2005).

For the period from 2004 to 2007, the population growth was estimated by the Department of Statistics with 2.3% (DOS 2010) and in another publication of the same Department with 2.5% (DOS 2007). To stem the rapid population growth rate, Jordan's National Population Commission has introduced birth-spacing programs on a national level. The result has been a growing awareness among Jordanians of the benefits of family planning. This might be the reason for the declination of the population growth rate from 3.1% (1994–2004) to 2.5% (2004–2007). We assumed that these data on national level also reflect the same growth rate in the urban and rural sectors in the investigation area. We decided to take the higher value (2.5% instead of 2.3%) because recent findings indicate that Jordan's annual population growth rate is increasing slightly (Pottera *et al.* 2009), which can be attributed to forced migration as a result of the current crises in the region.

Each settlement with 5,000 or more population was considered as "urban" and the remaining localities as "rural" (DOS 2004). The available data were collected and put into a Geographical Information System (ESRI ArcMap 9.2) to generate a spatial analysis GIS model.

No recent study has been identified on the daily per capita wastewater generation in Jordan. Therefore the wastewater generation was calculated by using data of recent surveys on urban and rural water consumption in Jordan. The identified water consumption for the rural and urban areas have been multiplied by the return factor of 0.825 published by von Sperling & de Lemos Chernicharo (2005) and Mara (2006), resulting in the daily wastewater generation per capita.

For the urban sector in the North of Jordan, CDM (2005) calculated a daily water consumption of 83 L $capita^{-1}\,d^{-1}$ (Lpcd). Al-Sharif & Abu-Ashour (2007) calculated 77 Lpcd for Irbid and Jamrah & Ayyash (2008) published for the cities of Irbid, Rusaifa and Zarqa 82.67, 69.63 and 82.34 Lpcd respectively. For the area of Amman, Ghunmi *et al.* (2008) published a water consumption of 84 Lpcd.

For the rural sector, two recent studies indicate a very low water consumption of 28 and 20 Lpcd (Ghunmi *et al.* 2008; Halalsheh *et al.* 2008).

Since both studies have been conducted in the investigation area, we defined the daily wastewater generation in urban regions of the investigation area as 65.8 Lpcd, which is the mean value of the before mentioned data on water consumption multiplied by the return factor. In the same way, the daily wastewater generation was calculated for the rural areas as 19.8 Lpcd.

The combined BOD_5 load in the rural and urban sector of the investigation area have been calculated by taking a mean BOD_5 load of 67 g capita^{-1} d^{-1} into account. This load represents the official mean value for total Jordan, which has been indicated in the national water master plan of Jordan (MWI & GTZ 2004). Recent data on the BOD_5 load for the rural and urban sectors in Jordan could not be obtained either from the responsible ministry or from recent publications. Therefore, a BOD_5 load of 25 g capita^{-1} d^{-1} was considered for the rural sector according to findings rural regions in South-East-Asian Countries (World Bank 2003; De 2006). Taking both numbers into account, an urban BOD_5 load of 73 g capita^{-1} d^{-1} was calculated as the difference between the daily BOD_5 load of the total investigation area (314.8 t d^{-1}) and the daily BOD_5 load of the rural sector (14.8 t d^{-1}) divided by the population of the urban sector of the investigation area.

It is important to clarify that the selected study area was defined by the hydrogeological criteria, not by the administrative districts. The investigation area stretches over 8 governorates. From those, Irbid, Ajloun, and Jarash were considered to lie completely within the investigation zone. The demographic data for Balqa Mafraq, Zarqa, Amman and Madaba did not lie in the investigation area and hence they were excluded.

Population analysis

The population in the investigation area was calculated as 4.7 million at the end of 2007. It represents approximately 82% of the Jordan population (5.75 million), although the surface of the investigation area represents only 6% of the country. The identified 411 rural communities have a population of 0.55 million in 2007, which was accounted for almost 12% of the total population in the study area. The mean population was calculated as 1,111 inhabitants per village (Table 1).

