JJEES
Jordan Journal of Earth and Environmental Sciences
Volume 8, (Number 2), Dec, 2017
ISSN 1995-6681
Pages 77 - 89

The Need for a Quantitative Analysis of Risk and Reliability for Formulation of Water Budget in Jordan

Fayha M. Al-Shibli*, William A. Maher, Ross M. Thompson

Institute for Applied Ecology – University of Canberra, Bruce, ACT, 2601 Australia

Received 21 May, 2017; Accepted 25 Aug, 2017

Abstract

Jordan is one of the most water-deficient countries globally, with a water demand consistently exceeding the water availability. The present paper reviews the state of current water resources and programmes being implemented to tackle this challenge. The authors of the present paper identify the recent trends and potential risks of maintaining a reliable water supply, discuss the past and the recent developments and extrapolate future water needs. The analysis found that the largest pressures on water supply come from population increases, the likely long-term consequences of climate change and groundwater over-abstraction. The authors conclude that, to date, projections of water use, supply and demand have not considered the different socio-economic factors and the various environmental and technological changes in a quantitative way. A new approach is suggested to quantify the future available water emphasising the need for quantitative assessment of the most influential pressures determining future water availability and use.

Keywords: Water system, Change in climate, Population growth, Groundwater over-abstraction.

1. Introduction

Jordan occupies an arid and semi-arid Mediterranean climatic zone, and is undergoing natural and human-driven changes that could have negative consequences for current and future water availability (Iglesias et al., 2011). Jordan is already suffering substantial water shortages because of limited natural water supplies (FAO, 2012) which are not sufficient for potable usage. UNEP (2007) has determined that annual freshwater needs will be 420 m^3 per capita by 2050. In Jordan, it is predicted that by 2025, freshwater supply could decrease to 90 m^3 per capita compared with 3600 m^3 per capita in 1946 (El-Naser, 2012; MWI, 2014). With no substantive reuse of water in Jordan currently, drivers, which increase water demand, are of critical importance (MWI, 2013c).

Many natural factors determine the amount of water, which is available for human use. These include hydro-climatic characteristics such as climate, geography, soil type, latitude, and vegetation cover. There are also significant human-pressures which determine water availability. These include groundwater over-abstraction, rapid population growth and the resulting changes in living patterns, technological advances, and land degradation due to overgrazing, deforestation, urbanization, and industrialization.

These pressures can act individually or in combination to affect water availability (Gleick, 1998; Zimmerman et al., 2008; FAO, 2012). Due to the threat of water shortages in Jordan, a number of efforts have been taken to manage the gap between the limited supply and high demand. Increasing demands of water across competing sectors have led to a growing need to develop policy and management solutions to ensure adequate water supply. Jordan has developed institutional, technological and strategic solutions to cope with water scarcity within the local cultural environment. The Jordanian government currently has focussed on large-scale water supply projects, such as inter-basin water transfers, dam construction, extraction of fossil groundwater aquifers, enhancing physical infrastructure and exploring for groundwater in the private sector (Al-Jayyousi, 2012). The government has issued more licences for groundwater well drilling and has imposed surveillance on existing wells. As a part of this initiative, 3043 legal wells were gauged for industrial, agricultural, municipal and livestock usage and 141 illegal wells were closed (MWI, 2013b). Moreover, a water pricing policy has been implemented to keep the extraction rates within recharge rates (MWI, 2013a), combined with increasing sewage connections, increasing wastewater and households tariffs, and reducing non-revenue water volume. At the household level, staggered water delivery times have been introduced, and compulsory water storage is required in new buildings. Water has been rationed for each economic sector and there is an expanding reliance on water trade for potable usage (Toppo, 2014). A range of measures has been applied to increase the efficiency of water use in irrigated agriculture. Farmers have been encouraged to rely on the reuse of treated wastewater and/or to purchase water from private wells. Efforts have been made to secure the rights to crops in neighbouring countries in order to reduce water consumption in agriculture, especially water consuming crops. Prioritization of water uses for drinking is the focal issue rather than water for irrigational or industrial uses (MWI, 2016d).

* Corresponding author. e-mail: fayha.al-shibli@canberra.edu.au

Nevertheless, reforming of water rights and allocations as well as water pricing probably have not succeeded in meeting water saving targets (Bengoechea, 2013).

Despite substantial reform of water policy, governance arrangements and management, it remains uncertain whether these measures will guarantee the future water needs for Jordan. Quantification of long-term future water system components including; demand, supply, future deficits, and the effects of the main drivers have been inadequately addressed by water industry planners.

This review evaluates the effects of pressures on water availability through water accounting, and uses quantitative analysis to estimate their effects on the water budget. We show the importance of quantitative studies for evaluating the consequences of interacting drivers in order to provide the basis for future management of Jordan›s water resources.

Due to the threat of water shortages in Jordan, a number of efforts have been taken to manage the gap between the limited supply and high demand. Increasing demands of water across competing sectors have led to a growing need to develop policy and management solutions to ensure adequate water supply. Jordan has developed institutional, technological and strategic solutions to cope with water scarcity within the local cultural environment. The Jordanian government currently has focussed on large-scale water supply projects, such as inter-basin water transfers, dam construction, extraction of fossil groundwater aquifers, enhancing physical infrastructure and exploring for groundwater in the private sector (Al-Jayyousi, 2012). The government has issued more licences for groundwater well drilling and has imposed surveillance on existing wells. As a part of this initiative, 3043 legal wells were gauged for industrial, agricultural, municipal and livestock usage and 141 illegal wells were closed (MWI, 2013b). Moreover, a water pricing policy has been implemented to keep the extraction rates within recharge rates (MWI, 2013a), combined with increasing sewage connections, increasing wastewater and households tariffs, and reducing non-revenue water volume. At the household level, staggered water delivery times have been introduced, and compulsory water storage is required in new buildings. Water has been rationed for each economic sector and there is an expanding reliance on water trade for potable usage (Toppo, 2014). A range of measures has been applied to increase the efficiency of water use in irrigated agriculture. Farmers have been encouraged to rely on the reuse of treated wastewater and/or to purchase water from private wells. Efforts have been made to secure the rights to crops in neighbouring countries in order to reduce water consumption in agriculture, especially water consuming crops. Prioritization of water uses for drinking is the focal issue rather than water for irrigational or industrial uses (MWI, 2016d). Nevertheless, reforming of water rights and allocations as well as water pricing probably has not succeeded in meeting water saving targets (Bengoechea, 2013).

Despite substantial reform of water policy, governance arrangements and management, it remains uncertain whether these measures will guarantee the future water needs for Jordan. Quantification of long-term future water system components including; demand, supply, future deficits, and the effects of the main drivers have been inadequately addressed by water industry planners.

This review evaluates the effects of pressures on water availability through water accounting, and uses quantitative analysis to estimate their effects on the water budget. We show the importance of quantitative studies for evaluating the consequences of interacting drivers in order to provide the basis for future management of Jordan›s water resources.

2. Geo-Climatologically Characteristic

Jordan has a hot climate characterized by dry summers, and the annual average temperature exceeds 18°C. According to the Köppen-Trewartha climate classification (KCC) (Belda et al., 2014) that considers types, subtypes and rainfall/temperature regime; the climate of Jordan can be classified as a BSh climate. BS refers to the semi-arid or steppe climates, and is found where the mean annual precipitation is lower than R (annual precipitation threshold), but higher than 0.5R. If mean annual precipitation is lower than 0.5R, the KCC defines the area as having an arid or desert climate BW. The eastern and southern areas of Jordan have a BWh climate: a hot, dry desert climate with annual average temperatures above 18°C.

Jordan is 88,778 km^2 in area with surface water occupying approximately 540 km^2 (DoS, 2015). Most of the land cover is aridisols and rich in carbonates. Low rainfall zones are covered with sand and silt which results in arid-adapted vegetation. The predominant land cover is pasture, with forest and cultivated fields covering less than 9% of the total area. Desert and semi-desert cover 85% of the total territory area and three quarters of the land is covered with rocks, granite rocks, sand and bare soil (Ababsa et al., 2012; MoEnv, 2006). Soil moisture regimes range from xeric to arid, while the soil temperature ranges between thermal and hyper-thermal.

Jordan can be sub-divided into nine identifiable climatic regions: cool arid Mediterranean, warm arid Mediterranean, very warm arid Mediterranean, very warm Saharan Mediterranean, warm Saharan Mediterranean, cool Saharan Mediterranean, cool semi-arid Mediterranean, warm semi-arid Mediterranean and mild sub-humid Mediterranean (MoEnv, 2006). The Jordan climate possesses these characteristics due to its transitional location between the Mediterranean climate in the west and the arid and semi-arid climate in the east and south. Across all zones, drought coincides with maximum temperatures to bring summer dryness. The Mediterranean climate within the highland regions is differentiated by moderate and dry summers and cold and rainy winters. The Desert zone prevails in Badia with total area of 70,000 km^2, which is characterized by hot summers and cold winters. A Semi-tropical climate is dominant in the Ghor area (Jordan Valley) which is differentiated by hot summers and warm winters (Figure 1).

