The Impacts of Climate Change on the Availability of Surface Water Resources in Jordan

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Abstract

Climate change in the Middle East area including Jordan has started to be reflected in decreasing precipitation and increasing temperatures with their impacts on the availability of surface and groundwater. This article aims to evaluate the impacts of decreasing or increasing precipitation by 10% and 20% on the quantities of flood runoff based on recorded precipitation and runoffs of catchments during the past 60 to 70 years of observation, during which the precipitation in individual or a few years increased or decreased by tens of percentages relative to the long-term average precipitation. The results of quantification show that in Jordan as a whole, decreasing precipitation by 10% and 20% has historically (during the recording period) resulted in reductions in flood flows by 26.2% and 52.8% and that increasing precipitation by 10% and 20% has resulted in increases in flood flows by 26.4% and 56.5% respectively. These results look somehow paradox, because the general perception is that flood runoff changes in the same percentage like precipitation although flood flow is not linearly correlated with precipitation but exponentially. Decreasing precipitation in the water-scarce stressed country, Jordan due to climatic changes, will have strong implications on rain-fed and irrigated agriculture and on household water supplies with very severe socio-economic percussions expressed in increasing unemployment and poverty which may lead to social and political unrest. Therefore, proactive measures have to be implemented before disasters hit. Such measures are limited in Jordan to seawater desalination, intensified water harvesting and improved water use efficiency in agriculture.

Keywords

Climate Change Impacts, Precipitation-Runoff Ratios, Surface Water, Socio-Economics

1. Introduction

Climate changes directly affect the quantity and quality of water resources due to changes in the distribution of climatic events (EPA, 2014; Houghton, Jenkins, & Ephraums, 1990). Moreover, rainfall, temperatures and intensity of rainfall events in Jordan show that climate change has started affecting the country's precipitation (P) and temperatures. Decreasing precipitation has strong negative percussion on the availability of water resources and hence the water supply for all water use sectors, which in turn have negative impacts on the health, environment and socio-economic sectors (Hansen & Sato, 2011). A simulation study for the period 2040-2099 and based on precipitation records (1961-1990) for the eastern Mediterranean and Middle East region, found that Jordan's precipitation will decrease by 17% in the middle of this century and by 21% at its end (Chenoweth et al., 2011). Furthermore, a regional climate model used to investigate changes in Israel and Jordan precipitation predicted dryness as a result of reduction in both the frequency and duration of rainy events (Black, 2009).

Decreasing availability of the quantitatively inelastic household water supply will be, from a management point of view, covered by allocating less water for the agricultural sector, which will also suffer from decreasing precipitation and hence decreasing available surface water amounts. Even, if household and industrial water become enhanced by allocating new sources (desalination of seawater or water import from other countries), the agricultural sector will still suffer from the consequences of climate change. For instance, warmer temperatures will lead to a more energetic hydrological cycle; that turns into possibilities for further dryness and/or floods in some areas and less severe droughts and/or floods in other areas as predicted by the Intergovernmental Panel on Climate Change (IPCC) (Houghton, 1996). However, the IPCC fourth assessment report proposed that the eastern Mediterranean region would become significantly drier under a future climate situation (IPCC, 2007).

In Jordan, several studies showed the impacts of climate change on runoff water and groundwater (Abu-Allaban et al., 2014; Al-Zu'bi, 2009; Smadi & Zghoul, 2006; Smiatek et al., 2011). Abdulla and Eshtawi (2015) studied the climate change impacts on runoff, sediments and groundwater recharge for King Talal Dam watershed using the SWAT model under different scenarios. The scenarios included: ±20% change in rainfall, and 1°C, 2°C and 3.5°C increases in average temperature. The study showed that climate warming can impact runoff, groundwater recharge and sediment yield in the basin, which will also be greatly influenced by changes in rainfall volume.

Therefore, the Jordanian government in 2015 originated Jordan's 2025 National Vision and Strategy (NVS), which involves more than 400 policies on environment and climate change (Bany Yasin, 2018; EcoPeace, 2019) beside the socio-economic policies (USAID, 2017). The NVS covered a list of measures for adaptation concerning the environment, food, agriculture, water, and energy. It additionally recognized, as superiority, the development of a legislative frame on climate change to maximize each benefit, minimize the negative influences, and

build up national capacity. In its summary, the study emphasizes the necessity of security and solid management of resources such as water, energy, food, and agriculture. Further details of Jordan's environmental policies and engagement on climate change are reported by Combaz (2019).

The flood flow of a catchment area depends on a variety of factors such as rainfall type (rain, snow), its intensity and duration, topography, geology (the type of rocks structures and dip angels), soil type and land use. For any defined catchment area topography, geology, soil cover and to some extent land use remain the same for tens of years unless radical changes take place. Therefore, and a result of that, flood flow remains only a function of the type of rain, its intensity and duration (Houghton, 1996; IPPC, 2007). The interplay of these factors with the soil conditions plays also a role in the amounts of resulting flood flows and their correlation with precipitation amounts.

If flood runoff and precipitation are correlated for many years with high, medium and low amounts of rainfall over a catchment, then correlation can be established between runoff and rainfall, and hence, for long-term correlations, dependence is found between runoff amounts and precipitation amounts.

In Jordan precipitation is recorded in more than 250 rainfall stations, operated by the Department of Meteorology (DoM) and about 150 additional stations operated by the Ministry of Water and Irrigation (MWI). Wadi and river runoffs are also recorded for all major and medium discharge wadis and rivers covering all catchment areas. The number of gauging stations was around 150 in the seventies of the last century, but by now some of them are not operated due to damage or remoteness in desert areas. Runoff and precipitation have also been measured for micro-catchments (one to two km^2 in areas) for scientific research (Attour & Ibbitt, 1966; MoPW & JCE, 1992; UNDP, 1992; AlKhoury et al., 2009; Odeh et al., 2015).

In this study, the runoff precipitation ratios for the different catchments and the different amounts of actually falling precipitation over them will be used to study the impacts of decreasing or increasing precipitation on the availability of floodwater by using historic data to correlate rainfall and runoff for rain-rich and rain-poor years. The authors think that during pre-developmental eras (before urbanization, construction of roads, buildings, dams and wastewater sewerage and treatment systems, strong utilization of water resources and changes in their flow regimes) rainfall-rich and poor years can easily be correlated to stream flood flows. Such years can form a solid basis to study the impacts of climate change on the availability of surface water, water stored in dams and weirs and green water (soil water) and the implications of such availability on water users and their social and economic situation (Hansen & Sato, 2011).

