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Community based adaptation options for climate change impacts on water resources: The case of Jordan

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Abstract

A strategic vision to ensure an adequate, safe and secure drinking water supply presents a challenge, particularly for such a small country as Jordan, faced with a critical supply-demand imbalance and a high risk of water quality deterioration. In order to provide sustainable and equitable long-term water management plans for the future, current and future demands, along with available adaptation options should be assessed through community engagement. An analysis of available water resources, existing demands and use per sector served to assess the nation's historic water status. Taking into account the effect of both population growth and rainfall reduction, future per sector demands were predicted by linear temporal trend analysis. Water sector vulnerability and adaptation options were assessed by engaging thirty five stakeholders. A set of weighed-criterions were selected, adopted, modified, and then framed into comprehensive guidelines. A quantitative ratio-level approach was used to quantify the magnitude and likelihood of risks and opportunities associated with each proposed adaptation measure using the level of effectiveness and severity status. Prioritization indicated that public awareness and training programs were the most feasible and effective adaptation measures, while building new infrastructure was of low priority. Associated barriers were related to a lack of financial resources, institutional arrangements, and data collection, sharing, availability, consistency and transparency, as well as willingness to adapt. Independent community-based watershed-vulnerability analyses to address water integrity at watershed scale are recommended.

Key words: *adaptation, climate change, Jordan, water resources*

INTRODUCTION

Observable negative effects of global climate change on the environment (e.g., ecosystems and biodiversity), water availability and quality, energy consumption, crop productivity, the magnitude and frequency of natural disasters, and the spread of disease are well documented [ADAMOWSKI *et al.* 2009; 2010; 2012a, b; ADAMOWSKI, PROKOPH 2013; ARAGHI *et al.* 2015; BELAYNEH *et al.* 2014; CAMPISI *et al.* 2012; DANESHMAND *et al.* 2014; HAIDARY *et al.* 2013; NALLEY *et al.* 2012; 2013; NAMDAR *et al.* 2014; PINGALE *et al.* 2014; SAADAT *et al.* 2014; TIWARI, ADAMOWSKI 2013]. According to the Intergovernmental Panel on Climate Change [IPCC 2007a; 2013], the magnitude of climate change effects on individual regions will vary over time and according to the different societal and environmental systems' capacity mitigate or adapt to change.

It no longer being a matter of debate whether climate change (e.g., increased uncertainty, variability and extreme weather events) is affecting our water resources, it is imperative that adaptation strategies in the water sector address emerging trends. Social and political contexts will further determine the net impacts of climate change on social systems and on the effectiveness of adaptation interventions [NICOL, KAUR 2009].

LIM *et al*. [2005] proposed four climate change adaptation policy framework approaches: (i) hazards-based – reduce climate-induced risks, (ii) vulnerability-based – ensure that critical thresholds of vulnerability in socio-ecological systems are not exceeded, (iii) raising adaptive-capacity – assess, then increase current adaptive capacity to enable systems to better cope with climate change and variability; and (iv) policy-based – ensure that robust policies are in place to address climate change.

As a rapidly developing country with limited water sources, Jordan is highly vulnerable to the adverse impacts of climate change. These have recently led the nation to become the world's fourth poorest in per capita water resources, dropping from 150 m^3 per capita per year in 2007 to 86 m^3 per capita per year in 2013, well below the severe water poverty threshold of 1000 m^3 per capita per year set by Jordan's Ministry of Water and Irrigation [MWI 2015].

Since the ratification of the United Nations Framework Convention on Climate Change (UNFCCC) in 1994, Jordan has committed itself to ensuring the success of the UNFCCC's global environmental management approach through its Ministry of Environment's focus on climate change issues. Despite the fact that many adverse water resource phenomena observed in Jordan were set in motion by anthropogenic actions over the past decades, the consequences of climate change have gained widespread recognition in recent years. A number of studies have been conducted to assess the impacts of climate change on water resources in Jordan. For example, Jordan's Ministry of the Environment (MoEnv) has regularly [GCEJ 1997; MoEnv 2009; 2014] submitted national communication reports to the UNFCCC. The latest of these [MoEnv 2014] reports the results of multi-model ensembles dynamic downscaling analysis. A warmer, drier future climate, with more frequent heat waves, droughts, and intense precipitation events was found to be likely to extreme likely. By 2070–2100, mean daily temperature is extremely likely to rise by 2.1°C to 4°C, while the annual cumulated precipitation is likely to decrease by 15% to 21%.

Several studies have highlighted the water sector's high sensitivity to potential impacts of climate change: *e.g*., groundwater level decline, groundwater quality deterioration, stream flow reduction, decline in groundwater recharge and increased water demand. Other predicted impacts include groundwater depletion and salinization, surface water contamination, soil erosion, desertification, disappearance of small springs, significant reduction in the discharge of major springs, violations of water regulations, vandalism, reduced abundance of arable land, social conflicts and economic stresses [ABDULLA *et al*. 2009; AL-QINNA *et al*. 2011; MoEnv 2014].

Since Jordan's current (2008–2022) water strategy ignores the impact of climate change, it is important to reconsider and re-construct the water budget and implement the necessary adaptations to reduce these risks and their potential impacts. Further, no studies have explored this issue. Therefore, the main objective of this study was to assess current and future water status under the influence of climate change, and to suggest and prioritize potential adaption measures based on community involvement.

METHODOLOGY

JORDAN AS A CASE STUDY

In Jordan, the Ministry of Water and Irrigation (MWI) is the main official government organism in charge of water sector activities, e.g., water supply, wastewater systems and related projects, planning and management, formulation of national water strategies and policies, as well as centralization, standardization and consolidation of data. Two parallel entities responsible for various water sector services, the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA), exist within the MWI.

Responsible for planning, implementing and operating all water supply and wastewater facilities in Jordan, the WAJ explores and manages existing water resources, and maintains and operates water and wastewater networks throughout the Kingdom. In contrast, the JVA is charged with the integrated social and economic development of the Jordan Rift Valley from the Yarmouk River in the north to Aqaba in the south. The JVA creates partnerships with the private sector where appropriate, and also implements projects stemming from regional agreements on water and development on behalf of the Jordanian government [JVA 2009]. Communication among the MWI, WAJ and JVA is limited, with each functioning in near isolation from the others.

The Institutional Support and Strengthening Program (ISSP) under MWI is now taking over the transfer of licensing and groundwater management functions from WAJ. In addition, an interim water utility regulator, the Performance Monitoring Unit (PMU), now regulates water and wastewater utilities under private management to support both the JVA and Water User Associations (WUAs). The WUAs are a farmers' body which has been created to manage the use of irrigation water in the Jordan Valley. Establishing public water companies is another emerging form of water sector management. Currently, there are three public companies operating in Jordan: the Aqaba Water Company in the south, the Jordan Water Company (Meyahona) in the central region, and the Yarmouk Water Company in the north. Each company has its own board of directors with representatives from MWI, concerned ministries and authorities [MWI 2009; 2015].

Jordan initially formulated its water strategy in 1997 and updated it in 2009 and again in 2013 [MWI 1997a; 2009]. The latest strategy (Water for Life) identifies future water planning until 2022. The actions that will be taken will serve to ensure that water is available for people, businesses and nature. With the obvious role of promoting sustainable utilization of an already scarce natural water resources, a Water Utility Policy [MWI 1997b], Irrigation Water Policy [MWI 1998a], Groundwater Management Policy [MWI 1998b], and Wastewater Management Policy [MWI 1998c] were also issued.