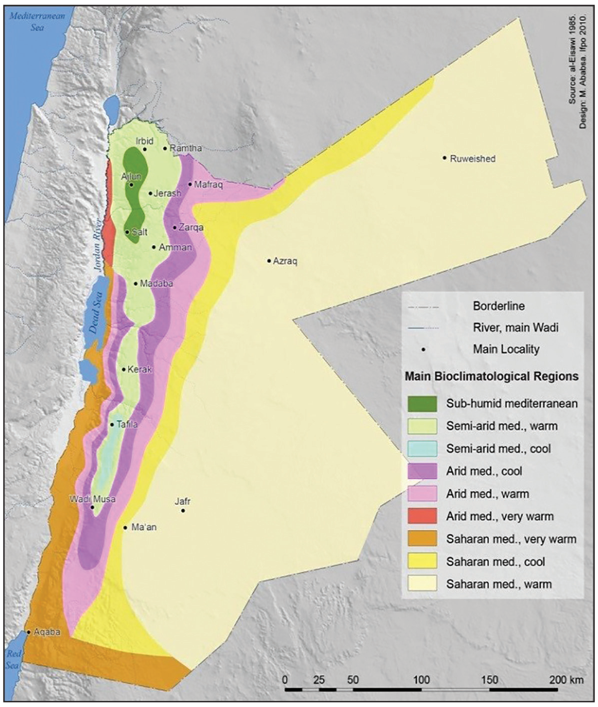

Figure 1. Main bioclimatological zones of Jordan; source: Ababsa and Kohlmayer (2013).

3. Annual Water Budget

The main water resources of Jordan consist of surface water resulting from precipitation (rainfall and snow), groundwater aquifers and/or fossil water in deep aquifers, and treated wastewater resources (Fig. 2). Currently, data on these resources quantities only exist for 2014 water year, so all calculations are based on that year.

Rainfall is the main water resource; the long-term average rainfall is about 8200 Million Cubic Meters (MCM; MWI, 2016g). Most rainfall evaporates (94.7%) and the remainder flows into rivers and other catchments, such as dams (2.3%) or infiltrates into underground aquifers (3.0%). In 2000-2013, it was estimated that the long-term average for total consumptive water use was 823.8 MCM consisting of municipal (429 MCM) that included domestic, refugee water use, commercial & tourism, agricultural (503 MCM) and industrial consumption (43.8 MCM; MWI, 2012; MWI, 2013a; MWI, 2014). In 2014, municipal consumption included 369.9 MCM for domestic and 59 MCM for non-domestic uses (commercial & tourism) but did not incorporate the 52.4 MCM used by refugees (MWI, 2016g). The Government›s aim is to reduce the gross volume used for irrigation in order to meet domestic demand. At present, most surface water is allocated for irrigation, primarily in the Jordan Valley (Raddad, 2005). Agriculture accounts for more than 60% (MWI, 2013b) of the total water withdrawal. Similar to global usage (Kassam et al., 2007), agriculture accounts for more than 90% of water consumption (FAO, 2012). It has been estimated that the distribution efficiency of irrigation conveyance systems across Jordan in 2013 was 87% (MWI, 2013b).

In terms of domestic water consumption, houses expend most water usage on bath, shower, washing machine, irrigated yards, and leaks (Jacobs and Haarhoff, 2007). This means that significant domestic consumption is of non-potable water. The peak daily outdoor water demand corresponds more closely to rainfall frequency rather than rainfall amount (Adamowski, 2008).

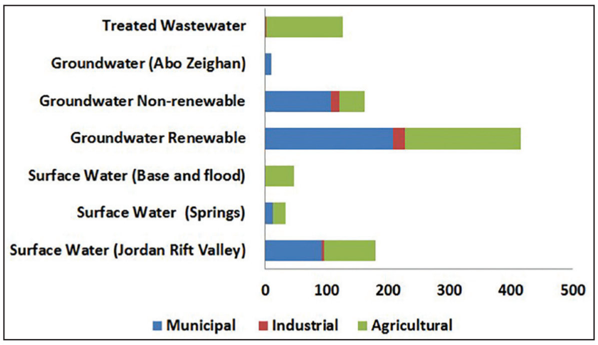

Figure 2. Main available water resources: surface water resources including base and flood, springs and Jordan Rift Valley, groundwater resources including Abo Zeighan aquifer, renewable and non-renewable aquifers, and treated wastewater. The main allocations of each resource to municipal, agricultural and industrial usages in MCM (million cubic meters), source (MWI, 2016d)

An estimate of the water budget of the Zarqa River Basin showed that the annual rainfall is lost as evapotranspiration (73.73%), infiltration (21.20%) and direct runoff (3.86%) (Shatnawi et al., 1999). It has been suggested that water supply systems in Jordan may also be characterised by high rates of loss (Table 1) (MWI, 2013a). Latest estimations by MWI (2016g) showed that the volume of supplied water for drinking purposes is equal to 126 L/day per capita, compared to the billed water volume of 59 L/day per capita; suggesting high waste and inefficiencies in water supply system.

Table 1. Supply, sold and wasted water volumes for drinking purposes during water years 2008-2014. The difference between water volume supplied through conveyance systems and water volume billed to consumers generates the wasted water volume (non-revenue water) in cubic meters; source: (MWI, 2010); (MWI, 2012); (MWI, 2013a); (MWI, 2016d).

	Water Supply (into distribution system) (m^3)	Water Sold (billed to consumers) (m^3)	Non-revenue water amount (m^3)	Percent of wasted (%)
2008	332410250	192400200	140010050	42%
2009	335500100	195210114	140289986	42%
2010	342500100	199500100	143000000	42%
2011	340500600	201100500	139400100	41%
2012	345616340	182424522	163191818	47%
2013	374742031	195632169	179109862	47%
2014	428100000	198800000	229300000	54%

Molden (1997) pointed out «water that is being lost is not always necessarily wasted.» Knowing the main drivers of water loss, however, are essential to identify best practices for avoiding non-revenue water. Van den Berg (2015) investigated the factors that affect high loss rates through leakage and identified the condition of the water supply system, defective water management, climate, topography, and high costs of maintenance as key contributing factors. For Jordan, non-revenue water may be the result of the considerable disorganized hydraulic infrastructure and planning. In other words, water losses could be due to leakages whether from defective pipes, meters and tanks and/or water theft. The large number of prosecutions for water theft suggest illegal use of irrigation water is widespread; there were 2688 cases in 2014 (MWI, 2014). Still, limited research on water losses in Jordan, in addition to the lack of leakage records and literature on real and apparent water losses, means that the problem has been over- or under-estimated. Measures being used in Europe suggest best management practises would prioritize quantifying and managing water leakage (Lambert et al., 2014). In particular, determining whether losses are due to the distribution system and service connections or to variability in inflow rates is critical (Lambert et al., 2014).

Managing these challenges in Jordan has led to a number of initiatives. New water plans suggest renovation of the ageing water distribution systems and development of detailed non-revenue water reduction plans. There is also significant effort aimed at engaging local communities, groups and institutions to achieve more efficient water usage (MWI, 2016d). The new water plans establish a target that the total water volume being sold to consumers will be just above 350 MCM by 2023, largely through reducing non-revenue water volume by 4% each year until 2018, and then by 3% annually through to 2023 (MWI, 2013c). These plans require investment of more than 7.8 billion USD including refugee backup plans and the Red Sea-Dead Sea Conduit (RS-DS; MWI, 2016d). In Table 2, water production and supply amounts for drinking purposes and per capita consumption regardless of the waste amounts due to leakage or infringements are shown.

Table 2. Water production and supply volumes for municipal uses and per capita allotments that fluctuating over water years (2003-2014) in MCM; sources: (MWI, 2010; MWI, 2012; MWI, 2013a; MWI, 2014)

Year	Water Production (MCM)	Water Supply (MCM)	Per capita consumption (Litre/day)
2014	428.1	339.2	172
2013	374.8	341.3	123
2012	345.4	339.1	145
2011	341.3	330.1	145
2010	339.2	327.7	147
2009	na	313.4	144
2008	na	na	na
2007	320.5	300.9	144
2006	298.2	286.3	139
2005	294.7	282.0	140
2004	287.0	275.8	134
2003	268.0	258.7	143

Regarding water use over sectors by time, it seems that competition among different sectors (as previously shown in Figure 1) for water has increased. Irrigation usage encroaches on the rights of domestic and potable usage since all systems must share the scarce available water. The new surface water utilization policy (MWI, 2016e) reallocates water shares among sectors based on the economic output per cubic metre of water consumed. Moreover, government has specified the maximum amounts of water usage in new buildings and settlements (MWI, 2016f). Decreasing agricultural water use will affect food production and food security in the face of a growing population with growing food requirements. These effects can be mitigated by improving water productivity in agriculture (Molden et al., 2003), with water savings prioritized for human use (Kassam et al., 2007).

4. Current Water Supplies

4.1. Surface Water Resources

Jordan has 15 surface water basins which drain into three different water bodies: the Dead Sea, the Red Sea and desert mudflats (Figure 3). The largest catchment by area is Hammad basin (19270 km^2) while the smallest catchment is the south side wadis of the Jordan River (434 km^2). Yarmouk basin has 39.3% of the total annual discharge from all basins followed by 9% sourced from the Zarqa basin. High annual rainfall is received by both catchments (375mm and 262mm, respectively). Only 50% of surface water is consumed with the remainder flowing in to wadis, springs and rivers. Surface water constitutes 65% of the available fresh water in Jordan (MWI, 2016e).