2. Data and Methods

2.1. Observed Data

Long term data, since 1985, on precipitation amounts over catchment areas and

runoff of wadis have been provided by the Jordanian Ministry of Water and Irrigation and the Department of Meteorology. Additional relevant literature and correlations of catchment's runoffs to precipitation amounts have been calculated. Available data (for the pre-developmental era of most catchments, before the 1990s) of precipitation (P) and flood runoff (R) has also been evaluated to obtain changes in runoff/precipitation ratios ($R/P = r$) with decreasing or increasing precipitation amounts relative to average precipitation amounts. Averages of precipitation amounts per catchment area were used as a basis to calculate decreases or increases in precipitation amounts by different percentages. Here the National Water Master Plan (NWMP, 1977 and its updates) and different studies carried out to evaluate the discharges of wadies for dam and weir constructions were much helpful for obtaining relevant data. Upon that flood runoff/precipitation ratios have been calculated and their changes with increasing or decreasing precipitation quantified, based on historical records, to analyze the impacts of precipitation as a component of climate change on the generation of floodwater in the different catchment areas of Jordan.

2.2. Calculation

For calculating the runoff coefficient (r), the following general equation (Equation (1)) is valid:

$$\frac{R}{P} = r \tag{1}$$

where: P = precipitation, R = runoff, r = runoff coefficient, which when differentiated becomes Equation (2):

$$\partial r = \frac{\partial R}{\partial P} \tag{2}$$

Hence, r is a function of the amount of precipitation in Million Cubic Meter per year (MCM/yr) and not a fixed ratio or percentage of precipitation. It increases and decreases with increasing or decreasing amount of rainfall over an area. The correlation of flood runoffs to precipitation is presented in Figure 1 and Figure 2 for selected catchments representing the different geological and climatic zones in Jordan. They show that the flood runoff coefficient "r" of each catchment area is a function of precipitation amount; increasing or decreasing as a result of increasing or decreasing precipitation, although the rate of decrease or increase in "r" relative to the amount of precipitation differs from one catchment to another due to differences in other catchment parameters such as topography, geology, soils etc..

2.3. Consequence of Changes in Precipitation Amounts

Changes in the amounts of precipitation falling over an area have the following consequences:
1) Increase or decrease in flood flows
2) Increase or decrease in groundwater recharge
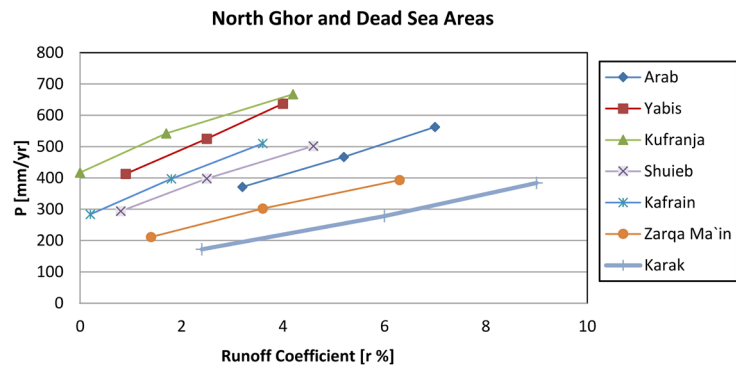
North Ghor and Dead Sea Areas

Figure 1. Correlation of precipitation amounts to runoff coefficients for the north Jordan Valley and Dead Sea side wadis based on yearly measurements of precipitation and flood runoffs for series of years with different amounts of precipitation and the resulting flood runoffs.
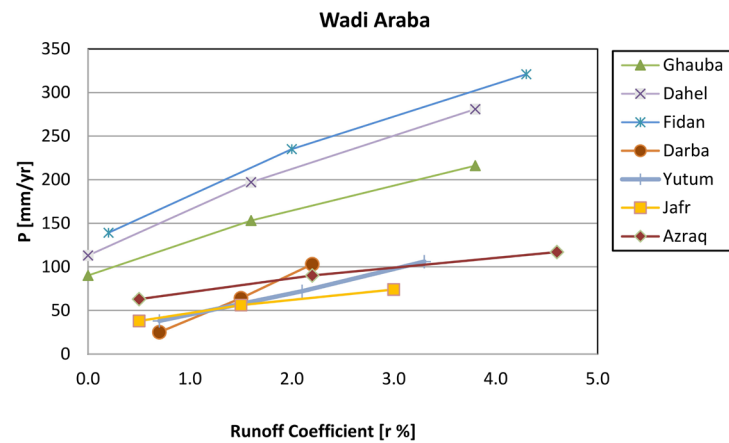
Wadi Araba

Figure 2. Correlation of precipitation amounts to runoff coefficients for Wadi Araba side wadis and the eastern desert catchments based on yearly measurements of precipitation and flood runoffs for series of years with different amounts of precipitation and the resulting flood runoffs.

3) Increase or decrease in soil moisture content; shorter or longer periods of soils being wetted and shift in agrarian climatic zone regimes

4) Increase or decrease in both surface and groundwater salinities

These consequences have further implications on the availability of surface and groundwater, rain-fed agriculture, water management and ecology. In this article, only the effects of changes in precipitation amounts on floodwater amounts will be discussed.

As already mentioned in the introduction flood flow of an area reflects many characteristics of that area such as topography, geology, soil cover and land-use, which may be reflected in increases or decreases in flood generation. For instance, buildings and road construction result in increasing flood generation, whereas planting trees and plowing soils result in decreasing flood flows. In many areas in Jordan land-use has dramatically changed, especially as a result of extension in urban areas and increasing industrial activities. Both incorporating

the construction of extensive road-nets and buildings and cementing or asphalting huge land areas all of which lead to changes (increases) in the flood flow to precipitation ratios. When such impacts are superimposed by increasing or decreasing precipitation, then quantification of flood runoff ratios becomes complicated and requiring detailed measurements. Hence, the pre-development eras with the recorded rainfall and runoff data are used in this work because the records contain fair accounts of rain-rich and rain-poor years and the resulting flood amounts for the different catchment areas of the country. Included in this study are the different major catchment areas in Jordan such as the Jordan Valley catchments with the Yarmouk and Zarqa Rivers' catchments, the Dead Sea catchments such as Mujib, Wala, Hasa, Zarqa Ma'in and Karak, Wadi Araba catchments such as Fifa, Dahal, Fidan, Wadi Musa and Yutum and the desert catchments such as Azraq, Jafr and Disi.