The urban population was defined as total inhabitants minus the rural population (see Table 1) and was calculated as 4.15 million in 2007. The identified 105

Table 1 | Identification of the "rural" and "urban" population and analysis of the population data in the investigation area by governorate (basis 2004)

Investigation area		**Rural sector**			**Urban sector**		
Governorate	**Total population**	**No. of communities ≤5,000**	**Population**	**Mean population per community**	**No. of communities >5,000**	**Population**	**Mean population per community**
Ajloun	126,296	40	32,782	820	9	93,514	10,390
Amman*	1,947,625	76	83,910	1,104	20	1,863,715	93,186
Balqa	363,520	70	106,432	1,520	13	257,088	19,776
Irbid	967,428	95	168,188	1,770	49	799,240	16,311
Jarash	162,963	46	56,988	1,239	9	105,975	11,775
Madaba	9,972	10	9,972	997	0	0	ND
Mafraq*	31,026	39	31,026	796	0	0	ND
Zarqa*	754,394	35	22,457	642	5	731,937	146,387
Total 2004	4,363,224	411	511,755	1,111	105	3,851,469	37,228
Total 2005†	4,472,305	ND	524,549	ND	ND	3,947,756	ND
Total 2006†	4,584,112	ND	537,663	ND	ND	4,046,450	ND
Total 2007†	4,698,715	ND	551,104	ND	ND	4,147,611	ND

*Population of some districts has been excluded.
†Calculated with a population growth rate of 2.5% (DOS 2007).
ND = Not determined.

urban communities were accounted for 88% of the population and almost 72% of the extrapolated total Jordanian population in 2007.

RESULTS AND DISCUSSION

Population density

In the current study, the population density distribution of the investigation area was calculated on the basis of the available population data of the settlements. Since the areas of the communities were not available, the method of Thiessen proximal polygons was used to determine the population density in the investigation area. The centre of each polygon thereby represents one settlement and was set in the most densely populated centre of the village. Thiessen polygons have the advantage that each polygon contains only one input point and any location within the polygon is closer to its associated centre than to the centre of any other polygon (Ryavec & Veregin 1997). The areas for each polygon were calculated using ESRI ArcMap 9.2 and the total population of each community was divided by the polygon area in km^2. This calculation and visualisation resulted in a patchwork distribution of community based population densities in the investigation area (see Figure 1).

Connection degree to existing WWTPs and future developments

One main criterion for the identification of potential sites for a future implementation of DWWT&R systems is the degree of connection of the population to already existing WWTPs. Since data were not available, the connection degree for the investigation area was estimated by analysing the actual loads of the existing WWTPs.

In 2007, a total of 21 wastewater treatment plants operated in Jordan and 13 of them are located in the investigation area. These plants have been mainly designed to treat the wastewater of cities and to serve urban areas surrounding these cities. Table 2 provides the 2006 loads of the existing WWTPs in Jordan (Data provided by the Jordanian Ministry of Water and Irrigation). For the WWTPs in the investigation area, a total treatment capacity of 3.14 million pe was estimated by using a specific BOD_5-load of 67 g capita^{-1} d^{-1}.

Assuming insignificant BOD_5-losses within the wastewater collection systems and low additional wastewater inputs from the stormwater, industry and the tourism sectors, it has been estimated that 67% of the population in the investigation area are connected to central sewer networks.

The method applied above does not allow distinguishing between the rural and urban population. Data from the literature indicate that the connection degree to sewer systems for the rural population in Jordan ranges between 2.8% (UN 2003) and 5% (DOS 2007). Since the connection degree has generally increased in recent years, we adopted the higher value of 5% for the connection degree of the rural population in the investigation area.

Potential for DWWT&R systems in the rural sector

Principally Jordan villages do not have sewer systems. Most households in rural communities have cesspits, but some of them are just ditches with trees planted to uptake some of the wastewater. Most of the cesspits leak (infiltrate) as they are not properly sealed and provoke significant groundwater pollution in those areas with abundant fractured rock (Werz & Hötzl 2007). Septage tankers pump cesspits and dump septage on designated sites (e.g. landfills) but some disorganized and even illegal dumping of septage into wadis exists.

DWWT&R system solutions may contribute to increasing the reliability and flexibility of Jordan's rural wastewater management. Innovative technologies may be combined into local "treatment and reuse trains" to meet hygienic standards, treatment goals, overcome site conditions and to address environmental and socio-economic requirements. We defined that the size of DWWT&R facilities range from individual buildings to several houses, hotels or small villages solutions up to a maximum size of 5,000 pe.

The overall potential for implementing such DWWT&R systems in the rural sector can be expressed by the total amount of wastewater that is not yet treated adequately.