Jordan abides by international political treaties to provide specific water allocations and allowable storage to the Jordan River and its tributaries based on mean annual flow volume. Due to political conflicts, diversion schemes, drought and constructed dams; the mean annual flow volume of the Jordan River has declined over the last decades, decreasing the allotments to each neighbouring country (Comair et al., 2012; UN-ESCWA&BGR, 2013). Although Jordan possesses 40% of the Jordan River basin and receives 36% of the total precipitation into the basin, Jordan receives only 100 MCM via the King Abdullah Canal (0.1% of the total withdrawal amount from the basin) due to high losses through evaporation (Comair et al., 2012). The King Abdullah Canal is fed by the Yarmouk River and some of the water is sourced from Lake Tiberias, the wadis of Arab and Ziqlab, and the Mukheibeh wells. Flow in the Yarmouk River is decreasing as a result of Syrian upstream abstractions by 25 constructed dams, with discharge declining from 430 MCM in 1970 to 260 MCM in the early 1990s (MoEnv, 2006).

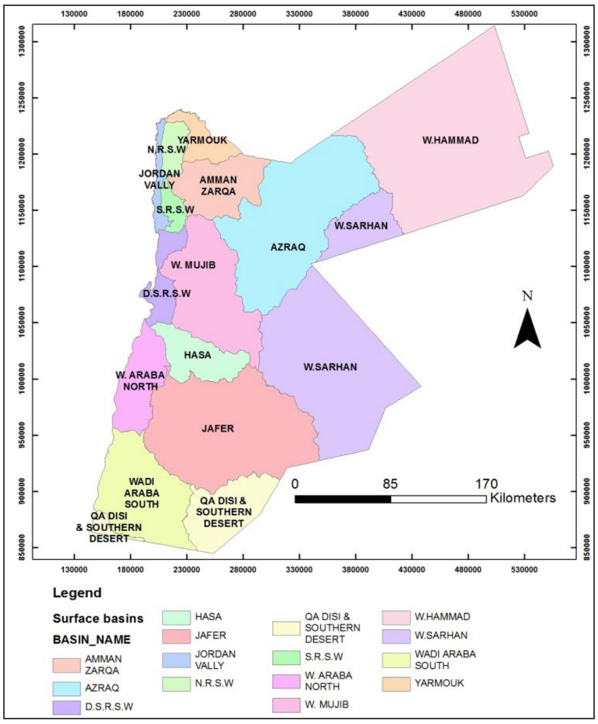

Figure 3. Jordan 16 surface water basins; (source, the Ministry of Water and Irrigation, Directorate of Water Studies, 2017)

The total capacity of large dams in the Jordan Valley is 330 MCM, with small dams and excavations storing approximately 111.43 MCM. King Talal Dam is the largest dam (86 MCM), harvesting the flow of Zarqa River for agricultural and industrial use .The Al-Wala dam (15.12 MCM), Al-Mujib dam (10.34 MCM) and Al-Tannour dam (5.38 MCM) are used for multiple purposes. Eighteen desert dams have been constructed for livestock and artificial groundwater recharge with a total capacity 31 MCM (MoEnv, 2006).

4.2. Groundwater Resources

Jordan has 12 main groundwater water basins (Figure 4). Eighty percent of groundwater of Jordan is contained within three aquifers; Disi, Amman-Wadi Es Sir aquifer and the Basalt aquifer (El-Naser, 2012). Groundwater contributes approximately 60% of water for all uses (79% of GW supplies for municipal uses) (MWI, 2016c). Groundwater bodies are classified as renewable and non-renewable. Geologically, groundwater aquifers are basalt bedrock, carbonate (e.g., Amman) or sandstone (e.g., the Ram aquifer). Unconsolidated aquifers also occur in riverine deposits, such as in the Jordan Valley. Depth of aquifers also varies, alluvial deposits are considered to be shallow aquifer, while Hummar aquifer exemplifies an intermediate aquifer, and Kurnuba deep aquifer (Jassim et al., 2015).

The largest groundwater extractions occur from the Disi- Mudawwara Basin (approximately 125 MCM/Year (MoEnv, 2006)). Due to over-abstraction, depression of the water level from 0.1m to 1.31m has occurred (MWI, 2014). In comparison, the Wadi Araba Basin, which yields 3.5 MCM/Year (MoEnv, 2006), has only recorded a water level decline of 0.46m (MWI, 2014). Most groundwater aquifers in Jordan are being over-pumped; the abstraction rate is higher than the safe yield except for the Hammad Basin and Sirhan Basin where abstraction is aligned to the safe yields. The Yarmouk (59 MCM), Amman-Zarqa (154 MCM), Dead Sea (71 MCM), and Azraq basins (80 MCM) are all considered over-extracted. Although the Jafr basin has a large catchment area (12710 km^2), it yields only 27 MCM due to low annual rainfall (45 mm) (MoEnv, 2006). Latest estimates by MWI (2016c) show that an additional 225 MCM of GW are pumped for agricultural use within highland plateaus. The total safe yield quantity available from renewable ground water is 275.5 MCM but the over-pumping volume is about 244.5 MCM according to Raddad (2005), with a government target to reduce to this 156 MCM in 2016 (MWI, 2016d).

Quantifying groundwater recharge rates is essential to determine the natural renewable component of any aquifer by precipitation and it has been estimated that 3.3% of the total rainfall groundwater recharge (Margane et al., 2002). A study of the Hasa basin water balance (Abu-Saleem et al., 2010) revealed that only 15.4% and 0.64% of the effective precipitation annually contributed in generating groundwater recharge and surface runoff, respectively, while the remainder was lost as evapotranspiration. Likewise, another study determined the recharge rate of the Zarqa Basin (Schulz et al., 2013) to be approximately 21.0mm annually.

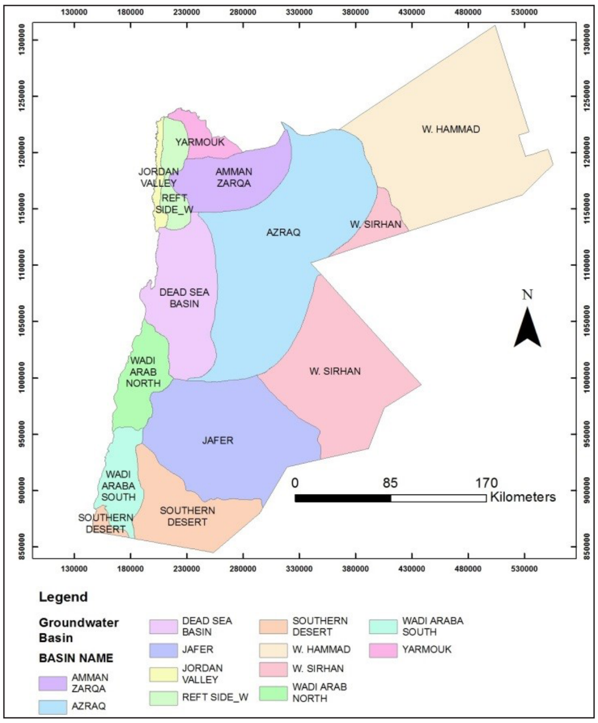

Figure 4. The twelve main groundwater basins of Jordan (The Ministry of Water and Irrigation, Directorate of Water Studies, 2017)

4.3. Treated Wastewater

Treated wastewater and brackish water are non-conventional resources which can be utilized for industrial and agricultural purposes. The high salinity content of reclaimed wastewater is the main limiting factor for agricultural use (Ammary, 2007). According to MWI (2016d), 125MCM of treated water is produced for agricultural use annually from 137 MCM of wastewater. Desalinization provides 50 MCM from brackish aquifers for urban use. Since the generated volume of wastewater in 2015 was 140 MCM, the 11 million projected population is estimated to produce 240 MCM by 2025 (MWI, 2016d); but unevenly distributed across the country (MWI, 2013a).

5. Water Availability and the Potential Risks

A number of factors influences the water availability, including population distribution, density, and growth rates, patterns of urbanisation and services to urban centres, climate variability and change, and a range of other anthropogenic impacts including land-use change (Gleick, 1993; Heathwaite, 2010; Molden, 1997; Wada et al., 2010; Pla et al., 2016). In order to effectively manage pressures on water supplies, there is a need to determine the separate and interacting effects of all relevant factors influencing water availability (Jooste, 2000).

5.1. Population Growth

Jordan has high rates of population growth due to both intrinsic factors and immigration. According to the latest official census (DoS, 2016), Jordan›s population is estimated to have reached 9,531,712, with only 69.4% of people being born in Jordan. The total population growth rate between the years 2004 and 2015 was approximately 5.3%. Amman the capital has the largest population with 4 million, with other major urban centres at Irbid and Zarqa (DoS, 2016). It is not only lifestyle and developmental changes that have caused water scarcity in Jordan (Schutte and Pretorius, 1997; Kassam et al., 2007; O›Brien, 2014) but also population growth. Increased population presents significant challenges for water management in urban areas, compounding the effects of environmental conflicts and resource deterioration (Toppo, 2014). This leads to inequities in access to water and water provided services. Jordan also faces considerable population pressure due to the influx of refugees from the surrounding politically unstable countries. Over 1,400,000 Syrians have entered the country (DoS, 2016) since 2011 and have been in competition with locals for their scarce water resources and exacerbated water shortages. There have been significant challenges in supplying water to refugees; MWI (2013c) estimated that each person in the Zaatari refugee camps is supplied with 37 L/day where the required amount is 50 L/day/person according to WHO standards. This rapid population growth has lift inadequate time to align with sustainable consumptive water rates, which its demand depending on alternate external supplies (Fischer and Heilig, 1997).

