



Navigating Environmental Challenges in Jordan: A Comprehensive Study on Degradation, Remediation, and Future Imperatives

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Abstract

Due to its recent geologic history and development dictating its topographic constellation with the strong relief of the Jordan Rift Valley and its Shoulder Mountains, the land of Jordan as a part of the Levant (Bilad esh Sham) has strongly been exposed to natural degradation processes, such as floods causing erosion, sedimentation and loss of soil, fragile biodiversity, earthquakes, volcanoes, and climate changes. In addition, during the last seven decades, human activities of urbanization, industrialization, and agricultural activities have led to accelerating rates of environmental degradation. To counteract these natural and man-made trends, programs and action plans have been developed and implemented, especially to alleviate the impacts of man-made degradation and to somehow challenge natural degradation processes.

This article discusses the main natural and man-made environmental degradation processes in Jordan, what has been done to alleviate their effects, and what ought to be envisaged, planned, and implemented to challenge these degradation processes. It also highlights the importance of building adaptive capacity and resilience in the face of ongoing environmental challenges in Jordan. This article aims also at encouraging stakeholders, policymakers, and the public to take action based on the study's recommendations. It also emphasizes the shared responsibility in addressing environmental challenges and the potential positive impact of collective efforts.

Keywords

Environmental challenges, Degradation processes, Remediation, Jordan

Introduction

The environmental degradation and water scarcity in Jordan indicate that the availability of water greatly determined and shaped the history of man in Jordan throughout the past four millennia. This basic socio-economic element places a significant influence on man's life when it is scarce, particularly under the prevailing climate change in the region.

In the past, the availability of water and the technologies employed for its exploitation restricted the number of the population. The amount of produced food relied on the accessibility of water resources. However, over the past few decades, both the natural population growth rate and the growth stemming from waves of refugees entering Jordan from Iraq, Palestine, and Syria have been notably high, approximately 3.5% per year (DOS open files).

The race between the deterioration, which has, during the last few decades, affected the water resources in their quantities and qualities and the mitigation and protection measures to save these resources has to be evaluated to determine where we stand and how is our present water

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situation. Such evaluation will certainly help in the planning of future water resources development and indicate the necessary measures to undertake to alleviate the consequences of water resources planning and utilization for the benefit of the present and future generations.

Until the 1970s, with a population of about 1.2 million, socio-economic life in Jordan was almost entirely restricted to

urbanization and agricultural activities, with very limited use of chemicals. Even traffic and the accompanying production of exhaust gases were very restricted. Hence, the effects on the environment, especially on the water resources were very limited to the impacts of household wastewater and some natural fertilizers reaching the water resources. The self-purification capabilities of soils and watercourses were able to cope with these sources of pollution. In addition,

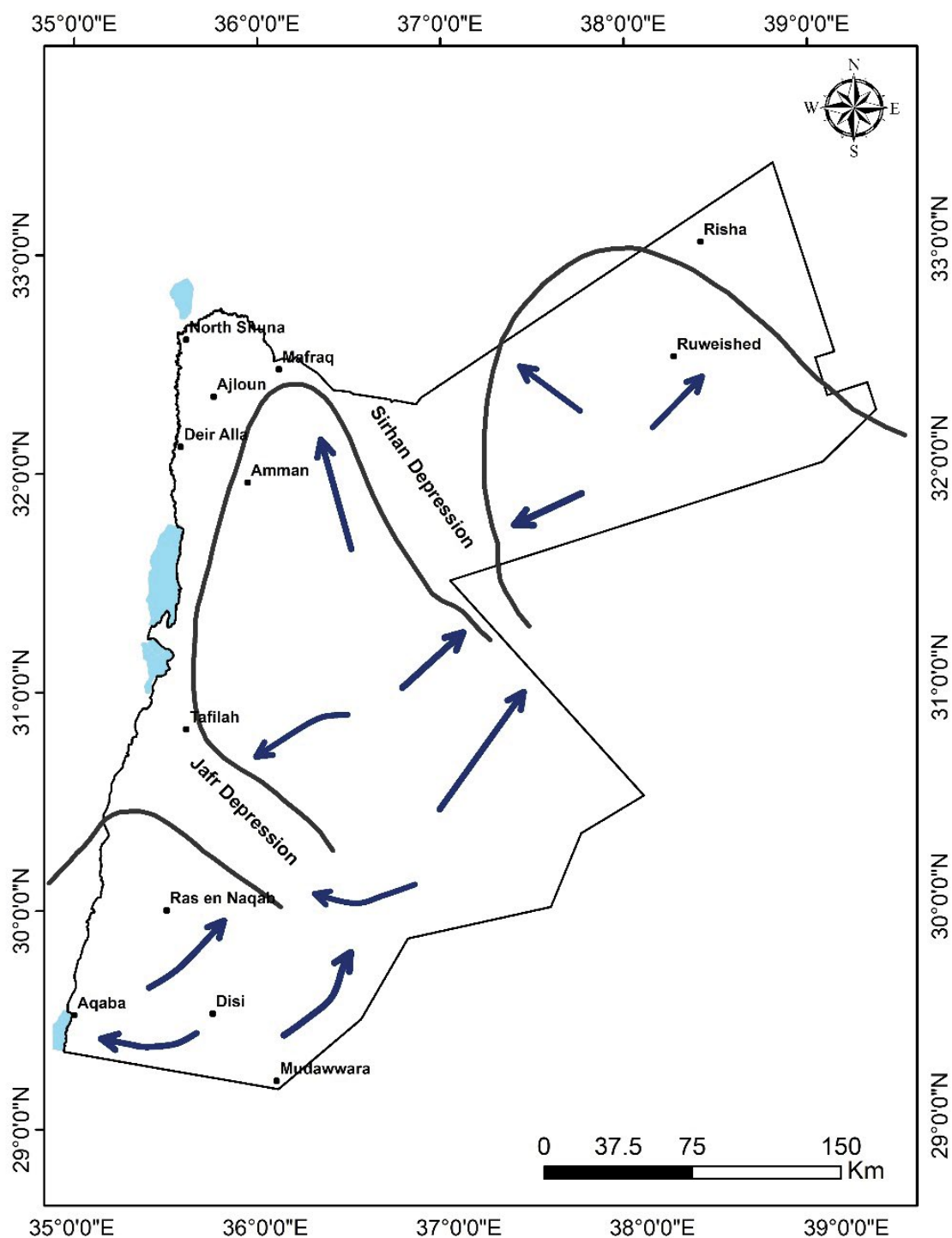


Figure 1: The shore lines during the different geologic eras indicating the transgression of the Tethys Sea and where, terrestrial, shore and marine sediments settled (Redrawn after Bender [6]).

landscape deterioration was very limited compared to the era of major quarrying and mining activities.

Relevant Recent Natural Evolution of Jordan

Tectonics

The recent and relevant geological evolution of the Levant including Jordan, which has led to its present topographic constellation, local climatic conditions, and erosion/sedimentation processes and their effects on living organisms’ communities, started at about 30 million years ago, during Oligocene?, when the Tethys Sea, the ancestor of the Mediterranean Sea started retreating lying behind the fest land of the Levant. This retreat left behind in Jordan two main drainage systems namely Jafr and Sirhan Depressions draining northwest towards the retreating (Figure 1).