Flood runoff/precipitation ratios have been calculated for all major catchments in Jordan in different studies such as Attour and Ibbitt (1966); National Water Master Plan (NWMP) of Jordan 1977 and updates; UNDP (1992); McDonald and Partners (1965); Japan International Cooperation Agency (JICA) Ministry of Planning (1987). In addition, many M.Sc. and Ph.D. theses and studies carried out for the construction of dams have also correlated runoff and precipitation. Moreover, the evaluation of flood runoffs and areas' precipitation has been carried out within the present study. The correlation of areas' precipitation to runoff is generally a straight or slightly convex line, very close to a linear line for the normal range (exempting extreme events) of precipitation in the individual catchments. The correlation shows that the yearly amount of flood flow in a certain area is a function of two variables namely; precipitation amount and the corresponding ratio of flood runoff amount to areas precipitation amounts (Table 1).

Table 1. Maximum, average and minimum annual precipitation amounts and the corresponding runoff amounts for the catchment areas of: the Eastern Jordan Valley side wadis, the flat area of the eastern Jordan Valley, the Dead Sea eastern catchments, the desert catchments and the eastern Wadi Araba side wadis.

Catchment area	Precipitation MCM/yr			Flood runoff MCM/yr			Remarks
	Min.	Av.	Max.	Min.	Av.	Max.	
Lower Jordan Valley eastern side wadis	3186	4140	5092	123	250	422	Including the Yarmouk River
Lower Jordan Valley eastern side wadis	1215	1633	2049	27	68	129	Excluding the Yarmouk River
Lower Jordan Valley eastern bottom area	120	157	193	2.0	4.55	8.90	Only the flat area of the Jordan Valley
Dead Sea eastern catchments	938	1406	1874	17.3	49.6	101.1	Including inter-wadi catchments
Wadi Araba eastern catchment	253.4	455.1	648.6	1.18	9.40	26.3	Including wadi Araba bottom catchments
Jafr	455	671	887	2.28	10.1	26.6	
Azraq	730	1043	1356	1.46	12.5	32.50	
Disi	57.1	91.8	126.5	0.29	1.84	5.06	
Durrah	12.4	20.7	29.0	0.07	0.31	0.60	
Hammad	760	1118	1453	3.18	15.6	42.1	
Sirhan	370	515	750	1.48	7.2	24.0	

3. Results and Discussion

3.1. Changes in Precipitation and Runoff

The results of the evaluation show the percentage changes in flood flows by changing precipitation amounts by +10%, +20% −10% and −20% relative to the long term averages of precipitation and the corresponding increases or decreases in the flood flows for the different catchment areas in Jordan (Table 2).

For Jordan, as a whole, a decrease in precipitation of 20% results in a decrease in flood runoff by 52.8% and a decrease in precipitation of 10% results in a decrease in flood runoff by 26.2%. By an increase in precipitation by 10% the flood runoff will increase by 26.4% and by an increase in precipitation by 20% flood runoff will increase by 56.5%. Figure 3 shows the Jordan main basins and sub-basins to illustrate the location and areas of each catchment in the study. Figure 4(a) and Figure 4(b) show the vertical profile from north to the south along the Jordan Valley (a) and Wadi Araba (b). No major differences in the precipitation-flood runoff ratios can be made between the different major catchment areas such as the Dead Sea, the Jordan Valley, Wadi Araba and the desert catchments. But it seems that the reactions of runoff to increases or decreases in precipitation amounts are more pronounced in the desert catchments and in the Dead Sea catchment, which partly extends eastward far into the desert areas such as in the cases of Mujib and Hasa catchments. Table A1 lists the amount of average precipitation water (P) falling over the different catchments in MCM/yr, flood discharges in MCM/yr and flood runoff/precipitation ratios (r) for the catchment areas all by 10% and 20% increases or decreases in precipitation.

Table 2. Summarizes the calculated increases or decreases in flood flow amounts in MCM/yr as a result of increases or decreases in precipitation by 10% and 20% relative to the long-term average annual precipitation and flood flow amounts for the different areas of Jordan.

Location	Increase or decrease in P			
	−20%	−10%	+10%	+20%
	Decreasing floods %		Increasing floods %	
All Jordan	−52.8	−26.2	26.4	56.5
Desert Areas	−57 - −70	−40 - −30	26 - 41.8	61 - 98
Desert Areas *	−57 - −64	−31 - −33.5	26 - 41.8	75 - 90.3
Dead Sea	−39.7 - −57	−18.2 - −38	22.2 - 43.6	47.9 - 81
Dead Sea*	−41 - −45.7	−26.2 - −32	29.3 - 37	52 - 60
Araba North	−50 - −77	−14.7 - −55	27 - 47	41 - 110
Araba North*	−50 - −71	−21 - −30	32.6 - 40	49.6 - 69
Araba South	−30 - −100	−14.5 - −39	16 - 142	41 - 278
Araba South*	−36.4 - −56	−21 - −30	25 - 48	43 - 103
Jordan Valley	−46.5 - −93	−27 - −68	18 - 80	56 - 189
Jordan Valley*	−52 - −66	−31.6 - −53	28– 46.7	80 - 110