5.2. Change in Climate

At the global level, the effects of climate change on fresh water resources have been analysed by IPCC (Shaman et al., 2004; Van den Berg, 2015). Oki and Kanae (2006) estimated that the effect of sea level rise and the mixing of saline sea water with groundwater aquifers would have profound effects on quality and quantity of groundwater resources. Projections through to 2090 show that populous regions will be susceptible to high water stress globally due to decreased water availability (Arnell, 2004). These effects may be compounded by changes in availability of freshwater as a consequence of changes in rainfall patterns and higher evapotranspiration rates (Oki and Kanae, 2006; Van den Berg, 2015).

Threats to water availability due to climate change include higher intensive precipitation which may lead to surface flooding and increased surface runoff with lower rates of groundwater recharge. Climate change may also affect drought frequency and consequently effect water demand and aquatic ecosystems. Long-term observations on eastern Mediterranean climate zones (Solomon et al., 2007) indicate warming of surface air temperature by 1-3ºC. Effects on precipitation, distribution and variability are as yet uncertain. Climate change has a perceptible effect on water availability and as a consequence affects the whole hydrological cycle (Morrison et al., 2009; Quevauviller, 2010; Quevauviller, 2011).

The effects of changing climate are exacerbated by Jordan›s location in the north mid-latitude climate between the subtropics and the equator. Previous studies have clearly shown declining rainfall of approximately 1.2 mm/year, although this is spatially variable across Jordan (Rahman et al., 2015). The western side of Jordan has had an increase in daily rainfall of approximately 2-3%, mostly in north western parts (Rahman et al., 2015). In terms of temperature over the last 30 years, Donat et al. (2014) noted drying trends in eastern parts of Arab countries due to the stronger effect of ENSO. The latest projections by MoEnv (2014) conclude that Jordan will experience warmer summers, drier winters, drier autumns, more droughts and more heat waves, but no clear trend towards increased precipitation or wind intensity. Therefore, MWI (2016b) forecasted a decrease in water availability which will be severe after 2040 due to climate change.

MoEnv (2009) concluded that water availability and quality will be the main stress on Jordan›s society and the environment due to climate change. These consequences would be compounded by the effects of demographic growth (Sowers et al., 2011). The variability of water flows in the Jordan and Yarmouk Rivers is predicted to increase. For example, the Jordan River flow was 620 MCM but recently decreased to 270 MCM (Verner, 2013; Verner et al., 2013). Climatic change might cause an increase in desertification, exacerbate inputs and withdrawals of water, decrease water availability, and thus; contribute to future water deficits as much as the human-driven increases in water demand (Verner et al., 2013; MWI, 2016b). Down-scaled General Circulation Models across all climate scenarios predict water demand will increase for all sectors, whilst water supply will decrease (MoEnv, 2014). Subsequently, the annual water deficit is predicted to reach 769 MCM by 2050 (MoEnv, 2014). Other studies have also highlighted the susceptibility of Jordan to more frequent drought periods (Menzel et al., 2007; Shatanawi et al., 2013).

Few studies have been conducted to assess the expected effects of climate change on water resources in Jordan. Abu-Allaban et al. (2015) used incremental climate scenarios to assess the influence of climate change on water resources of the Mujib basin. The study concluded that the main driver of decreasing runoff is air temperature. A decrease in rainfall and surface runoff to about 20 to 50% during the dry seasons was predicted. Another study assessed the effect of climate change on water resources in the Yarmouk and Amman-Zarqa Basins (Hammouri, 2015). The study predicted future possible change in temperature from +1 to + 4 ºC, and in precipitation from -20% to +20% while monthly surface runoff will decline by 41% by 2049; except during February when it will witness an increase by +1.7% and -21.9% for Yarmouk and Amman - Zarqa Basins, respectively (Abu-Allaban et al., 2015).

In terms of climate variability, the timing and quantity of the rainfall season is characterized by yearly and seasonal fluctuations of rainfall and uneven distribution across Jordan. For a country with a small area, like Jordan, non-uniformity of stream flow increases in time and space. The variability of flow depends on moisture and water resources including precipitation (Gleick, 1993). The higher the aridity index (dryness index), the greater variability of water resources occurs annually and seasonally across the region.

5.3. Human Use

5.3.1. Groundwater Over-Abstraction

Due to its importance, availability and management of groundwater resources have become a key issue in Jordan. Global groundwater depletion is a major issue globally; ground water volume extracted worldwide was $126x10^3$ MCM per year in 1960 and exceeded $283x10^3$ MCM per year in 2000 (Wada et al., 2010). In some countries, groundwater is considered to be a non-renewable resource (Kalf and Woolley, 2005). Characteristically, in Jordan, groundwater is the most reliable, accessible, and cheapest freshwater resource which makes it the favoured supply especially for urban and rural use. This has led to some aquifers being over-exploited. Overexploitation is defined as intensive groundwater use, either planned or unplanned, which has negative effects (Villarroya and Aldwell, 1998), or where the abstraction rate is greater than the recharge rate (Custodio, 2002). The end point of over-abstraction is the depletion of groundwater storage during a specific time and depends on aquifer size, storage and permeability (Custodio, 2002).

Since groundwater is the main water resource in Jordan, in some water basins abstracted volumes have sometimes exceeded safe yields threefold (Raddad, 2005; Al-Zyoud et al., 2015). Over-exploitation of aquifers can lead to a reduction or cessation of surface-water discharges. In Jordan, it is expected that most groundwater dependent creeks will be exhausted within the upcoming 20 years (Salameh, 2008). Therefore, over-abstraction of groundwater aquifers beyond their annual rechargeable quantities constitutes a major threat to future water availability and resource sustainability.

A simulation of average groundwater recharge for the Jordan River basin has estimated rates to be about (2-20) mm /per year while the rest of the Jordanian groundwater aquifers are estimated to be recharging at (0-2) mm per year (Wada et al., 2010). The south eastern aquifers of Jordan are particularly vulnerable to over-extraction, as they have a high groundwater footprint/area ratio (GF/A), indicating ecosystems which are strongly dependent on groundwater (Gleeson et al., 2012).

Previous research has indicated that most of groundwater resources in Jordan are already depleted beyond their safe yields (El-Naqa et al., 2007). Some groundwater basins have been lost; for example, Dhuleil and Agib (Salameh, 2008). Studies using remote sensing to measure cumulative drawdown of water level for the Amman-Zarqa basin have shown a depletion of 1.6-2.0 m/year (El-Naqa et al., 2007; Al-Zyoud et al., 2015). In that system, the basin safe yield is considered to be around 88 MCM, while the current pumping rate is approximately 156 MCM, with an estimated depletion volume of about 69 MCM by the end of 2013 (MWI, 2013b). Al-Zyoud et al. (2015) called for urgent changes in groundwater management practices to reduce deterioration of groundwater resources. Such effective management requires adequate information about the geology of aquifers and soil layer characteristics (Datta and Kourakos, 2015; Tessitore et al., 2016).

Overconsumption of groundwater has threatened not only the quantity but also the quality, especially shallow aquifers and moderately steep areas (Al Kuisi et al., 2014; Jassim et al., 2015). The main source of groundwater contamination in the Amman-Zarqa basin is contaminated water percolating into aquifers. Nitrate and selenium concentrations reached 157 mg/L and 580 µg/L, respectively, in some aquifers (Al Kuisi et al., 2014). Contamination sources ranged from very low hazard sources, such as from excavations and low intensity farming, to oil refinery waste. Wadi As-Sir and Kherbit As-Samra wastewater plants are located in areas that may contaminate groundwater. Another example of groundwater quality deterioration is at Disi and As-Swwan aquifers as a consequence of fertilizers and biocides from agriculture uses (Jassim et al., 2015).

5.3.2. Urbanization

Land misuse, urbanization, and land settlement patterns are important pressures on water availability (Song et al., 2016; Liu and Long, 2016). In semi-arid regions, large rivers have dried up because of reducing flows due to urbanization (Guo et al., 2000; Rosegrant et al., 2002). In the eastern and southern Mediterranean countries urbanisation is occurring five times faster than it is in Europe, threatening reliable supplies of drinking water (Shatanawi et al., 2007). Urban expansion affects surface runoff and stream discharge, in terms of quantity, the timing and frequency of high flows and quality (Burns et al., 1998), in addition to influences on the sustainability of water resources in the transitional urban areas (Grafton et al., 2015).