The start of the rifting process along the Jordan Rift Valley (JRV) has been the strongest factor in shaping the

land topographic constellation. It has started by forming a depression along the Jordan Rift Valley as a northern branch of the Red Sea initial stage of a ridge. The JRV deepened with time creating a new base level for the Levant surface and groundwater, but the Mediterranean Sea remained the base level for the waters of the area lying to the west of the western Rift Valley Shoulder Mountains. The epeirogenic upward movement of the Levant and the taphrogenic downward movements along the JRV led to increasing gradients between the highlands and the deepening base level of the JRV, increasing herewith the slopes along the wadis draining the highlands and accordingly the erosion and transportation capabilities) Figure 2).

Tectonics, both epeirogenic uplifts and Graben subsidence are continuing to affect the Levant as can be deduced from the structural activities along faults and weakness zones (Figure 3) and as can be seen in the recent sediments of the area [1,2]. These movements are creating higher elevation differences

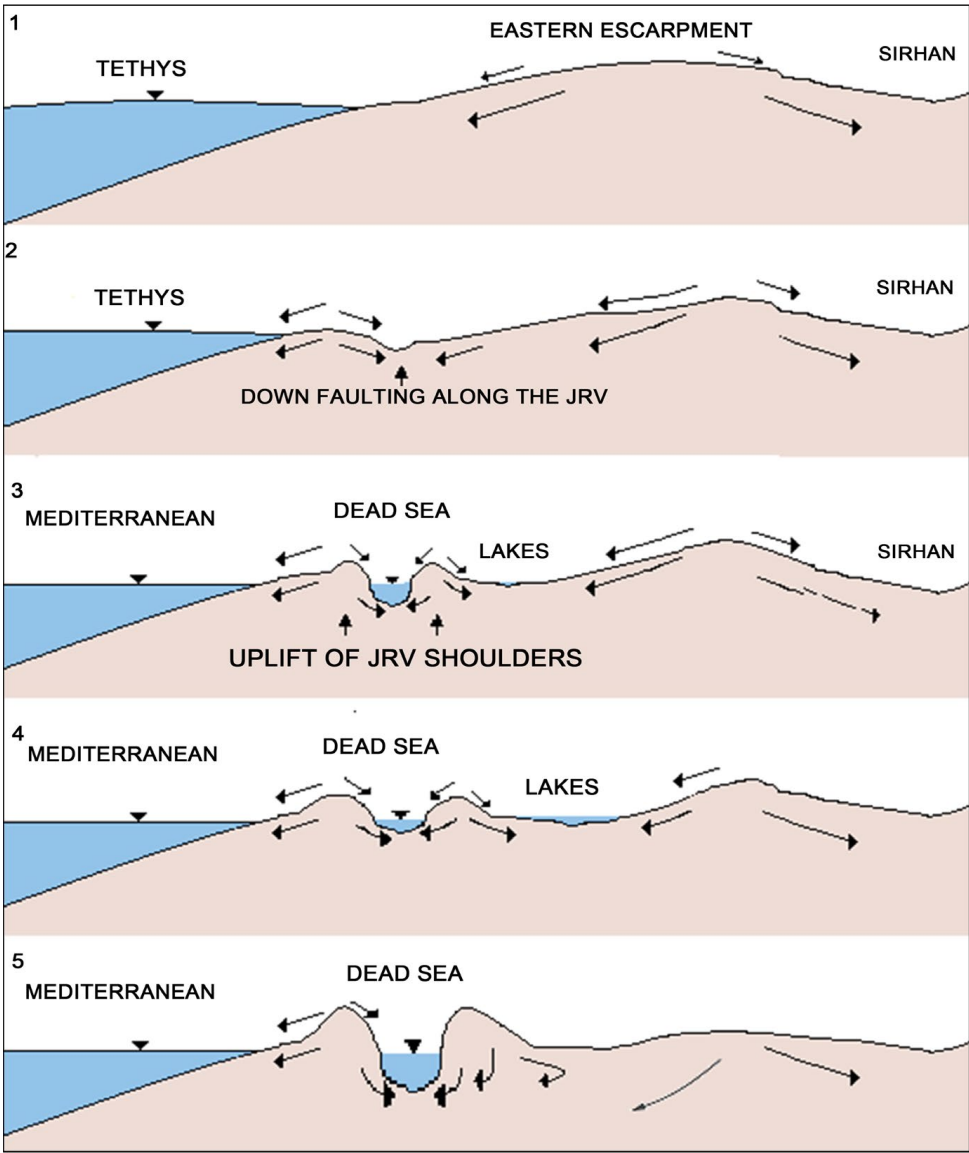
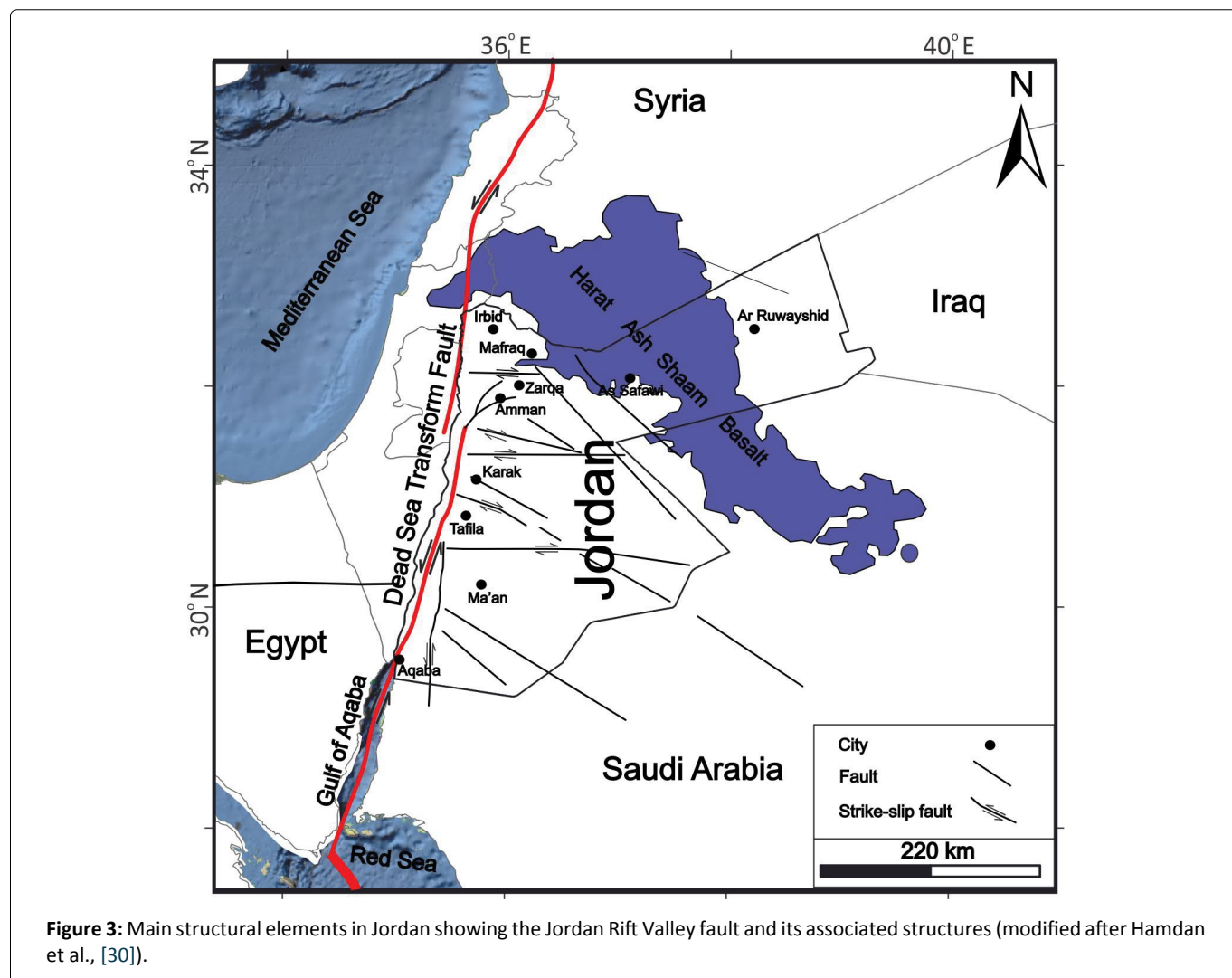