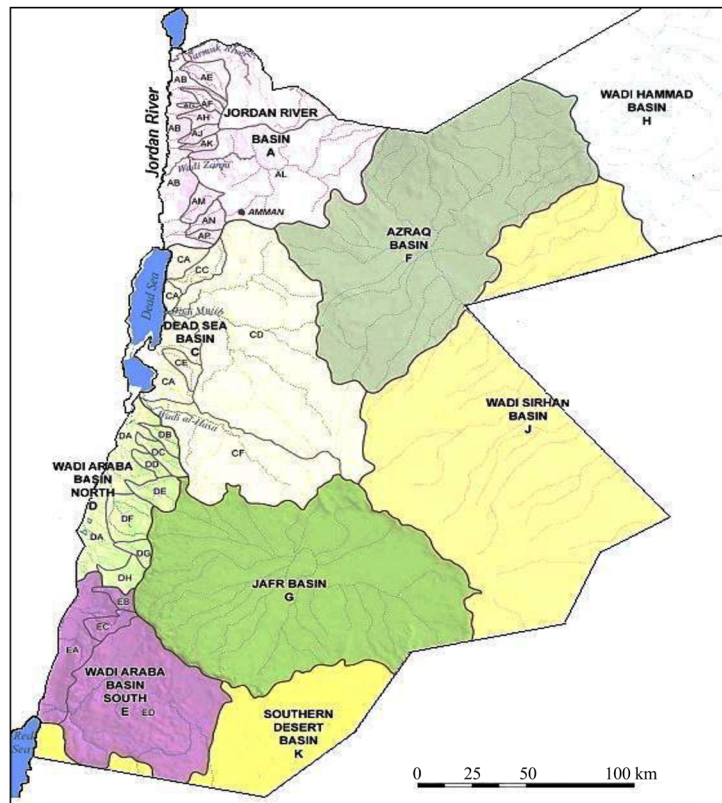* Without extreme values.

Figure 3. Jordan main and sub-water basins (after NWMP 1977 and GIZ 2010).
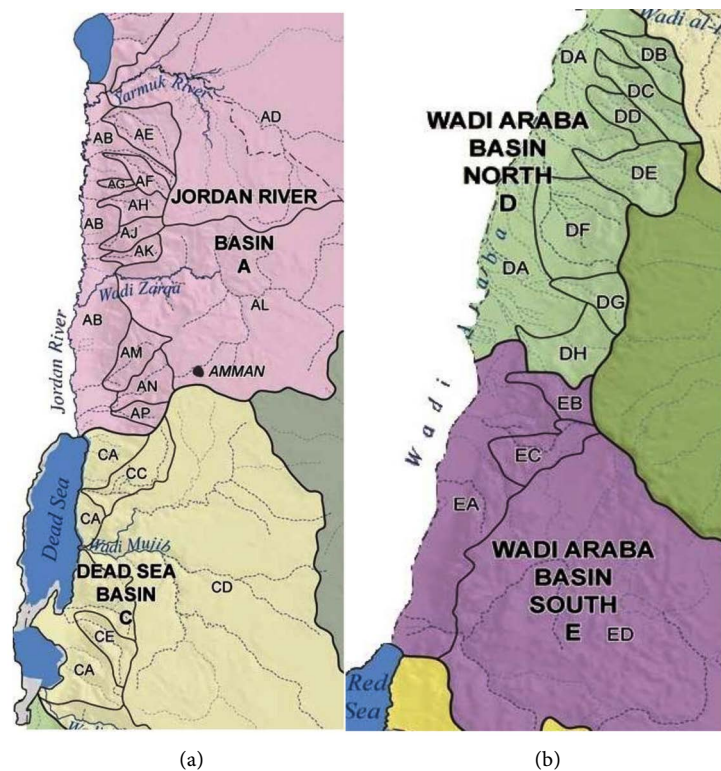

(a) (b)

Figure 4. Vertical profile of main and sub-water basins: (a) along the Jordan Valley and (b) along Wadi Araba in the south (after NWMP 1977 and GIZ 2010).

Table 3 lists the calculated percentage changes in flood flows by changes in precipitation amounts by +10%, +20%, −10% and −20% of the long-term average precipitation for the different catchment areas in Jordan. It shows that a 10% decrease in precipitation over the different catchment areas will reduce flood flows by a minimum of 14.7% (Fifa catchment) and of 53% (Kufranja catchment). By 20% reduction in precipitation, the minimum decrease in flood flows will be around 39% in both the Jordan Valley inter-catchments and Mujib catchment and a maximum of 93% in the case of Yabis catchment. These reductions seem to be a function of the flatness of the catchment area. Increases in precipitation by 10% will produce an increase in flood flow by a minimum of 16% in Durrah catchment and an increase in precipitation by 20% will result in flood flow increases by around 42% in the case of Fidan Durrah and Yutum catchments. This result shows the sensitivity of the semiarid mountainous areas of Jordan to climate changes. Table 4 lists the changes in flood flow amounts in MCM/yr as a result of decreasing or increasing amounts of precipitation by 10% and 20% relative to long-term averages and the corresponding flood flows for the different catchments in Jordan.

3.2. Impacts on the Agricultural Sector

3.2.1. Rain-Fed Areas

Rainfall distribution over Jordan for an average year is as follows:

- 1.350 km^2 receive more than 500 mm/yr
- 1.629 km^2 receive 300 - 400 mm/yr
- 11.250 km^2 receive 200 - 300 mm/yr
- The rest (75.188 km^2) receive less than 200 mm/yr.

In areas receiving more than 400 mm/yr of precipitation reduction in precipitation over these areas by 10% or 20% will not have a major effect on their present use in agricultural production because these areas are planted by olives and other fruit trees which can tolerate 10% - 20% reduction in the rainfall amounts.

Table 3. Calculated percentage changes in flood flows by changes in precipitation amounts by +10%, +20%, −10% and −20% of the long-term average precipitation for the different catchment areas in Jordan.

Area in Jordan	Catchment	% Increase or decrease in P			
		−20%	−10%	+10%	+20%
		Decreasing flood %		Increasing flood %	
	Hamad H	−57	−32	53	88
	Sirhan I	−64	−31	25.2	89
Desert Areas	Azraq F	−70	−40	41.8	90.3
	Jafr G	−57.3	−33.5	33.4	75.8
	Disi K	−64	−30	26	61