Over the last decades, Jordan has been developing major cities through expanding and modifying urban areas, and the process of urban sprawl is continuing. Urbanization is characterised by development of ‹hard› infrastructure, such as roofs, roads and divided highways, creation of landfills and waste dumps, and alteration to land cover for housing, industry, transport infrastructure and recreation areas. A typical example of such urbanization that caused desertification and biodiversity degradation is in the woodlands of northern Jordan. The northern woodland area has decreased from 30,895 ha in 1956 to 19,080 ha in 1987 (MoEnv, 2006). Urbanization has changed the quality of soils in the small areas that are suitable for vegetation (MoEnv, 2006). Regardless of land-use regulation, housing developments, including those based on illegal occupation of land have increased. This problem has been exacerbated by increased migration with major impacts on urban expansion and land tenure (Douglas, 2006). Supplying urban areas with services, such as water is a major challenge for administrators.

Although only 40% of Jordan›s agricultural lands are irrigated areas (about 102.5 million hectares) 90% of agricultural products are produced in these areas (MWI, 2016d). ACS (2007) recorded that in 1975 the total area of cultivated land in Jordan was 975000 hectares; with 82500 hectares as irrigated land. In 1997, the total area of irrigated and rain-fed cultivated lands had decreased due to urbanization to 187500 hectares and 575000 hectares, respectively. DoS (2014) estimated the total cultivated area was 260600 hectares in 2002 and 187200 hectares in 2007. In 2014, the total cultivated areas were 273950 hectares, which included 105050 hectares of irrigated land and 168900 hectares considered as rain-fed areas. Alsaaideh et al. (2012) showed that during the period from 1987 to 2005, urban areas increased by 220 km^2. This was largely at the cost of loss of natural vegetation (8.7 km^2) bare lands (101.4 km^2), forest (12.7 km^2), and agricultural land (98.9 km^2)

Menzel et al. (2009) applied a hydrological model with a land use/cover module to the Jordan River Basin (northern part of Jordan, Palestine and Israel), in order to determine available water (runoff and groundwater recharge only) and irrigation demands in the region. They found that using an assumption of no economic development and steady state political conditions, the population growth for Jordan would lead to widespread loss of natural vegetation by 2050, and an increasing shortfall in meeting water needs.

6. Interactions between Drivers

While there is a growing understanding of the effects of single pressures on water availability, there is a need at national scales to understand the combined and interacting effects of multiple pressures. For example, changes in land use have multiple effects on water including; deterioration of groundwater quality due to agrochemicals percolating into aquifers (Jasem and Alraggad, 2010), fertilizer contamination, salinization and changes in rates of runoff and recharge. They are also likely, however, to be associated with changes in population, demands for potable water and risk of illegal abstraction. These effects are then overlain by the consequences of climate change. Collectively there are multiple complex interactions between all of these pressures.

Human activities, unplanned urban growth, land misuse and concrete areas, interactively prevent rainfall reaching the ground and hence being infiltrated to recharge groundwater aquifers (Fikos et al., 2005). In turn, this combination cause deterioration of groundwater quality and overexploitation of groundwater resources (Datta and Kourakos, 2015). It is not only that the extreme-hazards of contamination caused by industries is considerable (Al Kuisi et al., 2014) but also the effects of growing population on groundwater quality. In Jordan, the wells that are situated directly beneath Zaatari Camp are contaminated due to the infiltration of discharges toward the saturated zone of groundwater wells (MWI, 2016c).

Physical characteristics of soil and land cover affect the amount of evaporation, surface runoff and hence the groundwater recharge. These effects also link climate influences, surface runoff, evaporation, groundwater recharge and abstraction. An assessment of the effects of climate change on the recharge of central western aquifers in Jordan revealed that increasing the temperatures by 1 °C and 2 °C will cause a decrease in groundwater recharge by 11% and 23%, respectively (Jassim and Alraggad, 2009), while the change to precipitation, decreasing by 10% and 20%, will result in decreasing groundwater recharge by 24% and 48%, respectively.

An analysis of the effects of climate change, population growth and increasing migration on water resources showed that Jordan is classified as a high water stress nation regarding the population growth and the medium to high stress regarding the climate change. This means that population and economic growth will drive water demand and supply rather than a changing climate (Vörösmarty et al., 2000). Hoff et al. (2011) compared the changes in future water demands in the Jordan River basin under five different scenarios combining climate change with socio-economic and technological factors. Their study showed that socio economic factors and the climate change projections will significantly affect the future unsatisfied water demands until 2050. The study expects that unsatisfied water demands within the basin will exceed 500 MCM due to socio-economic development compared to 1600 MCM by 2050. In addition, 1000 MCM of unsatisfied demands are caused by climate change (MWI, 2016b).

These factors may interact continuously through time or discretely depending on the complexity of the water basin and its conditions. Although numerous water supplies are used to meet water needs, the combined effects of these multiple interacting pressures can result in deterioration of water resources and cause water scarcity (Figure 5).

7. Future Water Supplies

The International Water Management Institute issued a report in 1998 that estimated the water

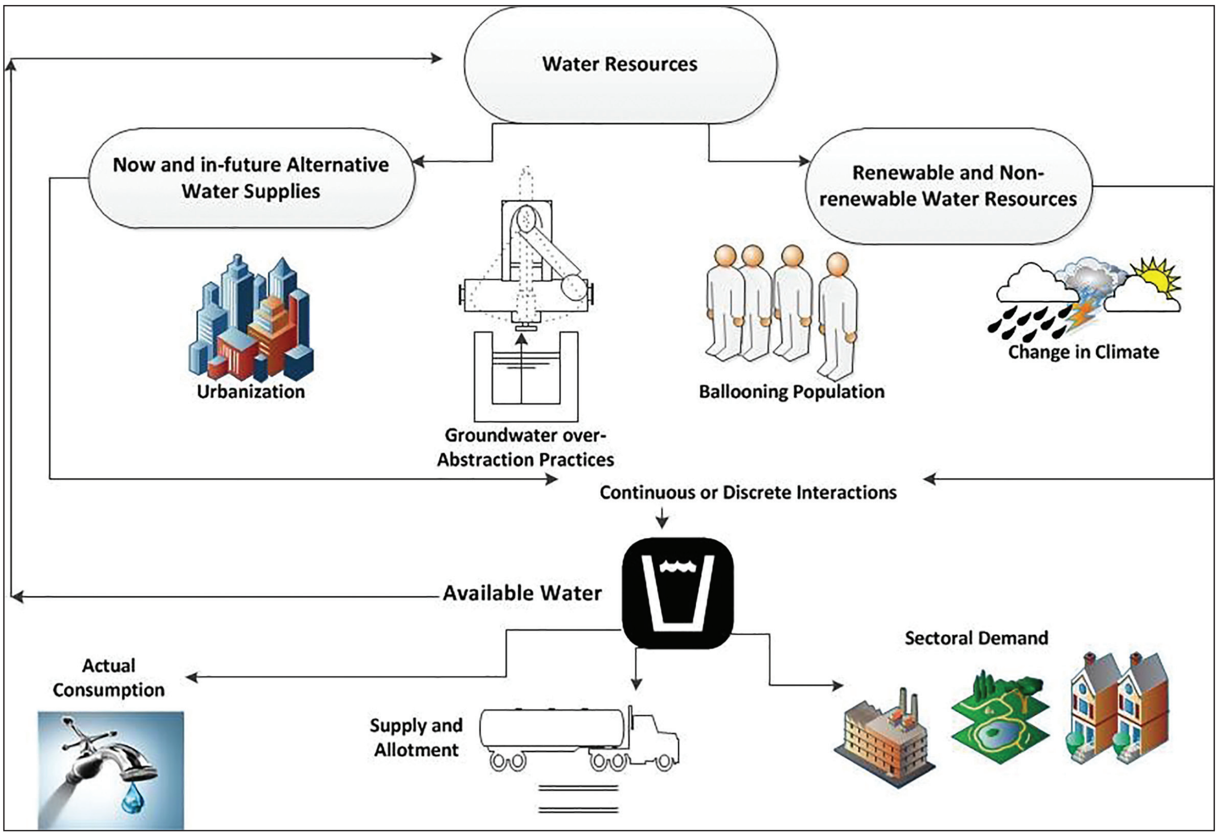

Figure 5. Schematic description of interacting pressures affecting water availability

scarcity of 118 countries by simulating annual total water withdrawals through the period 1990 to 2025 (Seckler, 1998). Jordan is one of the countries identified as being ‹water scarce›. The report concluded that Jordan should reduce withdrawals of water for irrigation in order to meet domestic and industrial water needs. By 2025, the report predicted that projected population growth will be 283% which will restrict the renewable water supply to 73 m^3 per capita and the total water withdrawals will equal 292% of the available water resources.

During 2016 to 2025, a new water strategy will be implemented in Jordan to increase water supplies for different uses (Table 3). This will provide about 187.5 MCM for drinking purposes by setting up new wells, deep aquifers, dams, desalination plants, and household water harvesting. The additional gross amount of water will be about 552.5 MCM (MWI, 2016d).