Figure 2: (1-5) Schematic hydrologic cross sections illustrating the development of the drainage system in Jordan after the start of the last regression of the Tethys during Neogene and the impacts of taphrogenic and epeirogenic movement on that system [29].



between the Highlands and the bottom of the JRV, which do not seem to be compensated by the weathering along the highlands, transportation, and sedimentation rates along the JRV, and which has created a difference in elevation between the two of around 450 m since Early to Middle Pleistocene [3-5].

The results of the above-mentioned natural development are increasing erosion, transportation, and sedimentation contributing to the loss of the soil cover, vehement flooding, and damage and deposition of huge quantities of flood sediment loads in areas, that were not formerly exposed to their deposition.

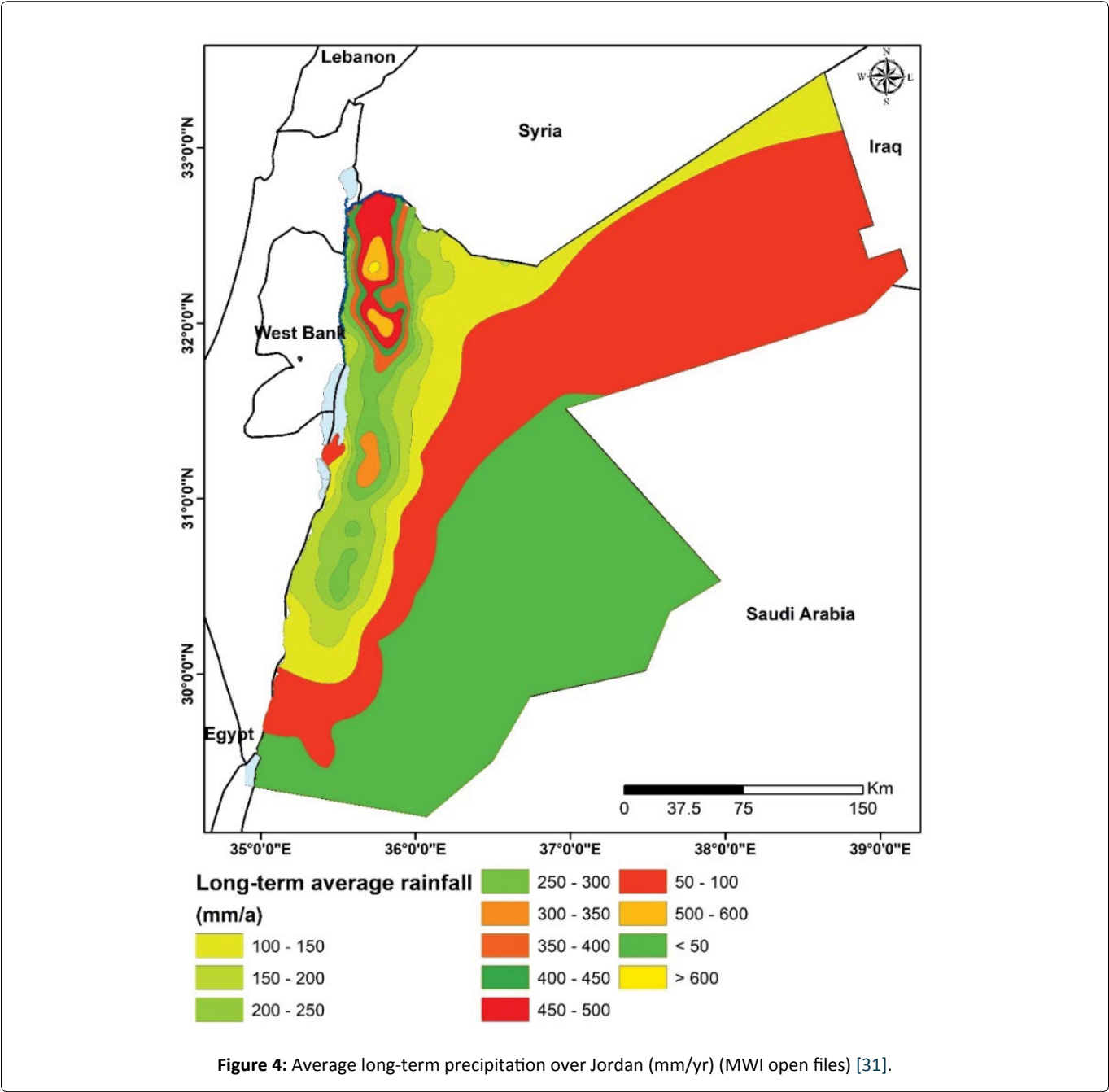
Remediation measures: In Jordan and elsewhere, very little can be done to lessen the uplift movements of the country as a whole (Epeirogenic Uplift), the uplift of the JRV Shoulder Mountains, the subsidence of the JRV bottom (Graben Tectonics), and, with that, connected increases in the steepness of slopes and activation of the fault and rock weakness zone with all their consequences. Best examples of that can be shown in the cases of the regional subsidence of the northern part of the Netherlands, including Amsterdam, and that of Venetia in Italy, both are sinking, increasingly becoming covered by seawater, and little can be undertaken to stop that.

In Jordan, some mitigation measures to alleviate the impacts of geologic uplift and sinking can still be undertaken, such as minimizing erosion and transportation of eroded materials, avoiding construction in the vicinity of active structures and adequately studying these structures and their movements to avoid their destructive implications to land set-up and life.