ASSESSMENT OF CURRENT AND FUTURE WATER STATUS PROJECTIONS

The country's current and historic water status was assessed through analyses of water resource, along with supply and demand data obtained from MWI [MWI 2015], which covered the years of 1985 to 2013. The data included allocated water resources, estimated water demands and actual water supplies ($10^6\ m^3 \cdot y^{-1}$) for various sectors. Water assessment was focused on four sectors; domestic, agricultural, industrial, and touristic. In addition, several national and international reports (e.g., those of the Gesellschaft für Internationale Zusammenarbeit (GIZ), United Nations Development Programme (UDNP), and French Development Agency (AFD), amongst others) were reviewed for further information on major national water resources issues at the national level.

The effect of a combined increase in population and reduction in rainfall on future sectoral water demand was analyzed. Population growth data for Jordan (1952–2012), was analyzed using a logistic population growth model (Eq. 1):

$$P(t) = \frac{\left(\frac{a}{b}P_0\right)}{P_0 + \left(\frac{a}{b} - P_0\right)e^{-at}} \qquad (1)$$

where:

a = the birth rate,
b = the death rate,
t = the time,
$P(t)$ = the population at time t, and
P_0 = the population at time $t = 0$.

Total nationwide annual precipitation data (million $m^3 \cdot y^{-1}$) over the period of 1938 to 2009 were obtained from the Jordanian Meteorological Department [Jometeo 2010].

To assess the vulnerability of Jordan's water sector, additional information on the capacity of dams and the extent of unconventional water production (i.e., treated wastewater and desalinization) were also obtained from the MWI [2010].

Future sectoral water demands were developed using linear temporal trend analyses, taking into account the effect of both population growth and decline in rainfall. All statistical analyses were performed using JMP 8.0 statistical software [JMP 2008]. The models' accuracy was assessed according to both the Root Mean Square Error *RMSE*, and the coefficient of determination R^2 with a significance level exceeding 95% (i.e., $P \leq 0.05$). Using appropriately calibrated models, future projections for the years 2022 and 2050 were determined on a per sector basis.

IDENTIFICATION OF POSSIBLE CLIMATE CHANGE IMPACTS

Possible climate change impacts to each sector were identified through a literature review and categorized as follows: (i) high rainfall intensities posing a flood hazard, (ii) low annual precipitation posing a drought hazard, and (iii) heightened minimum and maximum air temperatures, resulting in temperature variability.

In light of Jordan's water sector, the development of potential climate change adaptation measures, and their application through the formulation of appropriate legal and institutional strategies and targeted interventions was assessed by taking into account previously identified trends and potential impacts. All possible adaptation measures suggested were grouped into six categories [IPCC 2007b]: (i) supply management, (ii) surface water, (iii) groundwater, (iv) unconventional water (*i.e.*, domestic wastewater, industrial wastewater, brackish water, grey water, drainage water, and virtual water), (v) on-farm management, and (vi) capacity building [LEARY *et al.* 2007; LIM *et al.* 2004]. A total of one hundred proposed adaptation measures were classified according to the IPCC [2007b] adaptation chain into: prevention measures, improvement of resilience, preparation measures, response measures, and recovery measures.

MULTIPLE STAKEHOLDERS SELECTION AND DEVELOPING SELECTION CRITERIA

In order to accomplish the objectives of this study, major relevant stakeholders from different sectors were involved. Thirty five stakeholders were engaged in the adaptation evaluation processes, representing ministries, donor agencies, academia, NGOs, research centers, local communities and farmers.

A set of criteria were selected, adopted, and modified from different resources [BIZIKOVA *et al.* 2008; IPCC 2007b; MEASHAM *et al.* 2011; UNECE 2009; XIAO-JUN *et al.* 2014], then framed in legitimate, logical, comprehensive selection guidelines. The criteria, weighted according to the concerns they addressed, could also serve as indicators of the success or failure of the realization of objectives, and in the capacity of a monitoring-evaluation programme for adaptation strategies, policies and measures. Therefore, the developed criteria are simply evaluation guidelines of the suitability and potential of each adaptation measure to be implemented in a given country, based on each measure's requirements [MILLER, BELTON 2014].

In roundtable multi-stakeholder meetings, stakeholders individually weighted each criterion according to the importance they perceived it to have, based on their personal experience, knowledge, and their sector's requirements. A mean of all proposed weights became the final weight, such that each theme (i.e., sustainability, effectiveness, risk and urgency, opportunity, or implementation) has a weight that is sum of all sub-weights of the sub-theme criterions. Each theme contains multiple criteria addressing the degree of severity, timing of benefits, dependence of benefits on specific climatic conditions, environmental sustainability and flexibility, thresholds for adverse impacts, cost-effectiveness, etc.

REVIEWING OPPORTUNITIES AND BARRIERS

A barrier is any obstacle to reaching a potential that can be overcome by a policy, programme, or measure. An opportunity is a situation or circumstance to decrease the gap between the market potential of a technology or practice and the economic, socioeconomic, or technological potential [IPCC 2007b]. Willingness and ability to adapt are often affected by real and perceived barriers or constraints. This can lead to questioning the need for adaptation or may limit the effectiveness of a particular option.

The international experience has suggested many adaptation measures, however each of these measures has specific needs and requirements that might be site specific or require huge investments, while other measures may require great technical expertise.

Barriers to implementing water conservation and water demand management practices are commonly related to financial, planning, institutional, technical, capacity, and social constraints [MUKHEIBIR 2005]. Using three levels of effectiveness and severity ranking (low, moderate, high), a descriptive approach was used to assess the magnitude and likelihood of risks and opportunities (Tab. 1).

Table 1. Descriptive approach scaling of the magnitude and likelihood of risks and opportunities

	Exposure factors	Score		
		low	moderate	high
Description	risk magnitude (probability of occurrence in a given year)	event is not expected to occur, but possible (<33%)	event more likely than not, but may still not occur (33–95%)	event or change very likely to occur (>95%)
	confidence	very low: <10%	medium: ≈50%	very high: >90%

Source: own elaboration.

EVALUATION AND PRIORITIZATION OF THE SUGGESTED ADAPTATION MEASURE

To yield a multi-criterion score, the sum of the weights of each sub-criterion used in the evaluation was multiplied by an assigned ratio (1–5, low to high) representing each stakeholder's judgment for each proposed adaptation under each sub-criterion. Weights were assigned by the stakeholders according to their importance in the evaluation, and totaled 100%.

The most feasible immediate actions, particularly those involving the management of existing infrastructures and their associated institutional frameworks, should be the first implemented.

RESULTS AND DISCUSSION

ASSESSMENT OF CURRENT AND FUTURE WATER STATUS IN JORDAN

Analyses of Water Resources and Supply

Jordan's conventional and natural water resources originate in rainfall, groundwater, and surface water. Since the establishment of the MWI, the country has developed, according to the sector, various ways to capture, store and distribute these waters. Moreover, it has developed various reliable unconventional water resources (e.g., treated wastewater). The nation's main available water resources include: the Jordan and Yarmouk River valleys, renewable and non-renewable groundwater sources, rainwater collection, treated wastewater and limited desalination plants [DENNY 2008]. The Jordan and Yarmuk Rivers represent the nation's main sources of surface water, but in recent years their flow rates have become unpredictable due to upstream damming and diversion of river waters by neighboring countries (i.e., political issues).