Table 3. Jordan future water supplies and its contributions to national water budget in total volume equals to 552.5 MCM (MWI, 2016a)

Additional Water Supplies Projects	Supply volume (MCM)	Purposes
Setting up new wells, deep aquifers, dams, desalination plant, and water harvesting techniques	187.5	For potable uses
RS-DS project	235	For potable uses
Dams, dams expansions as in Wala and Mujib Dams, water harvesting setups	36.35	For different uses especially flood regulation and irrigation
Treated wastewater plants – expansion projects; for examples: Samra & Southern Amman WWTP	94	Not specified

Currently, projects, such as the Disi groundwater conveyor from the Disi aquifer, provide the Amman annually with 100 MCM conveying good quality water via a 325 km (El-Naser, 2009; Al-Amir et al., 2012). Recently, the Jordanian government has decided to utilize Disi water for drinking water rather than irrigation in order to satisfy water demands (Salameh et al., 2014). Other projects suggested by MWI (2009) include extracting water from Jafr, Hisban and Lajoun aquifers. This will provide additional amounts of non-renewable groundwater of 9% of the total water resources by the year 2022. Also, building and expanding wastewater plants will provide 15% of the total water resources used for irrigation and industry purposes. Moreover, desalination will supply 520 MCM of non-conventional water by 2022, for example, desalination of brackish water from Hisban Kufranjeh Dam and Wahdah Dam.

Another major project, the main mega Conduit (RS-DS), which connects the Red Sea with the Dead Sea, is still under construction. This project will tackle the rapid drop in water levels of the Dead Sea due to evaporation rates and increasing temperatures (Oroud, 2011). Water from the Red Sea will be desalinised, producing drinking water and hypersaline brine which will be used to augment the Dead Sea. Through this resource-sharing system, the amount of water allocated to Jordan will be around 580 MCM per year from the canal. The main obstacle for the project, however, is the financial cost (10 billion US dollars) (MoEnv, 2009). According to Al-Salihi and Himmo (2003), seawater desalination seems to be the most suitable development option for Jordan.

The Wahdah Dam is a bilateral project between Syria and Jordan and was built to generate hydropower as well as to provide irrigation water for both countries. The dam has been constructed in order to catch rainfall within the Yarmouk river basin which receives 2065 MCM of rainfall on average. Although the dam capacity is 225 MCM/year, the maximum stored volume recorded in 2014 was only 70 MCM/yr. The reasons behind the low annual level of the Wahdah dam could be due to drought and dams retaining water from Yarmouk Wadis and groundwater abstraction upstream (UN-ESCWA&BGR, 2013).

The view of Gleick (2003) is that, in Jordan, gains from seeking new sources of water supplies will be insignificant in comparison with improving water use by implementing water efficiency approaches. For example, in Israel, Australia, New Zealand and Japan, significant water savings have been gained by the introduction of dual flush toilets.

8. Quantitative Analysis of Potential Risks and Reliability of Undertaken Measures

Despite major reforms, Jordan is still encountering a significant water crisis. This requires a strategic approach to water resources management including the use of water pricing schemes, water trading and renovation of old water systems and restructuring of stakeholders. Future water plans will require detailed quantitative information as shown in (Figure 6).

This present review has shown that the future projections of water use, supply and demand might not take various challenges into consideration. The new water allocation initiatives will require data on socio-economic factors and environmental and technological assumptions. The new water allotments will be based on the following assumptions:

1. Domestic water demands needs to meet 80-120 L/day for locals as well as for refugees;
2. A constant annual population growth for all residents (1.94%) except for refugees (3%),
   refugees are resettled in the country;
3. Seasonality of water demand during summer (additional 17% of water amount);
4. Potential to reduce non-revenue water volume by 4% each year until 2018, and then by 3% annually through to 2023;
5. Changes in patterns of irrigation; irrigation demand is increasing in the Jordan valley and decreasing in highlands and therefore the irrigation future demands are constant by (700) MCM through the next 10 years;
6. The effects on consumption of changing demographics such as increasing family members in a single house are taken into consideration; and
7. The additional of annual 2% water amount for abrupt changes.

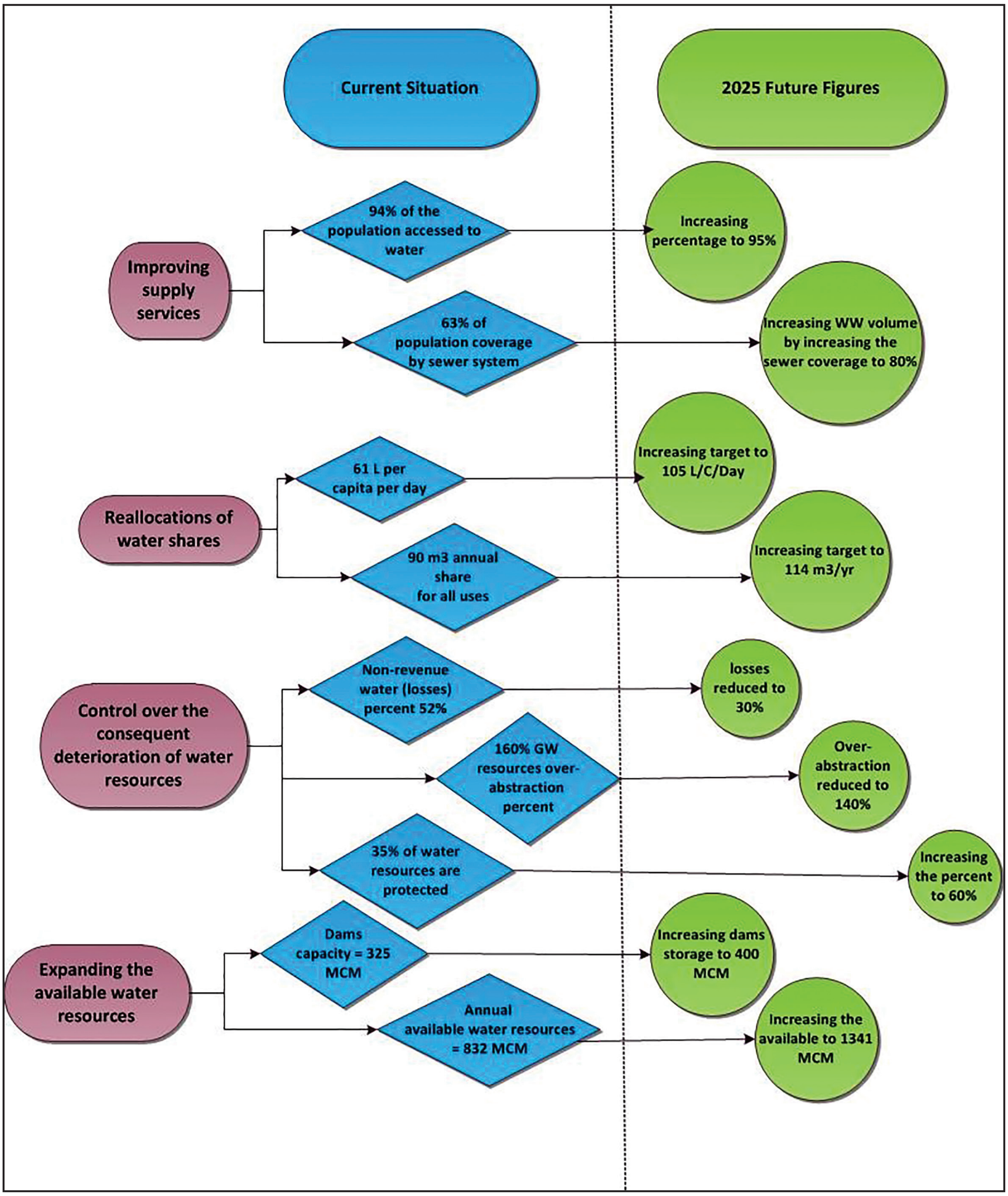

Figure 6. Quantitative analysis of potential risks and reliability of water supply based on water allotments. Reallocation of water predicts that the total available resources will provide 1459 MCM, where the total demands will be 1548 MCM, and hence, 89 MCM is the expected deficit (MWI, 2016g)

Conclusions:

It appears that current initiatives will unlikely guarantee water security. Certain estimates of water quantity, use and availability suffer from significant concerns; for example, errors in measurements and calculations that aligned with data scarce region, consequent over-allocation of water shares, uncertain predictions, complexity of water system modelling issues, and limited research on the factors affecting available water volumes.

Current and future water planning for Jordan has not rigorously tested the consequences of all major pressures and their cumulative and interactive effects. Since water scarcity and the consequent deterioration of water resources are major issues that require not only thematic research but also reliable applied outcomes, there is an urgent need for investigation of these pressures. The latest studies have focused on a single hydrological assessment and water balance of single water unit i. e. the use of a one-off water accounting method. Research is needed to identify water accounting measurement components in the light of water quantity, occurrence and intensity. Those measurements need to take into consideration the differences between supply and demand, and the consequently effects on users, sustainability of resources and hydrological cycle.

The concept of water quantification provides a useful approach within which the response to main pressures changes can be studied. This approach requires adequate information on multiple pressures and their interactions at the regional level especially in the long term. The emphasis on one pressure within short period would limit the readiness for sudden changes in other pressures.

References

[1] ABABSA, M., DUPRET, B. & DENNIS, E. 2012. Popular Housing and Urban Land Tenure in the Middle East: Case Studies from Egypt, Syria, Jordan, Lebanon, and Turkey, American University in Cairo Press.

[2] ABABSA, M. & KOHLMAYER, C. 2013. Atlas of Jordan: history, territories and society, Inst. Française du Proche-Orient.

[3] ABU-ALLABAN, M., EL-NAQA, A., JABER, M. & HAMMOURI, N. 2015. Water scarcity impact of climate change in semi-arid regions: a case study in Mujib basin, Jordan. Arabian Journal of Geosciences, 8, 951-959.