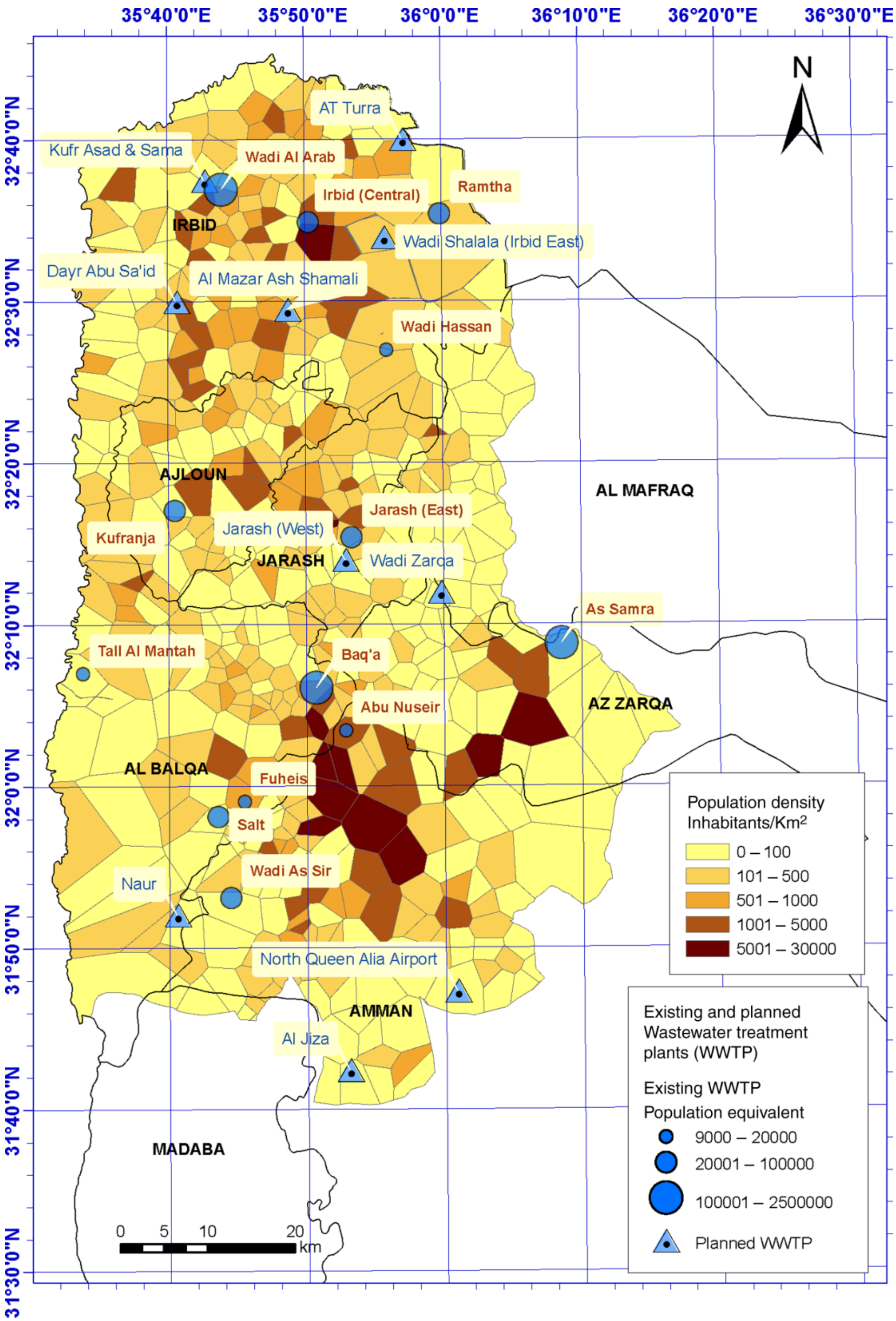

Figure 1 | Community based distribution of population densities and available data on existing and planned WWTP in the investigation area.