According to water resources data analyses (Tab. 2), the allocation for new water resources has been increasing by rate of $25 \cdot 10^6$ $m^3 \cdot y^{-1}$ reaching a total of $901 \cdot 10^6$ m^3 for 2013. With the efforts of the MWI, the fraction of surface to total water supplies has increased from 28.2% in 2000 to 36.2% in 2013.

There are 12 major dams in Jordan that account for a total capacity of $326.33 \cdot 10^6$ m^3 (Fig. 1), in addi-

Table 2. Estimated available water resources (MCM) available water resources

Water resource	Value (10^6 m^3) in years		
	2000	2007	2013
Developed surface water	163	295	326
Renewable groundwater	275	275	275
Non-renewable groundwater	63	91	115
Treated wastewater	77	98	121
Desalinated water	0	10	14
Peace treaty	0	50	50
Total available water resources	578	819	901

Source: own elaboration.

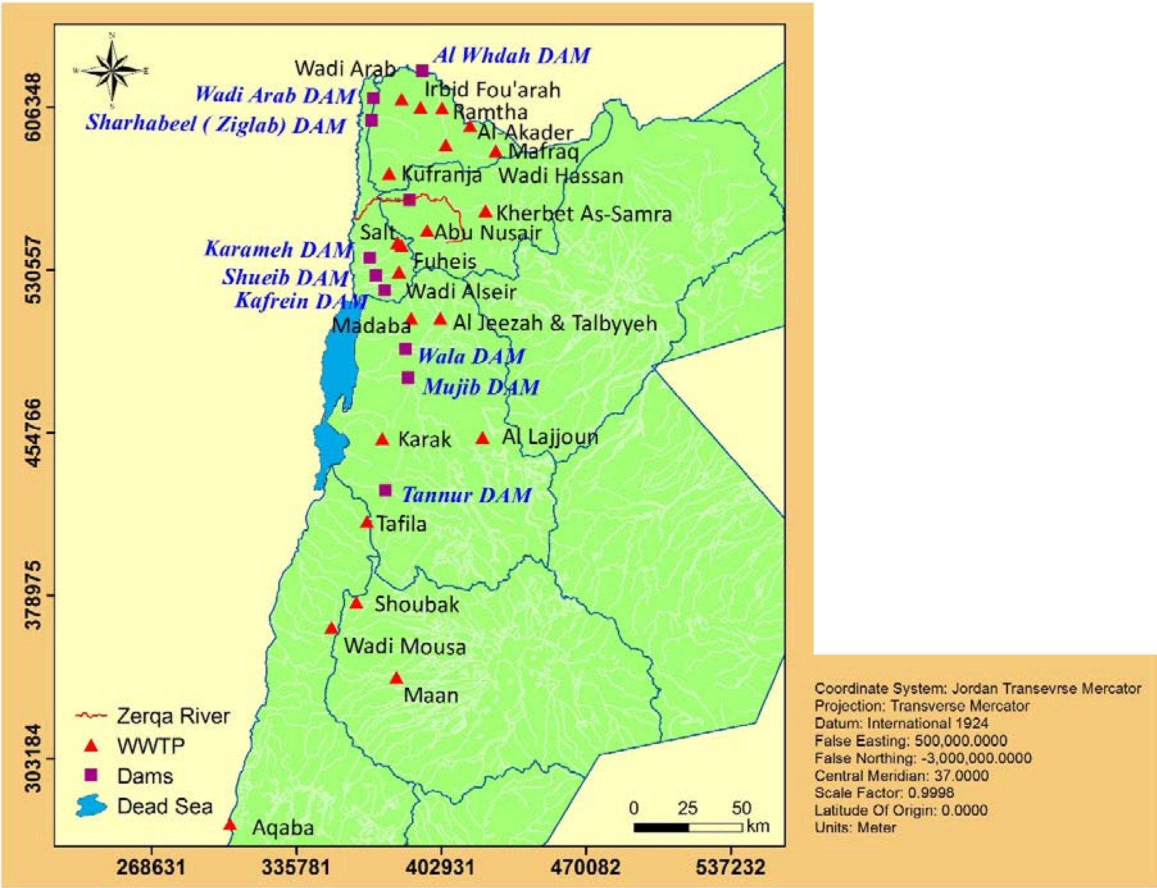

Fig. 1. Water resources in Jordan

tion to several excavations that are tendered or implemented with other agencies. Currently groundwater sources contribute approximately 43.3% of the total water supply. Non-renewable groundwater includes artificial recharge and the permanent groundwater basins of Jafr, Lajjoun, Disi, and Hisban that currently contribute about 12.8% of the total water resources. In contrast, renewable groundwater resources contribute around 30.5% of total water resources. The increase in non-renewable water resources is not an indication of use, but rather an indication of the newly implemented exploitation of previously untapped aquifers. Meanwhile, while water desalination projects are growing, especially those at Abu Zeighan and Aqaba, they contribute only 1.6% of total water resources.

There are approximately 3,034 groundwater wells in Jordan that are controlled and monitored by the MWI, however their over-pumping and illegal overexploitation had led to the deterioration of the water quality at half these wells [IRIN 2007]. So far only 141 illegal wells have been closed [MWI 2015]. The unsustainable abstraction of groundwater may be largely attributed to population growth and agriculture expansion and is exacerbated by a lack of enforcement of existing regulations on private sector well drilling, and the near absence of controls on licensed abstraction rates.

WAJ has established thirty-one wastewater collection and treatment services (Fig. 1) for more than 742,763 subscribers. The total treated wastewater production so far (2013) is about $110 \cdot 10^6 m^3 \cdot y^{-1}$ and is primarily used in agriculture and some industrial activities. Several brackish springs have been identified in various parts of the country. Estimates of stored volumes of brackish groundwater for the major aquifers suggest immense resources, but it will not be feasible to use all these resources.

The nation's drinking water supply has increased from $239 \cdot 10^6 m^3$ in 2000 to $381 \cdot 10^6 m^3$ in the 2013, representing a rate of increase about $10.65 \cdot 10^6 m^3 \cdot y^{-1}$. Although the government had provided various services to handle these water supplies, investments in municipal networks remain inadequate. With service to 97% of the urban population and 83% of the rural population, the level of Jordan's water supply sector services is fairly high; however, distribution systems are still far from optimal and efficiencies are still low. In 1995, unaccounted for water in municipal networks (Non Revenue Water "NRW") was estimated to be 55% of the quantity supplied, but dropped to 52% in 2000 and 48% in 2013. In contrast, water efficiencies in irrigation distribution networks were 87% and 93% in 2012 and 2013, respectively.

Another significant challenge is the transfer of water from one region to another. Since water is not equally distributed in Jordan, the transfer between surplus and deficit areas is managed by large-scale engineering systems such as pipelines [DENNY 2008]. These water conveyance systems are not very efficient and tend to deteriorate water quality as well as increase water losses from evaporation and leakages [FoEME 2002]. The government is exploring a number of projects to increase Jordan's water supply either temporarily or permanently. The largest projects, or "mega projects," include tapping the Disi aquifer and building a canal between the Red and Dead Seas. Other projects include desalination plants, water network updates and Public-Private Partnerships (PPPs).