Climate changes and floods

Climate changes in Jordan, as part of the broader Levant region, manifest in escalating temperatures, diminishing precipitation, and heightened storm rainfall, contributing to increased strength and frequency of floods along wadi and river courses. Recorded data on precipitation, temperatures, and rainfall intensity in Jordan indicate that climate change began impacting the country's water resources several decades ago (Figure 4, Figure 5 and Figure 6). This, in turn, has adversely affected the nation's water supply, resulting in detrimental consequences across various sectors, including health, environment, infrastructure (Figure 7), and socio-economics [6,7].

The rising temperatures in Jordan exacerbate water scarcity issues by intensifying evaporation rates, impacting the overall availability of water resources. Decreasing



precipitation further compounds this challenge, leading to reduced groundwater recharge and decreased surface water levels. The changing climate patterns have also resulted in an increase in the frequency and intensity of storms, contributing to more frequent and severe flooding events along the wadis and rivers. These climatic shifts pose significant threats to public health, as changes in water availability and quality can affect sanitation and disease spread. Additionally, the environment faces risks such as habitat loss, changes in ecosystems, and disruptions to biodiversity. Infrastructure, including water supply systems, may struggle to cope with these changing conditions, affecting their reliability and efficiency.

Socio-economic sectors are not immune to these challenges, with agriculture particularly vulnerable due to its reliance on water availability. Reduced water resources

can lead to lower agricultural productivity, affecting food security and livelihoods. Moreover, the consequences of climate change can exacerbate existing vulnerabilities, disproportionately impacting marginalized communities.

Many studies such as Chenoweth, et al. [8]; Salameh and Abdallat [6]; Salameh [9]; Abu-Allaban, et al., [10]; Smiatek, et al., [11]; Al-Zu'bi [12]; Black, [13]; Smadi and Zghoul [14] concluded that precipitation over Jordan will decrease by 12-20% in the middle of the this century and the generation of flood water which is proportional to rainfall intensity will produce more vehement and intensive flood flows. According to Salameh and Abdallat [6]; Salameh, et al., [15], the reduction in flood flow amounts in the different precipitation regions in Jordan as a result of 10% reduction in precipitation will range from 14% in rain rich areas to more than 60% in the low precipitation desert areas. That is because flood

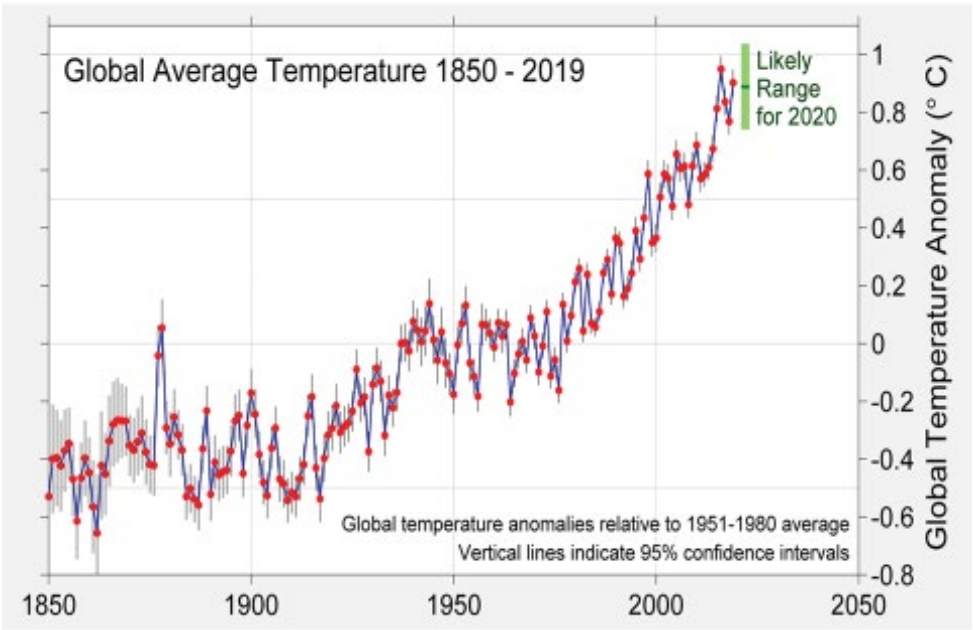


Figure 5: Global temperatures since 1850, with marked increases since 1940s.

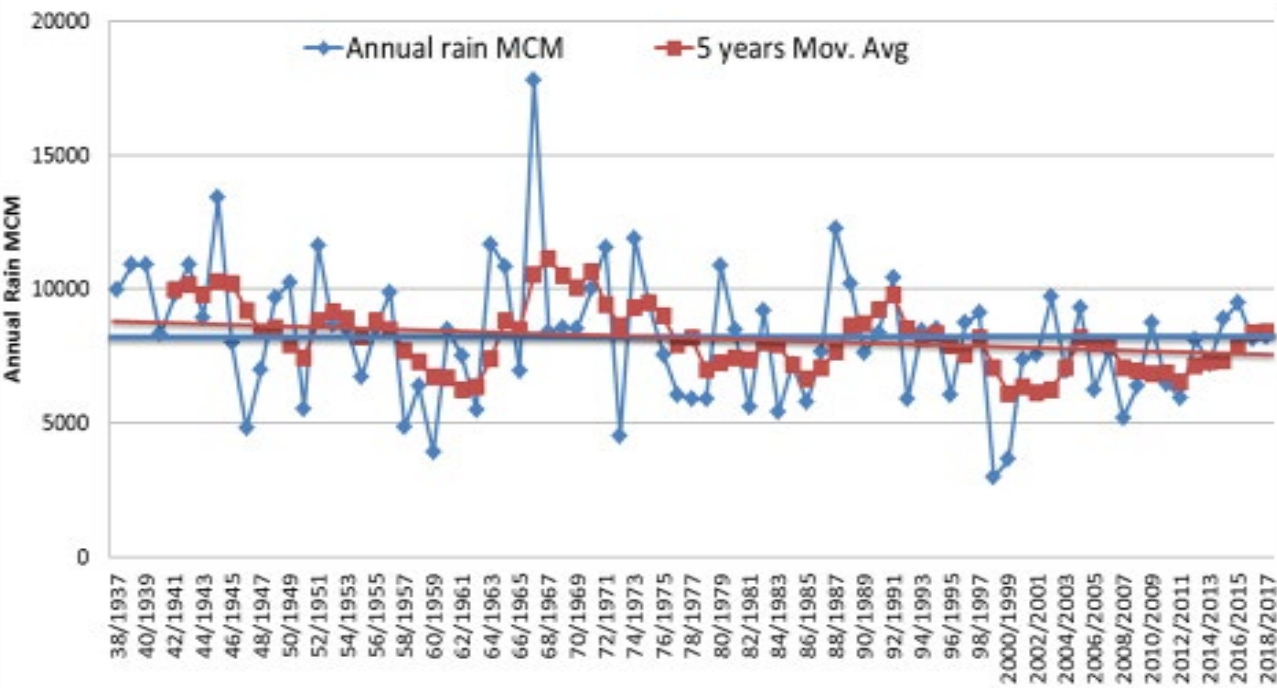


Figure 6: Decreasing precipitation. The blue line represents the long-term average, whereas the red line represents the 5-years moving average indicating the decrease of precipitation rates in Jordan (MWI open files) [31].

flow depends on various factors such as type of precipitation (rainfall duration and intensity, snow), topography, soil, geology, evaporation force of the climate, and land use.