Continued

	Yarmouk AD	−47	−27	18	56.6
	Arab AE	−52.2	−30.4	29.2	61.6
	Ziglab AF	−46.5	−31.8	36.4	80
	Jurm AG	−65	−40	50	110
	Yabis AH	−93.0	−68	42	80
Jordan Valley	Kufranja AJ	−88	−53	80	189
	Rajib-Zarqa AK-AL	−68	−40	51	95
	Shueib AM	−60	−31.6	32.8	92
	Kafrain AN	−66	−38	46.7	133
	Hisban AP	−53	−41	20	56
	Inter-catchments AB 21-26	−39	−19	41	74
	Inter-catchments AE-AP*	−62	−35.3	50	92
	Zarqa Main CC	−56	−−32	37	79
	Wala CD1	−41	−26.7	22.2	52.6
	Mujib CD2	−39.7	−18.2	42.6	47.9
Dead Sea (DS)	Karak CE	−44.7	−24.6	29.3	60.9
	Hasa CF	−45.7	−25.3	31.3	55.8
	DS inter-catchments CA1-CA4	−57	−38.0	32	81
	DS Basins	−61.5	−26.2	26.2	56.5
	GhaubaDA25	−57	−21	42	96
W.Araba (North)	Fifa DB	−50	−14.7	39	72.4
	Khuneizir DC	−71	−27	40	81
	Dahal DD	−77	−55	47	110
	Fidan DE	−62.0	−30.0	32.6	41.0
	Buweirde DF	−45.9	−21.7	27	49.6
	W. Musa DG	−100	−29	142	278
	Hawar DH	−55	−28	48	103
	Darba EA25	−30	−14.5	25	43.6
Wadi Araba (South)	Dilagha EB	−49	−39	28.6	93.6
	Rakiya EC	−53	−30	78	178
	Durrah K1	−43	−22	16	42
	Yutum ED	−44	−25	18	41.8
	Ghauba to Boweirda	−36.4	−24	20.5	65.2
	Musa W. Musa DG	−56	−30	29.9	110

*All above for the Jordan Valley area without the Yarmouk River. **Jordan Valley inter-catchments.

Table 4. Changes in flood flow amounts in MCM/yr as a result of decreasing or increasing amounts of precipitation by 10% and 20% relative to long-term averages of precipitation for all catchments in Jordan.

Catchment area	% Change in precipitation				
	−20%	−10%	Average	+10%	+20%
	Flood flow amounts in MCM/yr				
Sirhan	2.6	5.0	7.21	10.75	14.3
Hammad	6.7	10.6	15.6	24	29.5
Azraq	3.75	7.5	12.52	17.75	23.8
Jafr	4.3	6.7	10.07	13.43	17.7
Disi	0.66	1.28	1.84	2.32	2.97
Yarmouk	89.6	133	182	215	285
Arab	3.19	4.51	6.8	8.37	10.5
Shueib	0.7	1.21	1.77	2.53	3.4
Ziglab	0.96	1.53	2.2	3.02	3.96
Jurm	0.077	0.138	0.23	0.33	0.46
Yabis	0.11	0.52	1.63	2.32	2.93
Kufranja	0.12	−0.48	1.02	1.82	2.95
Rajib	0.42	0.79	1.31	1.98	2.55
Kafrain	0.45	0.84	1.35	1.98	3.15
Hisban	0.16	0.2	0.34	0.418	0.63
AE-AP	6.22	10.6	16.33	24.5	31.1
AB21-AB26	2.76	3.67	4.54	6.42	7.91
Zarqa Ma'in	1.3	2	2.96	4.5	5.32
Wala	9.75	12.2	16.64	20.3	25.4
Mujib	9.18	12.46	15.23	18.97	22.5
Hasa	2.64	3.63	4.86	6.38	7.57
Karak	1.69	2.38	3.17	4.1	5.1
Dead Sea basin	19.1	26.6	49.60	62.7	77.6
CA1-CA4	0.44	0.6	1.03	1.36	1.87
Ghauba	0.06	0.11	0.14	0.2	0.28
Fifa	0.66	0.99	1.16	1.6	2
Khuneizira	0.34	0.86	1.18	1.65	2.14
Dahal	0.068	0.136	0.3	0.44	0.63
Musa	0.004	0.1	0.14	0.34	0.53
Yutum	0.78	1.06	1.41	1.67	2.1
Fidan	0.5	0.92	1.32	1.75	2.29
Albuweirda	1.32	1.91	2.76	3.1	3.65
Hawar	0.132	0.21	0.29	0.43	0.59
Darba	0.048	0.094	0.11	0.138	0.16
Dilugha	0.1	0.143	0.22	0.35	0.43
Rakiya	0.037	0.063	0.09	0.16	0.25
Durrah	0.176	0.24	0.31	0.36	0.44
D22-D25	4.19	5.0	6.59	7.94	10.9
DF2-EB1	4.15	6.56	9.39	12.2	15.12

Areas receiving an average of 350 - 400 mm/yr will be affected by a reduction in precipitation and unless supplementary irrigation is provided the agricultural productivity of such areas will suffer, especially in dry to average rainfall years.

Areas receiving an average of 300 - 350 mm/yr of precipitation, which are generally used to produce field crops such as wheat and barley, will suffer in a major way and will be turned into grazing land by a reduction in precipitation by 10% and 20%.

Areas receiving an average of less than 300 mm/yr which are presently used as grazing land will suffer from lower productivity of forage and hence their use as grazing areas will decrease. All in all the productivity of dry farming areas in Jordan will reduce by 10% and 20% by decreases in precipitation by the same percentages.

3.2.2. Irrigated Areas

Irrigated agriculture in Jordan consumes at present an average of around 550 MCM/yr of water of which around 180 MCM/yr originate from treated waste-water, around 160 MCM/yr from flood flows and the rest from groundwater extraction. If precipitation over Jordan decreases by 10%, flood flow will decrease by an average of 26.2% and in case of a decrease by 20% flood flow will decrease by 52.8%. This means a reduction in the flood flow water used at present in irrigation of 160 MCM/yr to 118 and 75.5 MCM/yr respectively.

Because the total amount of water used in irrigation averaged during the last few years around 550 MCM/yr, 10% and 20% decreases in precipitation will leave only 508 and 465.5 MCM/yr for use in irrigation. This will result in around 8% and 15.4% reduction in the water amounts available for irrigation and hence irrigation products will also suffer of reduction by the same percentage, with all such reduction social and economic implications.

4. Conclusion and Recommendation

The common understanding that changes in precipitation amounts are reflected in flood water changes in about the same percentage seems to be a misleading concept and that is because the soils function as the storage medium for precipitation water according to soil infiltration capacities, precipitation frequency, type and intensity of precipitation and topography. Hence generation of flood flow is a function of all these parameters.

In Jordan precipitation and flood flows have been measured and calculated for the last 6 decades witnessing precipitation amounts of all ranges of extremely low to extremely high precipitation amounts. This enabled us to calculate flood runoff to precipitation ratios for a large number of years. The historical record allows using the calculation of flood runoffs of the different catchment areas in Jordan for precipitation increases or decreases by 10% and 20%.

The results show that for Jordan, as a whole, precipitation decrease by 10% and 20% will result in 26.2% and 52.8% decrease in flood flows and precipitation increase by 10% and 20% will result in 26.4% and 56.5% increase in flood flows.