Table 2 | Loads and person equivalents of existing WWTPs in Jordan (2006)

			BOD_5-load design			Actual load		
No.	**WWTP**	**Technology**	**Hydraulic capacity (m^3/d)**	**BOD_5 (mg/l)**	**Person equivalent* (pe)**	**Hydraulic capacity (m^3/d)**	**BOD_5 (mg/l)**	**Person equivalent* (pe)**
1	As Samra	Stabilization ponds	68,000	525	532,836	224,175	745	2,492,692
2	Irbid (Central)	Activated sludge & trickling filter	11,000	800	131,343	6,354	1,037	98,345
3	Salt	Activated sludge	7,700	1,090	125,269	4,322	919	59,282
4	Bagá	Trickling filter	14,900	800	177,910	10,978	877	143,697
5	Wadi Al Arab	Activated sludge	22,000	995	326,716	9,960	764	113,574
6	Ramtha	Activated sludge	5,400	1,000	80,597	3,492	750	39,090
7	Abu Nuseir	Activated sludge	4,000	1,100	65,672	2,309	538	18,541
8	Wadi As Sir	Aeration tank	4,000	780	46,567	2,872	494	21,176
9	Kufranja	Trickling filter	1,900	850	24,104	3,387	1,160	58,641
10	Jarash (East)	Activated sludge	3,500	1,090	56,940	3,312	1,208	59,715
11	Fuheis	Activated sludge	2,400	995	35,642	1,684	607	15,257
12	Wadi Hassan	Activated sludge	1,600	800	19,104	1,099	802	13,155
13	Tall Al Mantah	Activated sludge	400	2,000	11,940	274	2,743	11,217
Investigation area			ND	ND	1,634,642	ND	ND	3,144,380
14	Madaba	Activated sludge	7,600	950	107,761	4,584	1,356	92,775
15	Mafraq	Stabilization ponds	1,800	825	22,164	1,866	602	16,766
16	Aqaba	Activated sludge	21,000	420	131,642	13,525	403	81,352
17	Tafielah	Trickling filter	1,600	1,050	25,075	1,013	655	9,903
18	Karak	Trickling filter	785	1,080	12,654	1,618	536	12,944
19	Ma'an	Stabilization ponds	1,600	970	23,164	2,644	800	31,570
20	Wadi Musa	Activated sludge	3,400	500	25,373	1,670	320	7,976
21	El Lajjun	Stabilization ponds	1,000	1,500	22,388	502	1,488	11,149
Outside of investigation area			ND	ND	370,221	ND	ND	264,435
Total Jordan			ND	ND	2,004,863	ND	ND	3,408,815

*Person equivalents are calculated on the basis of a specific BOD_5-load of 67 g $capita^{-1}$ d^{-1} (MWI & GTZ 2004).
ND = Not determined.

The total wastewater production in the rural sector was estimated on the basis of the per capita wastewater production and the rural population that is not connected to central wastewater treatment plants. The rural population of the investigation area for the year 2007 was extrapolated from the 2004 Population and Housing Census and a connection degree of 5% was adopted as described above. The per capita wastewater generation rate, measured in Litres per capita per day (Lpcd = L capita^{-1} d^{-1}), was derived from the MWI, who estimated a specific wastewater generation rate of 86 Lpcd (MWI & GTZ 2004).

As shown in Table 3, the annual wastewater generation available for DWWT&R in the rural sector of the investigation area was estimated to be nearly 3.8 million m^3 at the end of 2007. The corresponding overall potential treatment capacity was estimated to be 0.52 million pe and an annual BOD_5-load of nearly 4,800 tons.

The future need of wastewater treatment and reuse facilities of the rural sector was estimated by calculating the mean annual population growth over 10 years, starting in 2007. By using an annual population growth rate of 2.5% and assuming that water consumption and wastewater production will grow with the same rate, the mean annual population increase was calculated to be nearly 15,500. This was resulting in an annual increase in wastewater generation available for DWWT&R of about 0.11 million m^3 (Table 3).

Potential of DWWT&R systems in the urban sector

As shown above the connection degree of the population in the investigation area to sewer systems was calculated to be 67%. For the rural sector, a connection degree of 5% was adopted. Taking both numbers into account, for the urban sector a connection degree to the existing central treatment plants of 75% can be calculated. These calculations are in agreement with the survey conducted by DOS (2007) for total Jordan.

The overall wastewater load in the urban sector that, in 2007, was not adequately treated and for which DWWT&R systems may represent a potential solution, was estimated to be almost 25 million m^3 year^{-1}. The overall potential required treatment capacity was estimated to be 1.04 million pe with an annual BOD_5-load of approximately 27,600 tons (Table 3).

The annual increase in required wastewater treatment and reuse facilities within the urban sector was estimated to be 2.8 million m^3, corresponding to an overall requirement for new treatment capacity of 0.12 million pe year^{-1} (Table 3).