In addition, urbanization due to population multiplication, improving living standards, rural migration to towns and cities, and migration of refugees from other countries, all requiring new buildings and asphalted roads on account of natural soil covers result in increasing flood flow generation,

flood water amounts, and flood intensities.

Remediation measures

Undertaken: Flooding impacts can be minimized by constructing water barriers such as dams and weirs and local water harvesting facilities. Reconsidering the capacities of drainage systems (Canalization in built areas), flood channels, land overflow drainage systems by increasing their discharge



Figure 7: Flood damage Maan area in 2023.

capacities have become mandatory in all areas threatened by increasing rainfall intensities as a result of increasing storm rains. In this context, countries worldwide are undertaking proactive measures, but the implementation of such measures require decades of work.

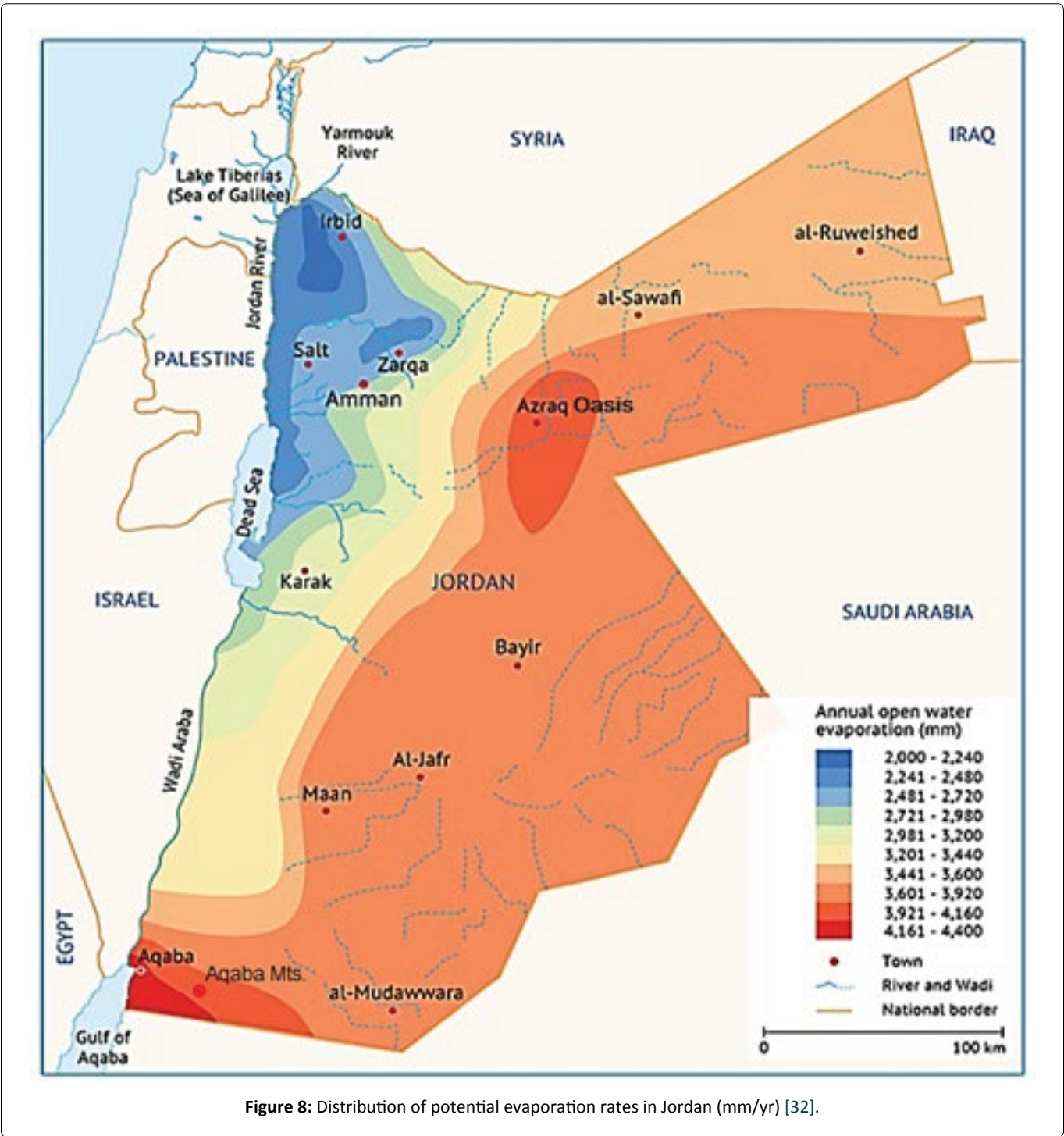
Needed: The recent floods affecting all continents (Europe, US, China, India, Libya etc., 2022-2023) and the climate changes affecting the whole Globe expressed in rising temperatures, redistribution of precipitation, and increasing rainfall intensities (Storm rain) show that unless the reasons behind these climate change are dealt with adequately, only consequences-alleviation measures can be undertaken to restrict their negative impacts. The world is planning to tackle the reasons behind climate changes (burning of fossil fuel) [16], but it will take many decades to feel the impacts. At present, not much can be done to stop the above-mentioned impacts of climate changes on Jordan. However, some measures and programs can be implemented to minimize their negative impacts.

Natural water scarcity

Nature does not know water shortages, it is we who perceive and suffer the shortages [17]. In average, Jordan receives an average of 8.3 billion cubic meters per year of

rainfall water distributed highly unevenly over its territory, ranging from 30 mm/yr in the most southern part of the country to around 600 mm/yr along its northwestern highlands falling in the period November to April, with totally dry summer months. In order to survive during the summer months and as a challenge, man has been obliged throughout the last 4-5 millennia to manage the water scarcity by technical and engineering innovation (Figure 4 and Figure 8).