The arid areas, especially the arid highlands of south Jordan will be stronger affected by both increasing and decreasing precipitation than other areas. That can be explained by their low precipitation amounts and illustrates the vulnerability of these areas to climate change. 10% less precipitation will cause 26% reduction in surface water availability for the irrigation, which in the case of Jordan amounts to around 42 MCM/yr. Irrigated agricultural production will reduce by the same percentage 8%. If precipitation decreases by 20% irrigation agricultural production will drop by 15.4%.

In addition, around 7.000 people presently working in agriculture and consequently with their families (35.000 people) will join the poor's category if precipitation decreases by 10% and if it decreases by 20% the numbers will be 14.100 unemployed and 70.500 people added to the poor category. Increasing unemployment and poverty in the country may lead to social discomfort and unrest with all their implications on the political stability of the country. Therefore, proactive policies to alleviate the impacts of climate change are needed, which might include immediate programs and action plans to raise the level of water use efficiency in irrigation which is still an elastic water use sector.

Improved irrigation methods, better selection of crops requiring less water, applying plant water requirement principles and improving the efficiency of water conveyance on farm and of irrigation water supply systems are some of the actions that can alleviate the impacts of decreasing precipitation. Rainfed irrigation will also greatly suffer from reduced precipitation due to shifts of rain zones towards more avidity. Here also improving utilization of rain and overland flow water is required and better selection of dry-resistant crops with supplementary irrigation by treated wastewater can alleviate the implication of decreasing land productivity of rainfed areas with their impacts on employment, poverty and their social and political percussions.

Diminishing water resources as a result of climate change will force Jordan to either import water from outside the country (limited amounts) or to desalinate seawater at Aqaba for drinking purposes. Both solutions will put additional pressure on the economy of the country and socio-economic state of the population.

Such strong changes in the availability of stream runoffs as compared to changes in precipitation amounts are horrifying and somehow paradox, but that is what the history of precipitation and flood flow monitoring shows.

Jordan and other countries, especially those of arid and semi-arid climatic zones should prepare themselves for such climatic change, because these changes will strongly strike the peoples' economic situation, food security and employment with all the latter's ramifications to political system's stabilities.

In the case of Jordan, adapting to climate change impacts can somehow be achieved by intensive rain and floodwater harvesting and storage either in surface water structures or aquifers. In addition, increasing water use efficiency in agriculture by introducing more efficient water use and water conveyance systems, better choice of crops and applying plant-water requirement principles are

sound programs to alleviate the climate changes effects. Due to increasing water stress resulting from increasing population and climatic changes Jordan ended having only one sound strategic option to mobilize adequate additional water resources and that is desalination of seawater at Aqaba. Since almost all the MENA countries are similar to Jordan in their climatic conditions, impacts of climate change and water stress abating climatic changes in these countries can follow the same recommendations mentioned above.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Annex

Table A1. Amounts of average precipitation water (*P*) falling over the different catchments in MCM/yr and the amounts of precipitation, flood discharges, flood runoff/precipitation ratios (*r*) for the catchment areas by 10% and 20% increases or decreases in precipitation.

(a)

Area	Parameters	Increase or decrease in precipitation				
		−20%	−10%	Av.	+10%	+20%
Yarmouk AD total	*P* [MCM]	2000	2256	2507	2758	3008
	r [%]	4.8%	5.9%	7.3%	7.8%	9.5%
	Flood discharges [MCM]	96	133	182	215	285
	Flood discharges relative to average	−86	−49	0.0	33	103
	Change in discharge as % of Av.	−47%	−27%	0.0	18%	56.6%
Jordan Valley area						
Arab AE	*P* [MCM]	99.8	112.2	124.7	137.2	149.6
	r [%]	3.2%	4.2%	5.2%	6.1%	7%
	Flood discharge [MCM]	3.19	4.51	6.48	8.37	10.47
	Flood discharges relative to average	−3.38	−1.97	0.0	1.9	4.0
	Change in discharge % of Av.	−52.2%	−30.4%	0.0	29.2%	61.6%
Shueib AM	*P* [MCM]	56.6	63.7	70.8	77.9	85
	r [%]	1.3%	1.9%	2.5%	3.3%	4.0%
	Flood discharge [MCM]	0.7	1.21	1.77	2.53	3.4
	Flood discharges relative to average.	−1.06	−0.56	0.0	0.58	1.63
	Change in discharge % of Av.	−60%	−31.6%	0.0	32.8	92%
Ziglab AF	*P* [MCM]	41.9	47.2	52.4	57.6	62.9
	r [%]	2.3%	3.3%	4.2%	5.3%	6.3%
	Flood discharge [MCM]	0.96	1.53	2.2	3.02	3.96
	Flood discharges relative to average	−1.24	−0.7	0.0	0.8	1.76
	Change in discharge % of Av.	−46.5%	−31.8%	0.0	36.4%	80%
Jurum AG	*P* [MCM]	7.68	8.64	9.6	10.6	11.52
	r [%]	1.00%	1.6%	2.4%	3.10%	4.0%
	Flood discharge [MCM]	−0.77	1.38	2.2	3.29	4.61
	Flood discharges relative to average	−1.43	−0.88	0.0	1.09	2.4
	Change in discharge % of Av.	−65%	−40%	0.0	50%	110%
Yabis AH	*P* [MCM]	44.9	58.6	65.1	71.6	78.1
	r [%]	0.3%	0.9%	2.5%	3.3%	3.8%
	Flood discharge [MCM]	0.11	0.52	1.63	2.32	2.93
	Flood discharges relative to average	−1.52	−1.11	0.0	0.69	1.3
	Change in discharge % of Av.	−93%	−69%	0.0	42%	80%