Proposed regions for DWWT&R systems within the rural regions

The data of population density, existing and planned treatment plants have been included in the GIS-Database.

Table 3 | Estimation of the current wastewater generation, wastewater treatment capacity and the annual increase in wastewater generation and treatment capacity in the rural and urban sector of the investigation area

Parameter	Unit	Rural sector	Urban sector
Specific wastewater production	L capita^{-1} d^{-1}	19.8	65.8
BOD_5-person equivalent	g capita^{-1} d^{-1}	25	73
Population 2007	No.	551,104	4,147,611
Connection degree public sewer	%	5	75
Population growth rate	%	2.5	2.5
Total annual wastewater generation	m^3 year^{-1}	3,783,687	24,903,293
Wastewater quality (BOD_5-load)	mg L^{-1}	1,263	1,109
Total annual BOD_5 production	t year^{-1}	4,777	27,628
Total treatment capacity to be installed	pe	523,549	1,036,903
Annual increase in wastewater generation	m^3 year^{-1}	111,553	2,790,011
Annual increase in BOD_5 production	t year^{-1}	141	3,095
Annual need of new treatment capacity	pe	15,436	116,168

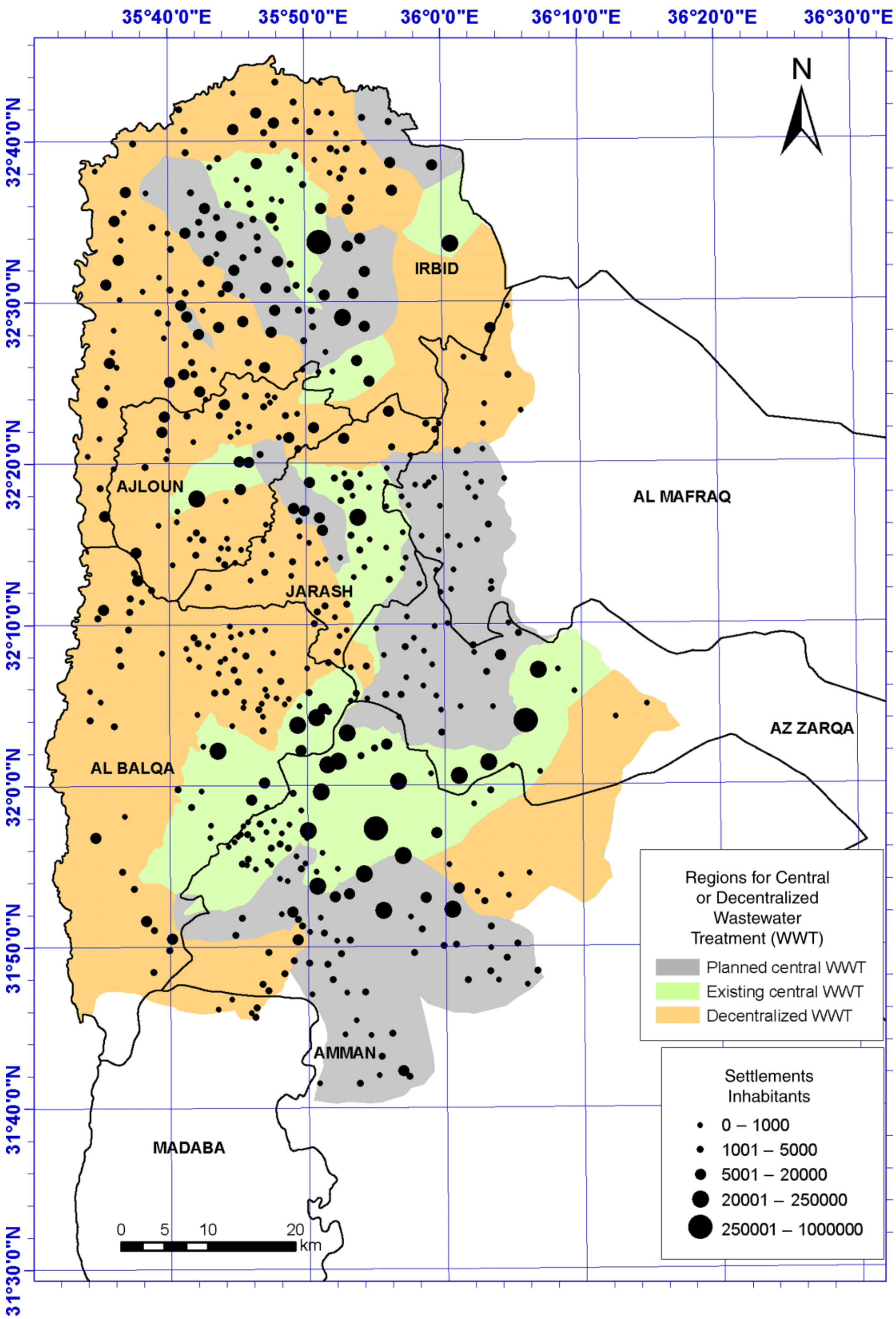

Figure 2 | Proposed regions for the future investigations on the implementation of DWWT&R systems.

The locations for which it is already planned or proposed to construct centralised wastewater infrastructure were provided by the MWI (Figure 1). The following three regions have been defined:

- Existing central WWT
- Planned central WWT
- Potential for decentralized WWT.

The regions that are covered by existing central wastewater treatment plants are mainly urban agglomerations. The connection degree to the existing central WWTPs within these areas is not 100% and consequently the classification does not imply that they are not suitable for decentralized systems. However, the actual policy of the government is apparently to expand the existing sewer networks within the region using already existing central treatment plants.

The second category ("Planned Central WWT") was defined as regions where future central developments for wastewater infrastructure greater than 5,000 pe are already planned. These regions are characterized by a low connection degree and mainly include fast growing urban areas and potentially rural villages in the surrounding areas as well. The uncertainties of some of the planned developments do not exclude these areas for a complementary implementation of DWWT&R systems but centralized solutions will be prioritized for most of the settlements in these regions.

The third category of regions ("Potential for decentralized WWT") is characterized by its rural and urban character and a low population density where in the nearer future no central wastewater infrastructure will be built. These regions are indicated in Figure 2 and cover the Lower Jordan River Valley from the Dead Sea in the South to the border with Syria in the North; the region North and East of Irbid and the centre of the investigation area.