[4] ABU-SALEEM, A., AL-ZU›BI, Y., RIMAWI, O., AL-ZU›BI, J. & ALOURAN, N. 2010. Estimation of water balance components in the Hasa basin with GIS based WetSpass model. Journal of Agronomy, 9, 119-125.

[5] ACS 2007. Alrai Center for Studies. Arabic Article: SEMINAR - Agricultural sector in Jordan.

[6] ADAMOWSKI, J. F. 2008. Peak daily water demand forecast modeling using artificial neural networks. Journal of Water Resources Planning and Management, 134, 119-128.

[7] AL-AMIR, S. M., AL-HAMARNEH, I. F., AL-ABED, T. & AWADALLAH, M. 2012. Natural radioactivity in tap water and associated age-dependent dose and lifetime risk assessment in Amman, Jordan. Applied Radiation and Isotopes, 70, 692-698.

[8] AL-JAYYOUSI, O. R. 2012. Islam and sustainable development: new worldviews, Gower Publishing, Ltd.

[9] AL-SALIHI, A. H. & HIMMO, S. K. 2003. Control and management study of Jordan›s water resources. Water international, 28, 1-10.

[10] AL-ZYOUD, S., RÜHAAK, W., FOROOTAN, E. & SASS, I. 2015. Over Exploitation of Groundwater in the Centre of Amman Zarqa Basin—Jordan: Evaluation of Well Data and GRACE Satellite Observations. Resources, 4, 819-830.

[11] AL KUISI, M., MASHAL, K., AL-QINNA, M., HAMAD, A. A. & MARGANA, A. 2014. Groundwater vulnerability and hazard mapping in an arid region: case study, Amman-Zarqa Basin (AZB)-Jordan. Journal of Water Resource and Protection, 6, 297.

[12] ALSAAIDEH, B., AL-HANBALI, A. & TATEISHI, R. 2012. Assessment of land use/cover change and urban expansion of the central part of Jordan using remote sensing and GIS. Asian Journal of Geoinformatics, 11.

[13] AMMARY, B. Y. 2007. Wastewater reuse in Jordan: Present status and future plans. Desalination, 211, 164-176.

[14] ARNELL, N. W. 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Global environmental change, 14, 31-52.

[15] BELDA, M., HOLTANOVÁ, E., HALENKA, T. & KALVOVÁ, J. 2014. Climate classification revisited: from Köppen to Trewartha. Climate research, 59, 1-13.

[16] BENGOECHEA, E. P. 2013. Water scarcity and climate change impact and vulnerability in irrigated agriculture in Mediterranean river basins. Agronomos.

[17] BURNS, D. A., MURDOCH, P. S., LAWRENCE, G. B. & MICHEL, R. L. 1998. Effect of groundwater springs on NO3− concentrations during summer in Catskill Mountain streams. Water Resources Research, 34, 1987-1996.

[18] COMAIR, G., MCKINNEY, D. & SIEGEL, D. 2012. Hydrology of the Jordan River Basin: Watershed delineation, precipitation and evapotranspiration. Water resources management, 26, 4281-4293.

[19] CUSTODIO, E. 2002. Aquifer overexploitation: what does it mean? Hydrogeology journal, 10, 254-277.

[20] DATTA, B. & KOURAKOS, G. 2015. Preface: Optimization for groundwater characterization and management. Hydrogeology Journal, 23, 1043-1049.

[21] DONAT, M., PETERSON, T., BRUNET, M., KING, A., ALMAZROUI, M., KOLLI, R., BOUCHERF, D., AL-MULLA, A. Y., NOUR, A. Y. & ALY, A. A. 2014. Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO. International Journal of Climatology, 34, 581-592.

[22] DOS 2014. DoS Yearbook. In: STATISTICS, D. O. (ed.). Amman- Jordan.

[23] DOS 2015. Jordan in Figures. In: STATISTICS, D. O. (ed.). Amman-Jordan.

[24] DOS 2016. The national population and housing census of 2015, Official Report. In Arabic In: STATISTICS, D. O. (ed.). Amman - Jordan

[25] DOUGLAS, I. 2006. Peri-urban ecosystems and societies transitional zones and contrasting values. Peri-urban interface: Approaches to sustainable natural and human resource use, 18-29.

[26] EL-NAQA, A., AL-MOMANI, M., KILANI, S. & HAMMOURI, N. 2007. Groundwater Deterioration of Shallow Groundwater Aquifers Due to Overexploitation in Northeast Jordan. CLEAN- WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 35 (2), 156 – 166.

[27] EL-NASER, H. 2009. Management of scarce water resources: a Middle Eastern experience, WIT Press.

[28] EL-NASER, H. 2012. Jordan›s Precious Groundwater Resources Is the Term Sustainability Applicable under Extreme Water Scarcity Conditions? 5Th ACWUA Best Practice Conference (Utilities Perspective on Water Resources Management in the Arab Region). Muscat - Oman.

[29] FAO 2012. Coping with water scarcity: An action framework for agriculture and food security. Food and Agriculture Organization of the United Nations - Rome.

[30] FIKOS, I., ZIANKAS, G., RIZOPOULOU, A. & FAMELLOS, S. 2005. Water balance estimation in Anthemountas river basin and correlation with underground water level. Global nest. The international journal, 7, 354-359.

[31] FISCHER, G. & HEILIG, G. K. 1997. Population momentum and the demand on land and water resources. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 352, 869-889.

[32] GLEESON, T., WADA, Y., BIERKENS, M. F. & VAN BEEK, L. P. 2012. Water balance of global aquifers revealed by groundwater footprint. Nature, 488, 197-200.

[33] GLEICK, P. H. 1993. Water in crisis: a guide to the world›s fresh water resources, Oxford University Press, Inc.

[34] GLEICK, P. H. 1998. Water in crisis: paths to sustainable water use. Ecological applications, 8, 571-579.

[35] GLEICK, P. H. 2003. Global freshwater resources: soft-path solutions for the 21st century. Science, 302, 1524-1528.

[36] GRAFTON, Q., DANIELL, K. A., NAUGES, C., RINAUDO, J.-D. & CHAN, N. W. W. 2015. Understanding and Managing Urban Water in Transition, Springer.

[37] GUO, Z., XIAO, X. & LI, D. 2000. An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecological Applications, 10, 925-936.

[37] HAMMOURI, D. N. 2015. Assessment of Climate Change Impacts on Water Resources of North Jordan. online presentation: Faculty of Natural Resources & Environment - The Hashemite University.

[39] HEATHWAITE, A. 2010. Multiple stressors on water availability at global to catchment scales: understanding human impact on nutrient cycles to protect water quality and water availability in the long term. Freshwater Biology, 55, 241-257.

[40] HOFF, H., BONZI, C., JOYCE, B. & TIELBÖRGER, K. 2011. A water resources planning tool for the Jordan River Basin. Water, 3, 718-736.

[41] IGLESIAS, A., GARROTE, L., DIZ, A., SCHLICKENRIEDER, J. & MARTIN-CARRASCO, F. 2011. Re-thinking water policy priorities in the Mediterranean region in view of climate change. Environmental Science & Policy, 14, 744-757.