Water resources in Jordan are directed towards four different sectors: agriculture, municipal supplies, industry, and tourism. By far the largest user of the country's water resources is agriculture, with irrigation contributing 71% of the water demand and using 64% of the water supply in 2007, while municipalities, industry and tourism use a further 30%, 5% and 1%, respectively [ALTZ-STAMM 2012]. However, the demand and use of drinking water is rapidly rising due to a sharp increase in population growth (Fig. 2). In contrast, agricultural use is declining over time due to changes in land use, land cover pattern, etc. In 2013, the water use by agricultural sector accounted for 53% of total supplies, while municipal demand had increased to 42%. The present rate of increase in total water use is about $3.84 \cdot 10^6 m^3 \cdot y^{-1}$, with increases in municipal and industrial use of $8.9 \cdot 10^6 m^3 \cdot y^{-1}$ and $0.4 \cdot 10^6 m^3 \cdot y^{-1}$, respectively, and a decline of $5.2 \cdot 10^6 m^3 \cdot y^{-1}$ MCM for the agricultural sector.

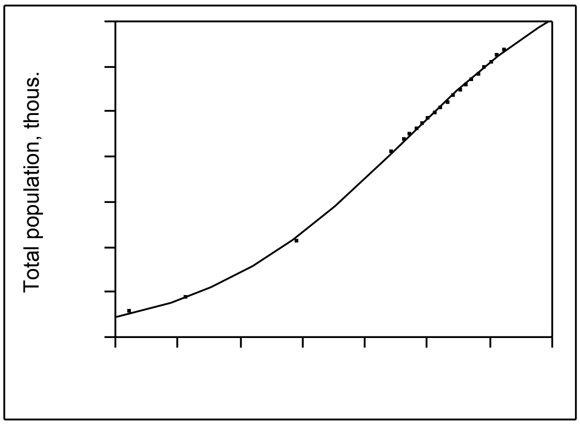

Fig. 2. Population growth rate of the Hashemite Kingdom of Jordan; source: own elaboration

Agriculture in Jordan is concentrated in two main regions, the Jordan Valley that obtains its water mainly from surface water resources and the Highlands that draw water from rainfall or wells. As municipal, industrial and touristic water use increases, irrigated agriculture in the highlands will need to be capped and regulated and water use by-laws reinforced. Groundwater extraction for agriculture is presently beyond acceptable limits, resulting in a groundwater deficit of $151 \cdot 10^6 m^3$ in 2007.

Total national water use in 2012 was $849.37 \cdot 10^6 m^3$, of which about 60% was drawn from groundwater. Agriculture remained the main water user ($456.2 \cdot 10^6 m^3$) at about 54% of total water use (Tab. 3).

Table 3. Source of water used in Jordan for 2012

Source	Sector water use, 10^6 m^3				
	municipal	industrial	irrigation	livestock	total use
Surface water	**122**	**5.67**	**105.2**	**7**	**239.87**
Jordan Rift Valley	105	5.67	36.5	0	147.17
Springs	17	0	31	0	49
Base and flood	0	0	37.7	7	44.7
Groundwater	**231**	**26**	**251**	**0.1**	**508.1**
Renewable	197	19	217	0.1	433.1
Non renewable	20	7	34	0	61
Desalinization	14	0	0	0	14
Treated waste water	**0**	**1.4**	**100**	**0**	**101.4**
Total	353	33.07	456.2	7.1	849.37

Source: own elaboration.

Future projected water demands

Based on an analysis of Jordan's population, a logistic trend model (Eq. 1) was found to accurately ($P < 0.0001$, $RMSE = 42.6$, and $R^2 = 0.9993$ describe the country's population growth rate. This was predicted to be 6.15% y^{-1} significantly higher than the mortality rate ($7 \cdot 10^{-7}$ % y^{-1}) (Eq. 2).

$$P(t) = \frac{\left(\frac{a}{b}P_0\right)}{P_0 + \left(\frac{a}{b} - P_0\right)e^{-at}} \tag{1}$$

$$P(t) = \frac{\left(\frac{0.0615}{7.06 \cdot 10^{-9}} \cdot 536848\right)}{536848 + \left(\frac{0.0615}{7.06 \cdot 10^{-9}} - 536848\right)e^{-0.0615t}} \tag{2}$$

The rapid growth rate is in part a result of sudden unplanned migrations that occurred (e.g., 1948 Arab–Israeli War, the Six-Day War in 1967, the Gulf War of 1990, the Iraq War of 2003 and the Syrian civil war since 2011) and had an impact on plans to reach a balanced supply and demand. Given this pattern of population change, the model was used to predict future populations of 7.244 and 8.424 million for the years 2022 and 2050, respectively ($P < 0.0001$).

Annual total rainfall over the full extent of Jordan's territory shows high temporal (inter-annual) variability, with no apparent trend in wet *vs*. dry years (Fig. 3). Although wet-year rainfall can be 3 to 4-fold the long term average ($8.243 \cdot 10^9 m^3 \cdot y^{-1}$) and increase flash flood risk, the effects of drought are more obvious: when flood events recently occurred in southern micro-scale regions, the effects of drought were more evident over the remainder of the country [MoEnv 2014].

According to the linear trend of total rainfall quantities, the number of dry years (below average

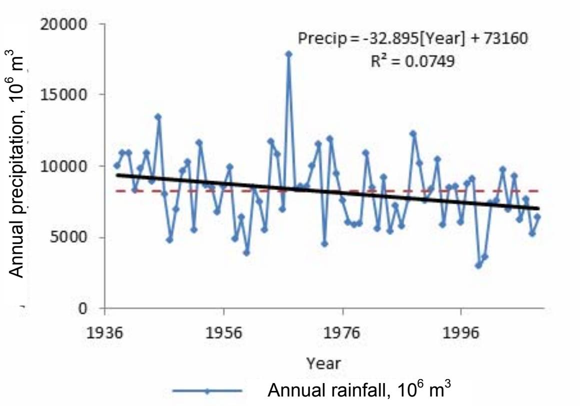

Fig. 3. Linear trend analysis of precipitation across all of Jordan; source: own study

rainfall) will be more frequent and conditions will range from slight to severe drought. The overall precipitation trend predicted a significant decrease ($P < 0.02$, $RMSE = 2.437 \cdot 10^9$ m^3, $R^2 = 0.0749$) of $32.9 \cdot 10^6$ m$^3 \cdot$y^{-1}, where for a mean annual precipitation of $8.243 \cdot 10^9$ m$^3 \cdot$y^{-1}. Thus the predicted decrease in rainfall until 2030 represents a drop to about $1.000 \cdot 10^9$ m$^3 \cdot$y^{-1} below the average. The predicted rainfall for 2022 and 2050 are $6.647 \cdot 10^9$ m$^3 \cdot$y^{-1} and $5.726 \cdot 10^9$ m$^3 \cdot$y^{-1}, respectively.

Since the water supply in the country is mainly dependent on surface supply and groundwater recharge from rainfall, a significant decrease in rainfall will certainly pose a threat to the available water supply if no adaptation plans are rapidly adopted. Based on trend analyses of water balance (demand vs. supply), the country will always face a deficit in water supply, forcing water use to exceed the safe yield in some basins and leading to the extraction of water from non-renewable sources in addition unconventional water sources (e.g., desalinization and treated wastewater) (Fig. 4). This deficit is actually increasing at a rate which parallels that of population growth.