Continued

	P [MCM]	48	54	60.2	66	72
	r [%]	0.3%	0.9%	1.7%	2.8%	4.1%
Kufranja AJ	Flood discharge [MCM]	0.12	−0.48	1.02	1.82	2.95
	Flood discharges relative to average	−0.9	−0.54	0.0	0.8	1.93
	Change in discharge % of Av.	−88%	−53%	0.0	80%	189%
	P [MCM]	35	39.4	43.8	48.2	52.6
	r [%]	1.2%	2.0%	3.0%	4.1%	4.9%
Rajib AK	Flood discharge [MCM]	0.42	0.79	1.31	1.98	2.55
	Flood discharges relative to average.	−0.89	−0.52	0.0	0.67	1.24
	Change in discharge % of Av.	−68%	−39%	0.0	51%	95%
	P [MCM]	60	67.5	75	82.5	90
	r [%]	0.8%	1.3%	1.8%	2.4%	3.5%
Kafrain AN	Flood discharge [MCM]	0.45	0.84	1.35	1.98	315
	Flood discharges relative to average	−0.9	−0.51	0.0	0.63	1.8
	Change in discharge % of Av.	−70%	−40%	0.0	46.7%	133%
	P [MCM]	14.5	16.3	18.1	19.9	21.7
	r [%]	1.1%	1.3%	1.9%	2.1%	2.9%
Hisban AP	Flood discharge [MCM]	0.16	0.2	0.34	0.418	0.63
	Flood discharges relative to average	−0.18	−0.14	0.0	0.07	0.29
	change in discharge % of Av.	−53%	−41%	0.0	20%	56%
	P [MCM]	414.4	460	518	570	622
	r [%]	1.5%	2.3%	3.1%	4.3%	5.0%
AE - AP*	Flood discharge [MCM]	6.22	10.6	18.50	24.5	31.1
	Flood discharges relative to average	−10.13	−5.73	0.0	8.17	14.9
	Change in discharge % of Av.	−60%	−35.3%	0.0	50%	92%
	P [MCM]	12.5	141.2	156.9	172.6	188.3
	r [%]	2.2%	2.6%	2.9%	3.7%	4.7%
AB21 - AB26**	Flood discharge [MCM]	−2.76	−3.67	4.54	6.42	7.91
	Flood discharges relative to average	−1.78	−0.87	0.0	1.88	3.37
	Change in discharge % of Av.	−39%	−19%	0.0	41%	74%

*Without Yarmouk.

(b)

Area		Parameters	Increase or decrease in precipitation				
			−20%	−10%	Av.	+10%	+20%
Desert Areas	Sirhan I	P [MCM]	412	463	515	566	618
		r [%]	0.65%	1.08%	1.4%	1.9%	2.32%
		discharge [MCM]	2.6	5	7.21	10.75	14.3
		relative to Average	−4.6	−2.21	0.0	3.54	7.09
		change in discharge % of Av.	−64%	−31%	0.0	25%	98%
	Hamad H	P [MCM]	894	1006	1118	1230	1342
		r [%]	0.75%	1.05%	1.4%	1.95%	2.29%
		discharge [MCM]	6.7	10.6	15.7	24	29.5
		relative to Av.	−9.0	−5.1	0.0	8.3	13.8
		change in discharge % of Av.	−57%	−32%	0.0	53%	88%
	Azraq F	P [MCM]	834	939	1043	1147	1252
		r [%]	0.45%	0.8%	1.2	1.55%	1.9%
		discharge [MCM]	3.75	7.5	12.52	17.75	23.79
		relative to Av.	−8.75	−5	0.0	5.23	11.29
		change in discharge % of Av.	−70%	−40%	0.0	41.8%	90.3%
	Jafr G	P [MCM]	537	604	671	738	805
		r [%]	0.8%	1.11%	1.5%	1.82%	2.2%
		discharge [MCM]	4.3	6.7	10.07	13.43	17.71
		relative to Av.	−5.77	−3.37	0.0	3.36	7.64
		change in discharge % of Av.	−57.3%	−0.33%	0.0	33.37%	75.87%
	Disi K	P [MCM]	73.4	82.6	91.8	101	110.2
		r [%]	0.9%	1.55%	2.0%	2%	2.7%
		discharge [MCM]	0.66	1.28	1.84	2.32	2.97
		relative to Av.	−1.18	−0.56	0.0	−0.48	1.13
		change in discharge % of Av.	−64%	−30.4%	0.0	0.26%	0.61%

(c)

Area		Parameters	Increase or decrease in precipitation				
			−20%	−10%	Av.	+10%	+20%
Dead Sea (DS)	Zarqa Ma'an	P[MCM]	73.9	82.1	82.1	90.3	98.5
		r[%]	2.0%	2.7%	3.6%	4.5%	5.4%
		discharge [MCM]	1.3	2.0	2.96	4.06	5.32
		relative to Av.	−1.66	−0.96	0.0	1.1	2.32
		change in discharge % of Av.	−56%	32%	0.0	37%	79%
	Wala	P[MCM]	361	406	451	496	541
		r[%]	2.7%	3.0%	3.69%	4.1%	4.7%
		discharge [MCM]	9.75	12.2	16.64	20.3	25.4
		relative to Av.	−6.89	−4.44	0.0	3.7	8.8
		change in discharge % of Av.	−41%	−26.7%	0.0	22.2%	52.6%
	Mujib	P[MCM]	270	304	338	372	406
		r[%]	3.4%	4.1%	4.5%	5.1%	5.6%
		discharge [MCM]	9.18	12.46	15.23	18.97	22.53
		relative to Av.	−6.05	−2.77	0.0	3.74	7.3
		change in discharge % of Av.	−40%	−18.2%	0.0	24.6%	48%
	Hasa	P[MCM]	117.4	132	146.8	161.5	176.2
		r[%]	2.3%	2.8%	3.3%	4.0%	4.3%
		Discharge [MCM]	2.64	3.63	4.86	6.38	7.57
		relative to Av.	−2.22	−1.23	0.0	1.52	2.7
		change in discharge % of Av.	−45.7%	−25.3%	0.0	31.3%	55.8%
	Karak	P[MCM]	42.2	47.5	52.8	58.1	63.4
		r[%]	4.00%	5.0%	6.0%	7.05%	8.1%
		Discharge [MCM]	1.69	2.38	3.17	4.1	5.1
		relative to Av.	−1.48	−0.79	0.0	0.93	1.93
		change in discharge % of Av.	−44.7%	−24.6%	0.0	29.3%	60.9%
	DS all basins	P[MCM]	1125	1265	1406	1547	1687
		r[%]	1.7%	2.1%	3.5%	4.1%	4.6%
		Discharge [MCM]	19.1	26.6	49.6	62.7	77.6
		relative to Av.	−30.5	−13	0.0	13.1	28
		change in discharge % of Av.	−61.5%	−26.2%	0.0	26.4%	56.5%
	CA1 - CA4 *	P[MCM]	141.7	159.3	177.1	194.8	212.5
		r[%]	0.3%	0.4%	0.6%	0.7%	0.9%
		Discharge [MCM]	0.44	0.6	1.03	1.36	1.87
		relative to Av.	−0.59	−0.39	0.0	0.33	0.84
		change in discharge % of Av.	−57%	−38%	0.0	32%	81%

*Dead Sea side inter-catchments.