Water played a pivotal role in shaping ancient Jordanian civilizations and influencing human lifestyles. The arid and semi-arid climate of the region necessitated a deep reliance on water sources for sustenance and development. Ancient Jordanian communities strategically settled near water bodies, such as the Jordan River and its tributaries, where fertile land facilitated agriculture. The availability of water not only supported crop cultivation but also enabled the establishment of permanent settlements, fostering social and economic stability. The development of sophisticated irrigation systems, such as the Qanat, allowed communities to efficiently manage and distribute water resources, enhancing agricultural productivity and enabling the growth of urban centers. Moreover, water sources in ancient Jordan served as focal points for cultural and religious significance. The Jordan River, for instance, held religious importance



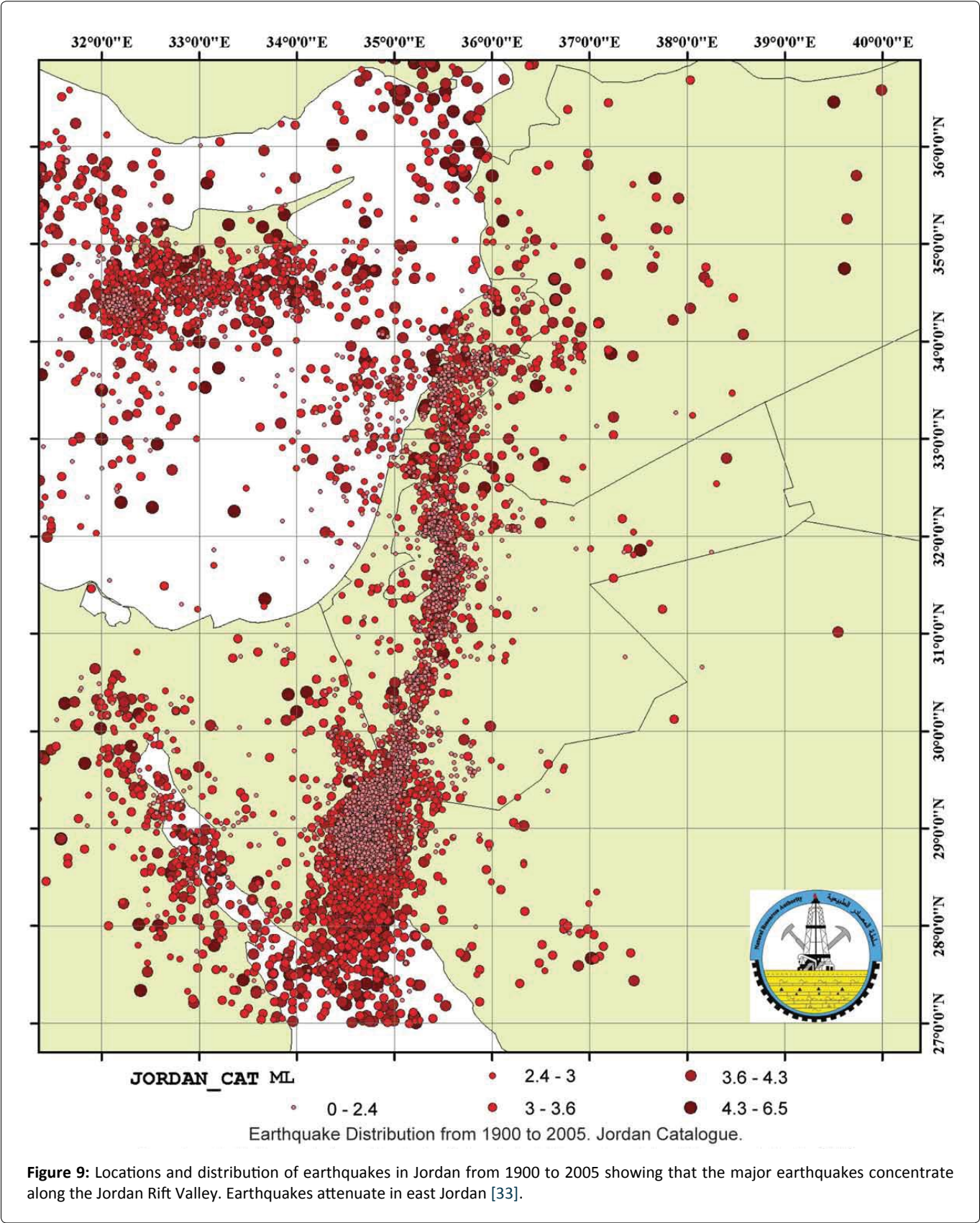
in various historical contexts, including biblical narratives. Rituals and ceremonies often took place near water bodies, reinforcing the cultural and spiritual significance of these natural resources. In essence, water was not only a practical necessity for survival but also a fundamental element that shaped the cultural, economic, and religious dimensions of ancient Jordanian societies, leaving a lasting imprint on human lifestyles in the region.

Remediation measures

Undertaken: Against natural water scarcity very little if anything can be done, as mentioned above, historically man has used technical and engineering innovation to adapt to

that scarcity. But, ancient innovations have almost become exhausted in Jordan and they can only secure very limited additional water quantities relative to the present demand of hundreds of millions of cubic meters of water per year. Such measures are dam projects, water harvesting projects, improved water conveyance systems, and measures to raise water use efficiency in irrigation.

Needed: Additional measures against climate changes using advanced technology such as sophisticated water harvesting programs, improved agricultural engineering management of rainwater stored in the soil (Green water), protected farming (Greenhouse), drip and sub-soil irrigation,



and improved seeds among others can be very effective in challenging climate changes [18]. Seawater desalination has become the only viable solution in providing the necessary additional water amounts needed for the country's economic and social development and even its survival.

Earthquakes

Due to its geologic position and geologic set-up, Jordan has been and is exposed to earthquakes. The Jordan Rift Valley and its surrounding mountains are the main areas affected by

such earthquakes. Small magnitude earthquakes of less than 3 degrees on Richter Scale happen very frequently especially along the JRV and faults sprinting of it, whereas, large scale damaging earthquakes of more than 6 degrees Richter Scale are scarce and were calculated to hit once in a century.

The last major earthquake that hit Levant in 1927 was of 6.1 or 6.2 degrees on Richter scale, affecting northern Palestine more than Jordan and a stronger earthquake stroke the area south of Aqaba in 1995 with a magnitude of 6.8 causing minor damage to old buildings and killing one person.

The geologic structure of Jordan shows that the faults, along which earthquakes may take place are relatively short in their extent, with the exception of the Jordan Rift Valley Fault and of, generally, extensional type, The Jordan Rift Valley fault is a pull-apart structure, with small parts of it exposed to compressional stresses due to the S-shaped fault trajectory and its strike-slip nature forming sag-ponds and very few small ridges along its course. The ridges are the playground of earthquakes (Figure 9).

Protection measures against earthquakes are included in the building codes especially of large buildings, bridges, and dams. Stronger measures in the design and construction do not seem necessary, although some danger of bigger earthquakes still exists. Of course, some old buildings, and buildings not constructed according to the building codes are exposed to large earthquakes or more than 6 degrees on Richter scale.

Remediation measures

Undertaken: Earthquake devastating impacts can, to a certain extent, be challenged by improving construction and application of suitable building codes. Building codes have been set in Jordan and building licenses observe these codes and no buildings especially big ones are constructed unless these necessary protective measures to fulfill the codes are undertaken. That of course does not apply to old buildings, which were constructed before the issuing of the codes. Observation of earthquakes, measuring their intensities locations, and depths have been carried out in Jordan for about 4 decades, which can help delineate areas exposures to earthquakes.

Needed: As has been witnessed, the damage of the earthquakes, which stroke Turkey, Syria, and Morocco in 2023 mostly affected old buildings and buildings constructed in discordance with the valid earthquake-resistant building codes. That shows the deemed necessity to control the abidance of the codes during the construction of new buildings and the control of old buildings and carry out any necessary measures to increase their resistance to earthquakes.