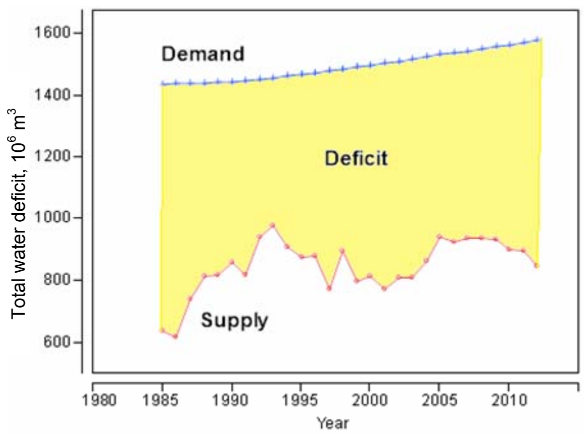

Fig. 4. Temporal changes in water demand, supply, and deficit (10^6 m^3 y^{-1}); source: own study

Water demands have always exceeded Jordan's available water resources, especially during the last decade, placing the Jordanian government in a critical situation in terms of allocating and search for new water resources. According to analyses of water demand data, this will continue to increase significantly ($P < 0.0001$) – at a rate of $5.5 \cdot 10^6$ m^3 y^{-1} – mostly as a result of increasing population growth, as indicated by the high municipal demand rate ($7.6 \cdot 10^6$ m$^3 \cdot$y^{-1}; Fig. 5, Tab. 4).

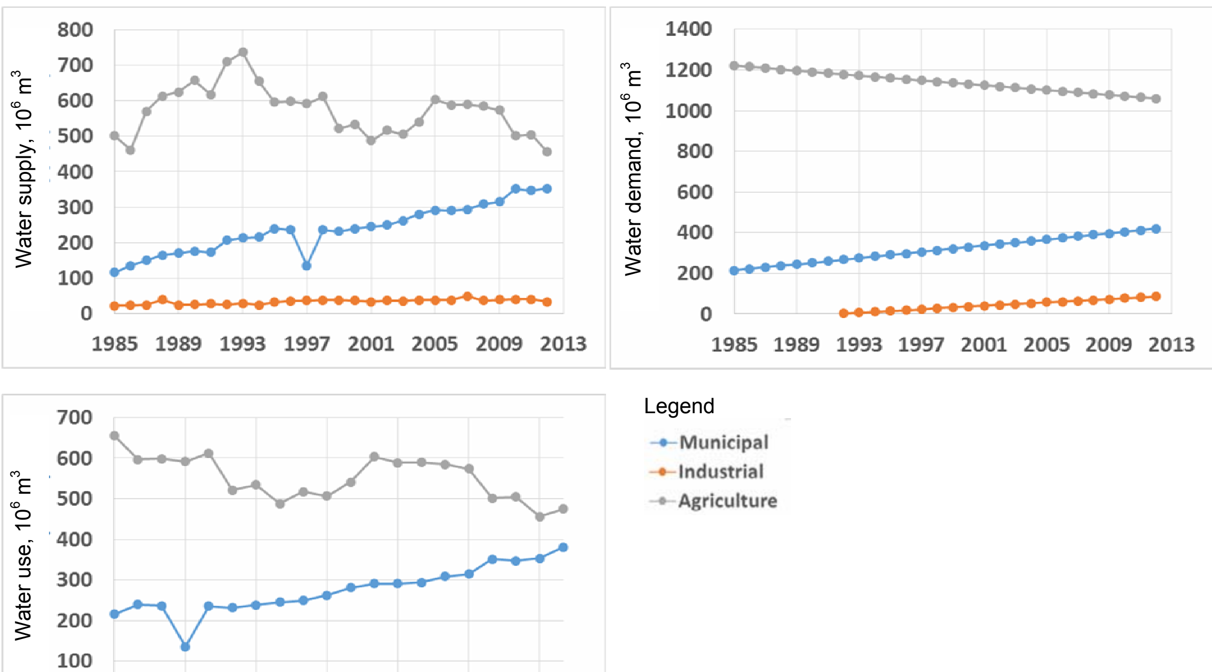

Fig. 5. Temporal changes in water supply, demand and use (10^6 m^3) per sector; source: own study

Table 4. Linear trend models predicting the water use by sector

	Sector	Linear trend	R^2	Root mean square error 10^6 m^3	Prob > F
Demand	municipal	= –14895.23 + 7.6119783 year	0.999	0.098769	<0.0001
	touristic	= –1956.405 + 0.9784528 year	0.999	0.125919	<0.0001
	industrial	= –8226.344 + 4.1311992 year	0.999	0.685007	<0.0001
	agricultural	= 13083.892 – 5.975906 year	0.999	0.000056	<0.0001
	total	= –9692.104 + 5.5975251 year	0.978	7.05392	<0.0001
Supply	municipal	= –15382.47 + 7.8154732 year	0.899	21.92126	<0.0001
	industrial	= –1208.75 + 0.6216998 year	0.580	4.43702	<0.0001
	irrigation	= 6649.7965 – 3.0405586 year	0.129	66.3637	0.0610
	livestock	= 571.28455 – 0.2808912 year	0.573	1.402826	0.0002
	total	= –10570.29 + 5.7142239 year	0.290	74.89812	0.0031
Deficit		= –878.1892 + 0.1166987 year	0.015	78.91781	0.9501

Source: own study.

Nonetheless, under duress the government has managed to allocate various water supplies from different local and international projects, through not without cuts in water supply for some sectors. Access to a safe water supply is an essential requirement. It is not the government's intention to restrict water destined for essential uses, but in some areas, there are excessive claims on the available water resources. Groundwater is being exploited at about twice its recharge rate, and there are hundreds of illegal wells. According to MWI [2009], annual per capita water availability has declined from $3.600 \cdot 10^3$ m^3·y^{-1} in 1946 to $0.145 \cdot 10^3$ m^3·y^{-1} today. It is projected that the population will continue to grow from about $5.87 \cdot 10^6$ in 2008 to over $7.80 \cdot 10^6$ in 2022, at which time total projected water demand will be roughly $1.673 \cdot 10^9$ m^3·y^{-1} [MWI 2011].

On the other hand, the rates of water demand for tourism, industry, and agriculture over the same period are were 1, 4.1, and $-6 \cdot 10^6$ m^3·y^{-1}, respectively. Industrial growth in Jordan and thus industrial water use is increasing due to population growth, as well as human and developmental demands. While the agriculture sector's demand is declining due to changing cropping patterns, shifting land use from vegetables to trees, and altering irrigation practices towards modern drip systems.

The main problem in balancing the nation's water demand and supply stands in the agricultural water needs. Since the country focuses in local food markets for vegetables and fruits as well as some forage crops for animal feeds, a significant portion of the total water demand is attributable to the agricultural sector, which consumes near two thirds of the total supply. According to an analysis of historic water use data, agriculture sector water use increased up to a maximum of $739 \cdot 10^6$ m^3 in 1994, then decreasing until 2002, when it began to increase again. The variability in the agriculture water use was compared to municipal wastewater treatment plant (WWTP) construction and the use of their effluents. By 1995, the WWTP began allowing the use of their effluents for agriculture at a rate of $75 \cdot 10^6$ m^3·y^{-1}. The construction of WWTPs helped to overcome the water shortages until 2002 where the WWTPs capacity became $75 \cdot 10^6$ m^3 per year.