(d)

Area		Parameters	Increase or decrease in precipitation				
			−20%	−10%	Av.	+10%	+20%
		P[MCM]	12.24	13.77	15.3	16.83	18.36
		r[%]	0.50%	0.80%	0.90%	1.20%	1.50%
	Ghauba	discharge [MCM]	0.06	0.11	0.14	0.2	0.275
		relative to Av.	−0.08	−0.03	0	0.06	0.135
		change in discharge % of Av.	−57%	−21%	0.0%	42%	96%
		P[MCM]	26.6	29.9	33.2	36.5	39.8
		r[%]	2.5%	3.3%	3.5%	4.4%	5.1%
	Fifa	discharge [MCM]	0.66	0.99	1.16	1.6	2
		relative to Av.	−0.5	−0.17	0	0.5	0.8
		change in discharge % of Av.	−50%	−14.7%	0.0%	39%	72.4%
		P[MCM]	28.5	32	35.6	39.2	42.7
		r[%]	4.2%	2.7%	3.3%	4.2%	5.0%
	Khuneizir	discharge [MCM]	−0.34	−0.86	1.18	1.65	2.14
		relative to Av.	−0.84	−0.32	0	0.47	0.96
		change in discharge % of Av.	−71%	−27.%	0%	40%	81%
		P[MCM]	15.1	17.01	18.9	20.8	22.7
		r[%]	0.5%	0.8%	0.3%	2.1%	2.8%
Wadi Araba	Dahal	Discharge [MCM]	0.068	0.136	1.6	0.44	0.63
		relative to Av.	−0.23	−0.16	0	0.14	0.33
		change in discharge % of Av.	−77%	−55%	0	47%	110%
		P[MCM]	22.2	24.9	27.7	30.5	33.2
		r[%]	0.20%	0.4%	0.5%	1.10%	1.6%
	Musa	Discharge [MCM]	0.004	0.1	0.14	0.34	0.53
		relative to Av.	−0.01	−0.04	0	0.2	0.39
		change in discharge % of Av.	−100%	−29%	0.0%	142%	2.8%
		P[MCM]	53.76	60.5	67.2	73.9	80.6
		r[%]	1.45%	1.8%	2.1%	2.26%	2.6%
	Yutum	Discharge [MCM]	0.78	1.06	1.41	1.67	2.1
		relative to Av.	−0.63	−0.35	0	0.26	0.59
		change in discharge % of Av.	−44.7%	−25%	0.0%	18.0%	41.8%
		P[MCM]	52.6	59.2	65.8	72.4	79
		r[%]	95.00%	1.6%	2.0%	2.42%	2.9%
	Fidan	Discharge [MCM]	0.5	0.92	1.32	1.75	2.29
		relative to Av.	−0.82	−0.4	0	0.43	0.54
		change in discharge % of Av.	−62.%	−30.%	0.0%	32.6%	41%

Continued

	P [MCM]		43.4	48.9	54.3	59.7	65.2
	r [%]		3.05%	3.9%	4.5%	5.20%	5.6%
El Boweirda	Discharge [MCM]	1.32	1.91	2.44	3.1	3.65
	relative to Av.	−1.12	−0.53	0	0.66	1.21
	change in discharge % of Av.	−45.9%	−21.7%	0.0%	27%	49.6%
	P [MCM]	26.3	29.6	32.9	36.2	39.5
	r [%]	0.5%	0.7%	0.9%	1.8%	1.5%
Hawar	Discharge [MCM]	0.132	0.21	0.29	0.43	0.59
	relative to Av.	−0.16	−0.08	0	0.14	0.3
	change in discharge % of Av.	−55%	−28%	0	48.0%	103.0%
	P [MCM]	5.9	0.7	7.4	8.14	8.8
	r [%]	1.3%	1.4%	1.5%	1.7%	1.8%
Darba	Discharge [MCM]	0.048	0.094	0.11	0.138	0.158
	relative to Av.	0.033	0.016	0	0.028	0.048
	change in discharge % of Av.	30%	14.5%	0.0%	25%	43.6%
	P [MCM]	8.48	9.54	10.6	11.66	12.72
	r [%]	1.3%	1.5%	2.0%	3.0%	3.4%
Dilugha	Discharge [MCM]	0.1	0.143	0.22	0.35	0.426
	relative to Av.	−0.114	−0.087	0	0.13	0.206
	change in discharge % of Av.	−49%	−39%	0	28.6%	93.6%
	P [MCM]	18.6	21	23.3	25.6	28
	r [%]	0.2%	0.3%	0.4 %	0.6%	0.9%
Rakiya	Discharge [MCM]	0.037	0.063	0.09	0.16	0.252
	relative to Av.	−0.053	−0.027	0	0.028	0.25
	change in discharge % of Av.	−53%	−30%	0.0%	25%	178%
	P [MCM]	16.6	118.6	20.7	22.8	24.8
	r [%]	1.1%	1.3%	1.5%	1.6%	1.8%
Durrah	Discharge [MCM]	0.176	0.24	0.31	0.36	0.44
	relative to Av.	−0.134	−0.068	0	0.05	0.13
	change in discharge % of Av.	−43%	−22%	0.0%	16%	42%
	P [MCM]	186.2	209.4	232.7	256	279.2
	r [%]	1.9%	2.4%	2.8%	3.1%	3.9%
D22 - D25 *	Discharge [MCM]	4.19	5	6.59	7.94	10.9
	relative to Av.	−2.4	−1.59	0	1.35	4.3
	change in discharge % of Av.	−36.4%	−24%	0.0%	20.5%	65.2%
	P [MCM]	360.8	410	451.1	496.1	541.2
	r [%]	1.2%	1.6%	2.0%	2.5%	2.8%
DF2 - EB 1**	Discharge [MCM]	4.15	6.56	9.39	12.2	5.12
	relative to Av.	−5.24	−2.83	0	2.81	10.3
	change in discharge % of Av.	−56%	−30%	0.0%	29.9%	100%