Volcanic activity

Around 12% of Jordan is covered by volcanic rocks distributed all over the country, especially in its northern part, the so called Harrat Ash Sham basalts and along the Shoulder Mountains of the Jordan Rift Valley. According to Bender [3] and Van den Boom, et al., [19] the last known volcanic eruptions in Jordan were active until around 4.500 years ago.

The strong volcanic activity during the Neogene, Pleistocene, and Holocene of less than about 12.000 years ago indicates that volcanic eruptions or re-eruptions are quite possible. Although such eruptions are very rare events, their eruption probability remains a fact that has to be considered in the planning of large projects in their specific areas such as dams and cities. Volcanic activity destroys life in its immediate surroundings and along its lava flow courses, which requires then tens to hundreds of years to recover and due to scarce precipitation the recovery in the arid and semi-arid climatic zones may take longer than that. Therefore volcanic activities contribute to the degradation of the living environment. Volcanoes create topographically elevated areas around their areas of eruption and hence stronger erosion, transportation and sedimentation processes of their rocks which contributes to the degrading environment. In Jordan, if erupted, volcanoes contributed both to the degradation of the land scape and to floral and faunal life detriments (Figure 10).

Remediation measures

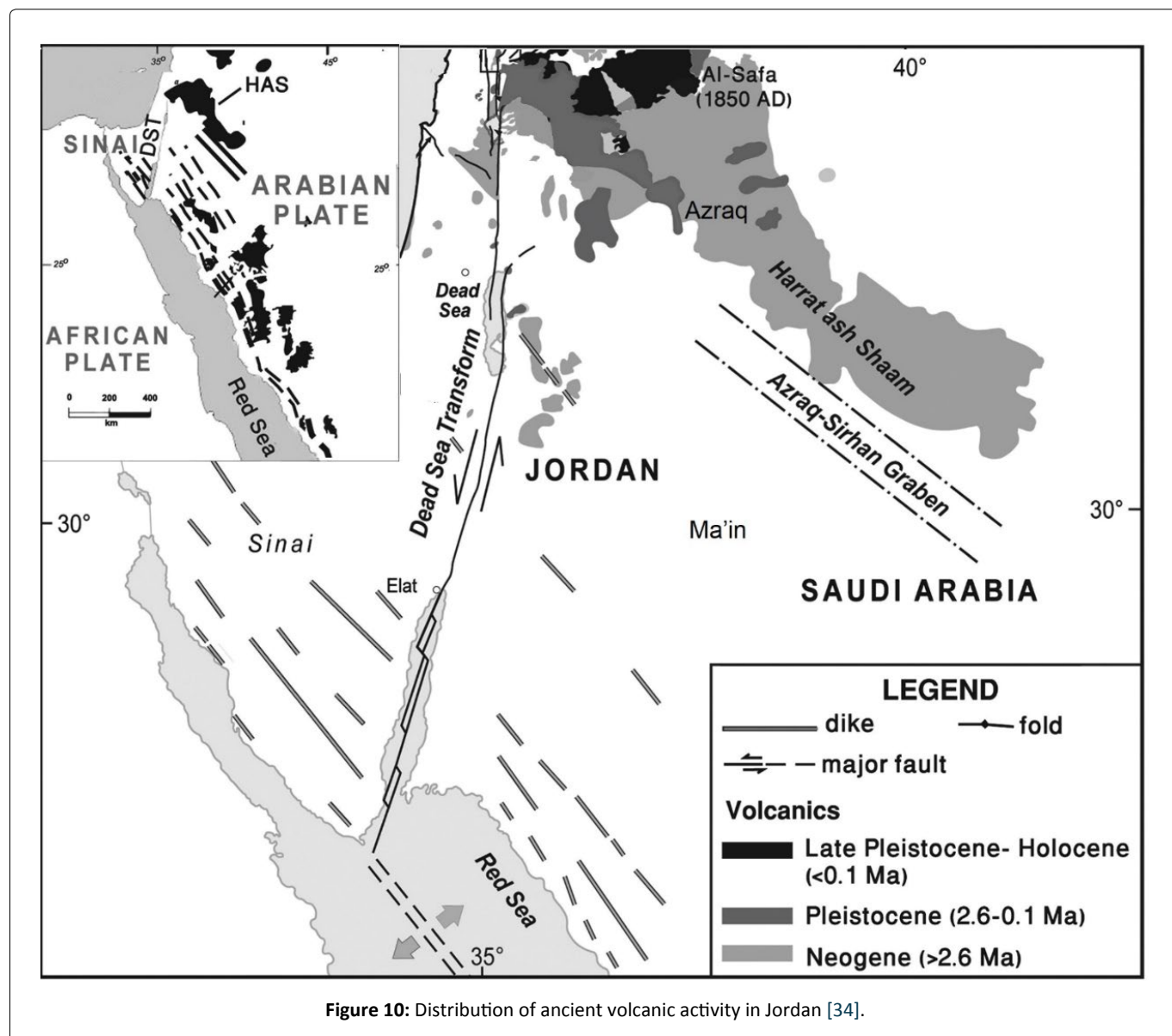
Undertaken: Nothing in Jordan has been undertaken to combat the probability of volcanic eruptions. Only, crises management has been planned for all cases of emergencies, which include probable volcanic eruptions.

Needed: Only moderate programs and measures can be undertaken to alleviate the impacts of volcanic eruptions such as avoiding major construction projects in the vicinity of potential volcanic eruption sites, observation of activities related to potential eruption, and intensified studies on volcanoes and their re-eruption probability. Examples of mitigation measures can be taken from those of Vesuvian and Etna volcanoes recent eruptions.

Soil degradation and erosion

The steep topographic relief of Jordan, especially between the Rift Valley and its eastern Shoulder Mountains allows land-overflow precipitation water to flow with high velocity over land and water courses. The high-velocity flow causes erosion of soil and rock covers and transportation in a downstream direction. Therefore, soils of appreciable depths of more than 50 cm in thickness cover only few percentages of the shoulder Mountains and their surroundings and the areas along their slopes towards the Jordan Rift Valley. Rainwater is stored in the soil in which plants establish their roots. However, when such soil cover is missing both natural plants and human planting become irrelevant.

While there may not be adequate awareness regarding the critical roles soils play in nature and human survival, their functions, such as regulating water, air, and organic and inorganic substance cycles, are fundamentally essential for life on solid earth. Soil serves as a reservoir for water, storing it for plant utilization and providing essential minerals crucial for their growth. Recognizing the significance of soil in these processes highlights its pivotal role in supporting the sustainability of ecosystems and ensuring the well-being of both the environment and human life. It purifies the water from pollutants by breaking down and decomposing waste material compounds through bacterial activities. Soils are the



main sites of food and biomass production. Soil, in addition, plays a major role in the transfer of materials between the atmosphere and the plant cover, and the groundwater. It provides a habitat for bacteria, fungi and animals. Therefore, soil erosion deprives nature of soil essential functions for life and humans on earth.