However, due to a sudden population growth attributable to migrations, lower rainfall adding to the visibility of climate change impacts, a shifting of planting season, and more frequent droughts, farmers have begun to change their cropping patterns towards more dependable water sources (rainfed → irrigated) and more to less water-demanding crops (forage → trees. This again puts more pressure on the water supply. Although the WWTPs' output is $111 \cdot 10^6$ m^3·y^{-1}, it is still not enough to compensate for the agricultural demand, so farmers are over-pumping water from groundwater to compensate for the deficit.

Given the 2022 and 2050 projected populations to be 7.244 and 8.424 million ($P < 0.0001$), respectively, if the same potential increase in water allocation exists, the demands for municipal, touristic, industrial and agricultural sectors are estimated to reach 9.3, 49.4, 242.6, and $833.3 \cdot 10^6$ m^3·y^{-1}, respectively for the year 2050, with a total demand of $1.783 \cdot 10^9$ m^3·y^{-1}, and a deficit of about $0.639 \cdot 10^9$ m^3·y^{-1}. On the other hand, if no further water reclamation projects are established, the total deficit will reach becoming $0.856 \cdot 10^9$ m^3·y^{-1} thus place the country's water status under maximum pressure. According to MWI, the expected deficit for 2022 is about $0.503 \cdot 10^9$ m^3·y^{-1} with a total demand of $1.635 \cdot 10^9$ m^3·y^{-1} and resources of $1.132 \cdot 10^9$ m^3·y^{-1}. Taking into account the Red Dead Conveyance, the water deficit becomes only $5 \cdot 10^6$ m^3·y^{-1}, where the Jordanian share will allow for total resources of $1.132 \cdot 10^9$ m^3·y^{-1}.

POSSIBLE IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

Climate change can have numerous impacts on a wide range of sectors (*e.g.*, water, agriculture, biodiversity, health, industry, tourism, social, even politics). Based on a review of pertinent literature on the potential effects of climate change on the water sector, several possible impacts were identified and categorized (Tab. 5): (i) extreme events (*e.g.*, heavy rainfall intensities, cold winter associated with freezing, and high snow depths) categorized as wet hazard), (ii)

Table 5. Major projected impacts on water sector

Phenomenon	Impacted water resources issues	Risk magnitude	Confidence (certainty) degree
Extreme Events (e.g. heavy rainfall intensities, freezing, and high snowfall events)	increased frequency and intensity of flood events	high	high
	deterioration of surface water	moderate	high
	contamination of ground water	moderate	high
	higher water losses in networking pipes	moderate	moderate
	damage to both water supply and sanitation infrastructure from flash flooding	moderate	moderate
	high water loss due to frost protection by irrigation water	moderate	moderate
Precipitation variability and overall reduction in annual precipitation quantities	less replenishment of surface water reserves	high	high
	reduction in groundwater recharge and table	high	high
	surface water quality deterioration	high	high
	groundwater quality deterioration	high	high
	salinization of coastal aquifers	moderate	moderate
	discharge reduction of large springs and possible disappearance of small springs	high	moderate
	densification of sewage water and thus reduction and deterioration of treated wastewater quality	moderate	moderate
	higher irrigation water demands due to drought events	high	high
Increased temperatures	higher water demand in summer		
	increased water temperatures	high	high
	increase in both evaporation and transpiration	high	high
	increase in irrigation water demand	high	high
	changes in mixing patterns and self purification capacity	moderate	moderate

Source: own study.

low annual precipitation leading to potential drought hazard, and (iii) increased minimum and maximum air temperatures, categorized as heat hazards.

SUGGESTED ADAPTION MEASURES

Taking into account both predicted trends and the list of possible impacts, one hundred possible adaptation measures were suggested and grouped into six categories: (i) supply management, (ii) surface water, (iii) groundwater, (iv) unconventional water (i.e., wastewater, industrial wastewater, brackish water, grey water, drainage water, and virtual water), (v) On-farm management, and (vi) capacity building. Adaptation measures were classified according to adaptation chain to include: prevention measures, improved resilience, preparation measures, response measures, and recovery measures [IPCC 2007b].

To prevent the negative effects of climate change and climate variability on water resources management a number of prevention measures were selected: implementation of water-efficient methodologies, improvement of water retention, reduction in water use by industries and agriculture, modernization and upgrades of the storage capacity of existing water reservoirs, minimization of losses by surface evaporation from existing water bodies, reduction of sediment deposition beyond construction and mining areas, use of piping to transfer treated water from WWTPs, recycling of treated industrial water, alteration in the mix and level of production, etc. Similarly, measures were proposed to improve resiliency by reducing the negative effects of climate change and variability on water resources management, as well as by enhancing the capacity of ecological, economic and social systems to adapt to the impacts of future climate change. Diversification into activities that are less inherently vulnerable to climate can enhance resiliency, e.g., conservation and restoration of ecosystems, use of brackish industrial water for specific on-site plant programs, public and stakeholder participation in groundwater management, operation of dams and water reservoirs (surface and underground) as water harvesters, protection of surface water supplies from point and non-point pollution sources, etc.

Aimed to reduce the negative effects of extreme events on water resources and their management, preparation measures include increasing monitoring systems, raising awareness, water storage, water demand management, implementing technological developments, constructing new surface dams and ponds, improving existing wastewater treatment plants, etc. Response measures targeted at alleviating the direct effects of extreme events could include: restriction of urban development in flood risk zones, development of evacuation protocols, establishment of safe drinking water and sanitation facilities inside or outside affected areas during extreme events, movement of assets out of flood zones, etc. Aimed towards restoring economic, societal and ecological systems after an extreme event, recovery measures can include: reconstruction of infrastructure as well as operations at the tactical level.

ANALYSIS OF BARRIERS AND OPPORTUNITIES FOR

Barriers to adapting to climate change can arise from financial, planning, institutional, capacity, or technical constraints [Tab. 5 GCEJ 1997; MoEnv 2007; 2009; 2014; NEEDS 2010]. In a low-income developing country such as Jordan, where resources are limited and fragile, the greatest barrier is a lack of financial resources to implement adaptation programs. On the other hand, most of the existing barriers devolve from a lack of institutional arrangements for data collection and data sharing. Data are often unavailable, inconsistent, lacking in transparency, inconvenient to access, or inappropriate.

Existing climatic and water resources monitoring in Jordan faces permanent problems in operation, slow modernization of equipment and a reduction in the monitoring network. In addition, socioeconomic data are either unavailable or available in inappropriate form. In general, data regarding some socioeconomic variables are available at the governorate level, but not at the city, town or village level. Moreover, existing financial resources are insufficient to address needs, conduct research and studies, and implement adaptation measures.

Willingness and ability to adapt are often affected by real and perceived barriers or constraints that lead to questioning the need for adaptation or limiting its effectiveness. The present study presents a series of tasks representing a logical progression from an assessment of climate change impacts, through an analysis of risks and opportunities, and the identification of adaptation options. Table 6 shows some of the identified risks and opportunities, categorized into institutional, political, financial, social, technical, and environmental constrains.