Future research will be directed to the estimation of the investment costs needed to connect the urban and rural population to DWWT&R system solutions. Maurer *et al.* (2005) estimated the costs for decentralised wastewater treatment systems in Western Europe and North America between 260 and 680 USD per capita for scenarios with sewer systems. However, a cost analysis for the definition of concrete investment plans requires a more detailed analysis of suitable technologies and operation and maintenance schemes (Fane & Mitchell 2006). The selection of technologies and operation and maintenance schemes should thereby consider social and legal framework conditions of the region.

CONCLUSIONS

In most arid regions in the world, the use of reclaimed water as an additional water resource is inevitable, especially if water stress factors such as population growth and living standard increase. The recovery rate of wastewater for reuse by the existing central treatment facilities is limited and can only be expanded by appropriate DWWT&R system solutions that include treatment, local storage and reuse of the treated wastewater (Bakir 2001; Massoud *et al.* 2009). In Jordan, decentralized wastewater management strategies have been integrated in the "Water Strategy 2009–2022" as a suitable measure to meet the goal that adequate wastewater collection and treatment facilities shall be provided for all major cities and small towns by 2022 (MWI 2009).

The results presented here contribute to establish targets for providing DWWT&R systems in Jordan, particularly in rural locations where approximately 0.52 million people are not connected to central sewers.

The presented results and the methodology of mapping the potentially suitable areas for DWWT&R systems provides a useful planning tool for the sustainable development of the water sector in rural and urban areas. The generated maps may serve as a basis for a more detailed analysis of the sector needs and as a support for future investment decisions.

Suitable DWWT&R technologies, for example, should meet the strict Jordanian standard for Reclaimed Domestic Wastewater (MWI *et al.* 2006) and at the same time should be achievable, robust and not require highly qualified personnel for operation and maintenance (Al-Omari & Fayyad 2003; Abbassi 2008; Bdoura *et al.* 2009). The calculations presented here and findings from Ghunmi *et al.* (2008) and Halalsheh *et al.* (2008) indicate that the technology selection should especially consider the high BOD_5 concentration of the strong wastewater in Jordan that are due to the low water consumption.

Before specifying the costs and suitable financing and operation models for the implementations of DWWT&R technologies, future work should be directed to define design criteria, performance specifications and guidelines not only for wastewater treatment, but also for sewer, irrigation, storage and groundwater recharge systems (Bdoura *et al.* 2009).

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