[42] JACOBS, H. & HAARHOFF, J. 2007. Prioritisation of parameters influencing residential water use and wastewater flow. Journal of Water Supply: Research and Technology-AQUA, 56, 495-514.
[43] JASEM, A. H. & ALRAGGAD, M. 2010. Assessing groundwater vulnerability in Azraq basin area by a modified DRASTIC index. Journal of Water Resource and Protection, 2010.
[44] JASSIM, A. H. M., ALMOMANI, T. & ALHEJOJ, I. 2015. Groundwater Vulnerability for the Surface Outcropping Aquifers in Jordan. Journal of Environmental Protection, 6, 250.
[45] JASSIM, A. H. M. & ALRAGGAD, M. M. 2009. GIS modeling of the effects of climatic changes on the groundwater recharge in the central western parts of Jordan. Jordan J. Civil Eng, 3, 347-356.
[46] JOOSTE, S. 2000. A model to estimate the total ecological risk in the management of water resources subject to multiple stressors. WATER SA, 26, 159-166.
[47] KALF, F. R. & WOOLLEY, D. R. 2005. Applicability and methodology of determining sustainable yield in groundwater systems. Hydrogeology Journal, 13, 295-312.
[48] KASSAM, A., MOLDEN, D., FERERES, E. & DOORENBOS, J. 2007. Water productivity: science and practice—introduction. Irrigation Science, 25, 185-188.
[49] LAMBERT, A., CHARALAMBOUS, B., FANTOZZI, M., KOVAC, J., RIZZO, A. & ST JOHN, S. G. 14 years experience of using IWA best practice water balance and water loss performance indicators in Europe. IWA WaterLoss 2014 Conf., Vienna, Austria, 2014.
[50] LIU, Y. & LONG, H. 2016. Land use transitions and their dynamic mechanism: The case of the Huang-Huai-Hai Plain. Journal of Geographical Sciences, 26, 515-530.
[51] MARGANE, A., HOBLER, M., ALMOMANI, M. & SUBAH, A. 2002. Contributions to the Hydrogeology of Northern and Central-Jordan.
[52] MENZEL, L., KOCH, J., ONIGKEIT, J. & SCHALDACH, R. 2009. Modelling the effects of land-use and land-cover change on water availability in the Jordan River region. Advances in Geosciences, 21, 73-80.
[53] MENZEL, L., TEICHERT, E. & WEISS, M. Climate change impact on the water resources of the semi-arid Jordan region. Proc. 3rd International Conference on Climate and Water, Helsinki, 2007. 320-325.
[53] MOENV 2006. National Strategy and Action Plan to Combat Desertification 2006. In: ENVIRONMENT, M. O. (ed.). Amman - Jordan: UNDP.
[55] MOENV 2009. Jordan›s Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). In: ENVIRONMENT, M. O. (ed.).
[56] MOENV 2014. MoEnv . Jordan›s Third National Communication on Climate Change. Amman-Jordan (Ministry of Environemnt)
[57] MOLDEN, D. 1997. Accounting for water use and productivity, Iwmi.
[58] MOLDEN, D., MURRAY-RUST, H., SAKTHIVADIVEL, R. & MAKIN, I. 2003. A water-productivity framework for understanding and action. Water productivity in agriculture: Limits and opportunities for improvement.
[59] MORRISON, J., MORIKAWA, M., MURPHY, M. & SCHULTE, P. 2009. Water Scarcity & climate change. Growing risks for business and investors, Pacific Institute, Oakland, California.
[60] MWI 2009. Water for Life. Jordan›s Water Strategy (2008-2022). In: DIRECTORATE, M. O. W. A. I. O. J.-A. A. M. (ed.). Amman-Jordan.
[61] MWI 2010. Ministry of Water and Irrigation, Jordan. Annual Report. Amman, Jordan: Ministry of Water and Irrigation - Awareness and Media Directorate
[62] MWI 2012. Ministry of Water and Irrigation, Jordan. Annual Report. Amman, Jordan.
[63] MWI 2013a. Annual Report2013. Amman: Ministry of Water and Irrigation - Awareness and Media Directorate
[64] MWI. 2013b. Jordan Water Sector Facts and Figures Bulletin [Online].
[65] MWI 2013c. Structural Benchmark/ Action Plan to Reduce Water Sector Losses. In: JORDAN, M. O. W. A. I. O. (ed.). Amman.
[66] MWI 2014. 2014 Annual Report. Amman- Jordan: Ministry of Water and Irrigation - Awareness and Media Directorate
[67] MWI 2016a. Annex 1, Additional Water Supply CIP. In: JORDAN, M. O. W. A. I. O. (ed.). Amman
[68] MWI 2016b. Climate Change Policy for a Resilient Water Sector. In: JORDAN, M. O. W. A. I. O. (ed.). Amman
[69] MWI 2016c. Groundwater Sustainability Policy. In: JORDAN, M. O. W. A. I. O. (ed.). Amman.
[70] MWI 2016d. National Water Strategy of Jordan, 2016 – 2025. In: JORDAN, M. O. W. A. I. O. (ed.). Amman.
[71] MWI 2016e. Surface Water Utilization Policy. In: JORDAN, M. O. W. A. I. O. (ed.). Amman.
[72] MWI 2016f. Water Demand Management Policy. In: JORDAN, M. O. W. A. I. O. (ed.). Amman
[73] MWI 2016g. Water Reallocation Policy. In: JORDAN, M. O. W. A. I. O. (ed.). Amman.
[74] O›BRIEN, M. 2014. The Worth of Water: A Look at the Water Scarcity Crisis and the Perceptions of the Basic Need of Water in South Africa. Senior
[75] OKI, T. & KANAE, S. 2006. Global hydrological cycles and world water resources. science, 313, 1068-1072.
[76] OROUD, I. M. 2011. Evaporation estimates from the Dead Sea and their implications on its water balance. Theoretical and applied climatology, 106, 523-530.
[77] PLA, C., VALDES-ABELLAN, J., TENZA-ABRIL, A. J. & BENAVENTE, D. 2016. Predicting Daily Water Table Fluctuations in Karstic Aquifers from GIS-Based Modelling, Climatic Settings and Extraction Wells. Water Resources Management, 1-15.
[78] QUEVAUVILLER, P. 2010. Water sustainability and climate change in the EU and global context–policy and research responses.
[79] QUEVAUVILLER, P. 2011. Adapting to climate change: reducing water-related risks in Europe–EU policy and research considerations. Environmental Science & Policy, 14, 722-729.
[80] RADDAD, K. 2005. Water supply and water use statistics in Jordan. International water session water statistics, Vienna, Austria.
[81] RAHMAN, K., GORELICK, S. M., DENNEDY-FRANK, P. J., YOON, J. & RAJARATNAM, B. 2015. Declining rainfall and regional variability changes in Jordan. Water Resources Research, 51, 3828-3835.
[82] ROSEGRANT, M. W., CAI, X. & CLINE, S. A. 2002. World water and food to 2025: dealing with scarcity, Intl Food Policy Res Inst.
[83] SALAMEH, E. 2008. Over-exploitation of groundwater resources and their environmental and socio-economic implications: the case of Jordan. Water International, 33, 55-68.
[84] SALAMEH, E., ALRAGGAD, M. & TARAWNEH, A. 2014. Disi Water Use for Irrigation–a False Decision and Its Consequences. CLEAN–Soil, Air, Water, 42, 1681-1686.
[85] SCHULZ, S., SIEBERT, C., RÖDIGER, T., AL-RAGGAD, M. M. & MERZ, R. 2013. Application of the water balance model J2000 to estimate groundwater recharge in a semi-arid environment: a case study in the Zarqa River catchment, NW-Jordan. Environmental earth sciences, 69, 605-615.
[86] SCHUTTE, C. & PRETORIUS, W. 1997. Water demand and population growth. WATER SA-PRETORIA-, 23, 127-134.
[87] SECKLER, D. W. 1998. World water demand and supply, 1990 to 2025: Scenarios and issues, Iwmi.
[88] SHAMAN, J., STIEGLITZ, M. & BURNS, D. 2004. Are big basins just the sum of small catchments? Hydrological Processes, 18, 3195-3206.
[89] SHATANAWI, K., RAHBEH, M. & SHATANAWI, M. 2013. Characterizing, monitoring and forecasting of drought in Jordan River basin. Journal of Water Resource and Protection, 2013.
[90] SHATANAWI, M., HAMDY, A. & SMADI, H. 2007. Urban wastewater: Problems, risks and its potential use for irrigation. The use of non-conventional water resources, 15.

[91] SHATNAWI, M., RAHBEH, N. & AL-KHARABSHEH, A. 1999. Rainfall-Runoff Relationship and water budget for Zarqa river basin. International Refereed Research Journal-Dirasat (Jordan).

[92] SOLOMON, S., QIN, D., MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K., TIGNOR, M. & MILLER, H. 2007. IPCC, 2007: Summary for Policymakers, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

[93] SONG, Y., LIU, H., WANG, X., ZHANG, N. & SUN, J. 2016. Numerical simulation of the impact of urban non-uniformity on precipitation. Advances in Atmospheric Sciences, 33, 783-793.

[94] SOWERS, J., VENGOSH, A. & WEINTHAL, E. 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. Climatic Change, 104, 599-627.

[95] TESSITORE, S., FERNÁNDEZ-MERODO, J., HERRERA, G., TOMÁS, R., RAMONDINI, M., SANABRIA, M., DURO, J., MULAS, J. & CALCATERRA, D. 2016. Comparison of water-level, extensometric, DInSAR and simulation data for quantification of subsidence in Murcia City (SE Spain). Hydrogeology Journal, 1-21.

[96] TOPPO, D. 2014. Political Agitation and Water Shortages in the Hashemite Kingdom of Jordan. Claremont McKenna College.

[97] UN-ESCWA&BGR 2013. Inventory of Shared Water Resources in Western Asia. . In: FÜR, U. N. E. A. S. C. F. W. A. B. & ROHSTOFFE)., G. U. (eds.). Beirut. : Online version. .

[98] UNEP 2007. Global Environment Outlook GEO4 - environment for development Malta.

[99] VAN DEN BERG, C. 2015. Drivers of non-revenue water: A cross-national analysis. Utilities Policy, 36, 71-78.

[100] VERNER, D. 2013. Adaptation to a changing climate in the Arab countries.

[101] VERNER, D., LEE, D., ASHWILL, M. & WILBY, R. 2013. Increasing Resilience to Climate Change in the Agricultural Sector of the Middle East: The Cases of Jordan and Lebanon, World Bank Publications.

[102] VILLARROYA, F. & ALDWELL, C. 1998. Sustainable development and groundwater resources exploitation. Environmental Geology, 34, 111-115.

[103] VÖRÖSMARTY, C. J., GREEN, P., SALISBURY, J. & LAMMERS, R. B. 2000. Global water resources: vulnerability from climate change and population growth. science, 289, 284-288.

[104] WADA, Y., VAN BEEK, L. P., VAN KEMPEN, C. M., RECKMAN, J. W., VASAK, S. & BIERKENS, M. F. 2010. Global depletion of groundwater resources. Geophysical research letters, 37.

[105] ZIMMERMAN, J. B., MIHELCIC, J. R., SMITH & JAMES 2008. Global stressors on water quality and quantity. Environmental science & technology, 42, 4247-4254.