Table 6. Sample of analysed set of possible barriers and opportunities

Barrier	Opportunities
Weak of pertinent laws or regulations	• Revision of the governance arrangements and policy strategy are necessary.
Insufficient and/or ineffective law enforcement	• A multi-stakeholder coordination committee should be established to manage national adaptation strategies, chaired by a senior ministry.
Lack of Effective Regulatory Agencies	• A risk-based approach to adaptation should be adopted, informed by bottom-up experiences of vulnerability and existing responses
The incongruence between long term processes of climate change and the short time horizon of politicians and policies.	• Legislation and agency policies may be highly static, inhibit dynamic planning, impede flexible adaptive responses and force a fine-filter approach to management
Lack of cooperation between sectoral	• Protecting and enhancing migration
Little research work on the practical application of policy measures for adapting to climate change	• Capacity building campaigns at the policy makers and the stakeholders should be conducted
National scientific community has not had an active role in addressing vulnerability and adaptation issues	• The capacity of existing poverty reduction and risk reduction mechanisms should be expanded to incorporate climate adaptation where possible
Lack of coordination on cross-sectoral issues	• Gender issue should be taken into consideration in climate change adaptation measures

Source: own elaboration.

PRIORITIZATION OF ADAPTATION MEASURE

In order to evaluation of all suggested measures as to their feasibility, legitimacy and correctness, fully-detailed criteria were suggested and evaluated by the stakeholders. These criteria took into account the sustainability, effectiveness, risk and urgency, opportunity, and implementation feasibility. Each criterion was subdivided into subgroups with variable weights relative to its impact on the adaptation to change in the water sector. According to multiple stakeholders' group discussions, each sub-criterion was described briefly (Tab. 7).

Table 7. Selection criteria for community-based proposed and adopted adaptation measures

Criteria	Sub-criteria	Description	Weight	Sub-weight
Sustain-ability	benefits	degree of benefits in terms of reducing impacts and exposure, and enhancing resilience or opportunities	20	10
	ecosystem impact	degree of environmental impacts on ecosystems		10
Social Aspect	gender issue	number of women benefiting from the adaptation, including involvement in and benefits of local ownership	20	6
	youth empowerment	number of youth benefiting from adaptations, including involvement in and benefits of local ownership		7
	public acceptability	public support or opposition to measure		7
Effectiveness	robustness	potential effectiveness of measure for wide range of plausible future scenarios	20	5
	reliability	identify if measure is untested or its effectiveness unproven		5
	urgency	identify the time frame of impact occurrence in recent past, present, and both short- and long-term futures		5
	uncertainty	estimate how well the risks are understood		5
Opportunity	ancillary benefits	identify how this measure will contribute to other community goals	20	6
	no-regret option	identify if this measure has benefits regardless of actual climate change impacts		7
	window of opportunity	identify if there is currently a window of opportunity to implement this measure		7
Implementa-tion	cost effectiveness (low-regret)	identify if this measure will bring high relative benefits to the costs	20	6
	funding sources	identify availability and sources of potential funding		7
	capacity building	estimate if current capacity is sufficient and, if not, what are the capacity gaps		7

Source: own elaboration.

Stakeholders agreed to have the maximum weight associated with implementation, followed by suitability then risk and urgency, while effectiveness and opportunity had the lowest weights. The final evaluation sheet included the suggested criteria. Proposed adaptation measures was individually proposed by the representatives of decision making bodies such the Ministry of Environment, the Ministry of Water and Irrigation, the National Center for Agricultural Research and Extension, and the Jordan Meteorological Department, local municipalities and communities (Zarqa Chamber of Commerce), research and academic institutions, industries (e.g., Hussein Thermal Power Station (HTPP, CEGCO) and Jordan Petroleum Refinery Company (JPRC)], and international funding agencies (e.g., UNDP). Most of the participants were in high level management.

Not surprisingly, water sector prioritization exercises suggested that public awareness and training programs were the most feasible and effective adaptation measures (Tab. 8), since such adaptation measures exhibit: (i) ideal implementation options (i.e., low initial and operating costs, high public acceptability, sufficient existing capacity and institutional coordination), (ii) high opportunity (i.e., ancillary and no-regret options) and (iii) are sustainable, effective and urgent. Among the first priorities as effective, urgent, and sustainable adaptation measures with large windows of opportunity, are the introduction and implementation of pan-sectoral (incl. households) water conservation techniques, and the use of available unconventional water resources (e.g., treated wastewater, industrial wastewater and greywater). However, any adaptation measure that is related to building complex new infrastructure or requires high ancillary and implementation costs will certainly be set as a low priority option, especially if it does not receive public acceptance or involve local owners' involvement. Table 9 shows the prioritized adaptation measures based on MCA Analysis across all water sector categories.

Table 8. Sample of prioritized adaptation measures based on multiple stakeholder analysis according to water sectorial category

	Farmers	Municipalities	NGOs	Menv	MoA	MWI	Average Scores
1. Supply Management							
Reduction of losses from the supply networks (Network Improvement, Rehabilitation & Expansion)	74	74	75	77	80	74	63.3
Introduction of water saving technologies	84	87	73	91	71	64	67.7
Network modeling and installation	77	80	67	60	70	65	59.0
2. Surface Water							
Water harvesting	76	83	85	95	86	83	70.8
Constructing subsurface storage and dams	75	63	68	56	64	53	54.3
Transfer of water among different basins	57	48	56	28	73	68	43.7
3. Groundwater							
Implementation of artificial groundwater recharge to sustain water demands	74	65	71	70	73	71	58.8
Providing sources for recharge the aquifer	74	66	55	51	71	71	52.8
Protection of groundwater from contamination	71	67	60	66	75	75	56.5
4. Unconventional Water							
4.1 Domestic Wastewater							
Enhance the potential reuse of treated wastewater	79	76	74	57	85	82	61.8
Rehabilitate sewerage network	74	68	69	55	73	71	56.5
Importing water intensive agricultural products	67	61	78	71	72	65	58.2
5. On-Farm Water Management							
shift to crops with low water requirements	76	72	76	68	72	72	60.7
adapat updated crop calender	76	72	68	61	77	77	59.0
6. Capacity Building							
Building resilient housing	64	51	74	44	74	69	51.2
Restriction of urban development in flood risk zones	59	55	80	73	65	65	55.3
monitor and maintain water distribution network	71	67	75	50	78	78	56.8

Source: own elaboration.

Table 9. Prioritized adaptation measures based on MCA analysis across water sector categories

Prioritized Adaptation Measure	Score
Public education, awareness raising, and public participation.	71.0
Surface water harvesting.	70.8
Raising awareness.	69.7
Encourage farmer water groups.	69.5
Introduction of water saving technologies.	67.7
Public and stakeholder participation in groundwater management.	66.8
Implementing new desalinization projects.	64.0
Reduction of losses from the supply networks (Netwrok Improvement, Rehabilitation & Expansion)	63.3
Evaluation of fresh springs and submarine water	47.7
Emergency handling and containment facilities for industrial waste dischargers	47.3
Importing water from other basins	46.7
Engaging in water trade, in either the temporary or permanent market	46.5
Transfer of water among different basins	43.7
Alter the mix and level of production	41.7
Reduce production	35.2
Weather modification (cloud seeding)	33.2

Legend

Supply management	Surface water	Ground water
Unconventional water	On-farm water management	Capacity building

Source: own elaboration.

Some of the lowest prioritized adaption measures were related to reduction of crop production and the use of weather seeding. Both cases are not applicable and rejected by society. Farmers are seeking to improve water use efficiency in order to reduce the loss of precious water, but one cannot convince them to reduce their production or parcel of agricultural land.

CONCLUSIONS AND RECOMMENDATIONS

Jordan's strategic water vision to ensure an adequate, safe and secure drinking water supply poses a significant challenge. Being a small growing country with limited water resources and access to financial aid, limits its sustainable economic development. A high population growth rate and the consequent increasing water demand have brought about a critical supply-demand imbalance, which poses a high risk for pollution, water quality deterioration, over-exploitation of non-regenerating water resources, as well as the harsh risks of climate change.

In order to provide sustainable and equitable long-term water management plans for the future, current and future demands, available adaptation options and affordable trades between various sectors should be fully understood. At the same time, community engagement (e.g., citizens, private, public and institutional sectors) as decision-makers and stakeholders is necessary to assure water governance and avoiding advocacy.

Although climate change phenomena are widely recognized, the alleviation of the impacts of climate change on Jordanian water resources has not been seriously considered in any strategic plan. Jordan has implemented some measures to increase the availability/allocation of various water resources to overcome the demand, without taking into account any criteria for selecting the best adaptive measures.

According to assessments of Jordan's current and historic water status in terms of resources, demand and supply from 1985 to 2013, available water resources were found to be very limited, and demand to be increasing considerably, thereby imposing a stress in terms of allocating new water resources. Although the allocation of new water resources has increased at a rate of $25·10^6\ m^3·y^{-1}$, to reach a total of $0.901·10^9\ m^3$ in 2013, this increase will not compensate for the increase in water demand.

The MWI, along with all its entities, has developed several plans to increase the surface water supply, allocate new groundwater aquifers, and ensure the existence of new non-conventional water resources. Indeed, the WAJ has established thirty one WWTPs with a total production of about $110·10^6\ m^3·y^{-1}$, and adopted several brackish water projects that accounted for $14·10^6\ m^3·y^{-1}$ of addition water resources. According to trend analyses of the combination of a sharp rise in population growth and climate change-driven decrease in precipitation, resulting in a reduced surface water supply, water demand will subjected to a significant increase ($5.5·10^6\ m^3·y^{-1}$), thus aggravating the water resource deficit problem. Associated with sudden unplanned migrations, the sharp rise in population growth was estimated at around $6.15\%·y^{-1}$. By 2030 the predicted decrease in rainfall and therefore in surface water will bring nationwide rainfall to some $1.00·10^9\ m^3·y^{-1}$ below the current average. Given the expected increase in municipal demand to be $7.6·10^6\ m^3·y^{-1}$, annual per capita water availability is to decline below $86·10^6\ m^3·y^{-1}$.

On the other hand, the rates of water demand per sector are directly influenced by the impacts of climate change. The change in water demand for the touristic, industrial, and agricultural sectors were estimated to be 1, 4.1, $-6·10^6\ m^3·y^{-1}$. The industrial growth in Jordan is considered a part of climate change due to human and development demands. While the demand for agriculture sector is declining over due to changing crop patterns (e.g., vegetables to trees), land use, and irrigation practices (towards modern drip systems).

Within the present study, several climate change impacts were identified, ranging from extreme events: (i) wet hazards (e.g., heavy rainfall intensities, cold winter associated with freezing temperatures, and high snow depths), (ii) drought hazards, due to low annual precipitation, and (iii) warmth hazards related to increased air temperature minima and maxima. The estimated risk magnitudes associated with these impacts ranged from moderate to severe with medium to high confidence, indicating that immediate adaptation actions should be seriously considered.

This study has proposed one hundred possible adaptation measures in terms of prevention, improved resilience, preparation, response, and recovery. Based on the feasibility, legitimacy, and honesty criteria developed for adaptation measure prioritization, public awareness and training programs were the most feasible and effective adaptation measures, given their ideal implementation options (i.e., low initial and operating costs, high public acceptability, sufficient existing capacity and institutional coordination). Similarly, introducing and implementing water conservation techniques in all sectors, including households, and the utilization of available unconventional water resources (e.g., treated wastewater, industrial wastewater and greywater) in all sectors are among the first priorities as effective, urgent, and sustainable adaptation measures with large opportunity windows. Low priority options were those adaptation measures tied to building complicated new infrastructure and therefore involving high ancillary and implementation costs.

Finally, this study determined that barriers associated with most of the adaptation measures in the Jordanian context were associated with Financial, Planning, Institutional, Capacity, or Technical constraints. The study highlights the importance of community sharing in developing honest and applicable adaptation measures based on local community needs to help transition to more collaborative, integrated, and adaptive water resources management [BUTLER, ADAMOWSKI 2015; HALBE *et al.* 2013; KOLINJIVADI *et al.* 2014; 2015; MAHMOOD *et al*. 2015; MEDEMA *et al*. 2014a, b; STRAITH *et al.* 2014].

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Wpływ zmian klimatu na zasoby wodne – społeczne możliwości przystosowania na przykładzie Jordanii

STRESZCZENIE

Słowa kluczowe: *adaptacja, Jordania, zasoby wodne, zmiany klimatu*

Zapewnienie zasobów wody pitnej dobrej jakości i odpowiedniej ilości stanowi wyzwanie, szczególnie dla państw rozwijających się, np. Jordanii, które doświadczają skrajnie niezrównoważonego popytu i podaży oraz narażone są na ryzyko pogorszenia jakości wody. Obecny i przyszły popyt oraz możliwości adaptacyjne gospodarki wodnej powinno się oceniać na podstawie planów uwzgledniających sprawiedliwy rozrząd wody i analizę istniejących zasobów. Znajomość dostępnych zasobów wodnych, istniejącego zapotrzebowania i zużycia wody w poszczególnych sektorach posłużyły do oceny stanu gospodarki wodnej w Jordanii. Uwzględniając wpływ zarówno wzrostu populacji, jak i zmniejszenia wielkości opadów, przewidziano przyszłe zapotrzebowanie poszczególnych sektorów na wodę, stosując analizę liniowych trendów czasowych. Wrażliwość sektora wodnego i opcje adaptacyjne oceniono, biorąc pod uwagę 35 użytkowników wody. Wybrano, przyjęto i zmodyfikowano zestaw kryteriów ważonych i następnie ujęto je w formę całościowych wytycznych. Do oceny wielkości i prawdopodobieństwa ryzyka oraz korzyści związanych z każdym z proponowanych środków adaptacyjnych zastosowano proporcjonalne podejście ilościowe uwzględniając poziom wydajności i wagę danej sytuacji. Na podstawie rankingu priorytetów stwierdzono, że kształtowanie świadomości społecznej i programy szkoleniowe były środkami najbardziej skutecznymi i najłatwiejszymi do zastosowania. Budowa nowej infrastruktury miała niski priorytet. Brak środków finansowych, założenia instytucjonalne, zbieranie, wymiana, dostępność, zwartość i przejrzystość informacji oraz skłonność do adaptacji stanowiły barierę w tych działaniach. Zaleca się niezależne społecznościowe analizy wrażliwości zlewni, by zwrócić uwagę na znaczenie wody dla wszystkich działów gospodarki w skali całej zlewni.