Remediation measures

In instances of natural soil degradation and erosion, there are many opportunities for implementing conservation and remediation measures. These may include land terracing, water harvesting, and the construction of barriers, weirs, dams, plantations, and engineered plowing, among others. These proactive measures not only address soil issues but also contribute to the longevity of water harvesting structures like dams, weirs, and pools. By strategically applying these techniques, we can mitigate the impact of soil degradation, enhance water conservation, and promote sustainable land management practices.

Undertaken: Jordan has implemented some programs

to conserve soil and landscape such as terracing parts of the Zarqa River catchment area, proper ploughing of land, and floodwater harvesting in the upper reaches of catchments collecting sediment loads of floodwater among others.

Needed: Due to its steep topography and hence vulnerability of its rocks and soils to weathering and erosion processes Jordan must plan and apply very intensive programs to protect its degrading geology, soils, and topography mainly by local water harvesting to avoid the damaging effects of floods and to conserve soils and rock. And although this represents a very big and ambitious undertaking it should start and be implemented as soon as possible. Loosing soils represent very big loss of a natural resource, essential for life, the environment, and survival of human beings and their economic sustainability.

Man-made

Floods

Urbanization and global changes due to improving living

standards, rural migration to towns and cities, migration of refugees from other countries, require more houses, asphalted roads industrial plants among others (Figure 11). This takes place on the account of natural soils and results in increasing land-overflow water, flood generation, and high-intensity floods. As example on that, King Talal, Wadi Arab, Ziglab, Shueib, Kafraïn, Zarqa Ma'in, Karak, and Wala are affected by the rapid development of their catchment areas, which results in increasing the natural runoff/precipitation ratios of their respective catchments and hence increases in their flood quantities and intensities. This, partly, counteracts the impacts of climate change of decreasing flood flows as a result of precipitation. In addition, treating household and industrial wastewater and reusing it has also alleviated the climate change impacts manifested in substituting the use of surface and groundwater.

The discharge of the treated wastewater along wadis has resulted in increasing wadi flows and hence the water stored in dams and other water harvesting facilities. Dams such as King Talal, Shueib, Kafraïn, and Karak receive appreciable amounts of treated wastewater and to a lesser degree Wadi Arab, Ziglab, Zarqa Ma'in, and Wala so that the declining flood flows due to climate change are compensated for by adding

the treated wastewater to the wadis and by additional floods due to urbanization. For example, King Talal Dam receives some 120 MCM/yr of treated wastewater, which is around double the amount it receives from natural flood and base flow water.

Remediation measures to counteract flooding

Undertaken: More than 30 small and large dams have been constructed in Jordan to collect flood water and to counteract the damaging effects of floods on dams' downstream areas. The dams served that purpose, in addition, dams, weirs, artificial pools, and other water harvesting structures served as sediment traps of wadis and river courses they were constructed on. And, although this is not the purpose of their construction they reduce the sediment loads of water courses. These structures do not reduce the erosion processes in the structure-upstream areas, but they collect the transported sediments in their higher latitude areas, reduce the water velocity, the quantity of eroded materials, and the damaging impacts on the downstream areas. They also reduce the quantity of deposited rocks in their natural sedimentation terminal localities.

Table 1 shows the quantities of sediments accumulated in

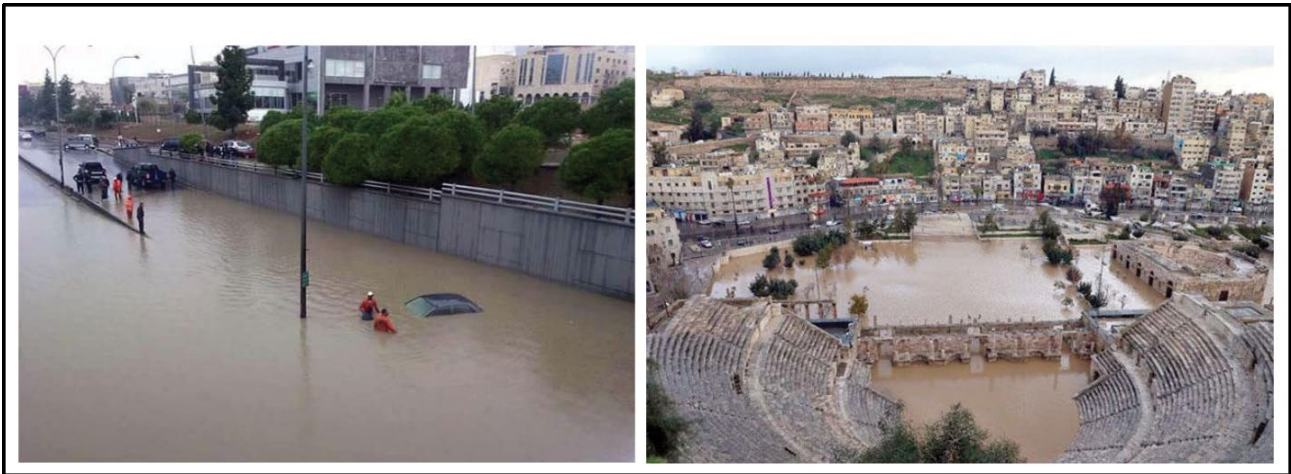


Figure 11: Amman's downtown flash flood in 2019.

Table 1: Main dams in Jordan, accumulated sediments in their lakes, annual sedimentation rates, catchment area and area's average precipitation [35].

Dam name and year of construction	Sediments (1000 m³)	% sediments of capacity	Catchment area (km²)	Av. catchment precipitation (mm/year)
Wadi Al-Arab 1986	2900	17.2%	262	462
King Talal 1977	18000	24%	3700	272
Wadi Shueib 1969	900	52.9%	178	400
Al-Kafraïn 1967	1900	22.4%	163	397
Wala 2002	4600	18.2%	1770	216
Al-Muiib 2003	6500	21.8%	4380	317
Al-Tannur 2001	2500	17%	2160	150
Al-Karak 2017	140	7%	170	273

the major dams' lakes in Jordan and their construction year. It illustrates the magnitude of average sediment rates reaching dam lakes. Not enough data is there to relate flood quantities and sediment loads due to the fact that most dams receive in addition to flood water base flow water and treated waste water containing small quantities of suspended sediments.

Urbanization plays a similar role to water harvesting project in reducing sediment transportation and deposition in downstream areas. Because urbanization is accompanied by reducing soil erosion, because precipitation water falls over areas covered with concrete or asphalt with limited erodibility because these are less susceptible to erosion. But, urbanization limits the groundwater recharge, because it covers the native soil with concrete and asphalt that do not allow precipitation water to infiltrate and recharge the groundwater and hence it increases the flood amounts.

Needed: There are good opportunities to locally collect the floodwater of natural and urbanized areas and to divert it to be stored in surface water storage facilities such as weirs, pools, and cisterns or to recharge it into aquifers. Although an appreciable number of such projects have been undertaken to make use of rainfall and floodwater, which ended up in reducing the impacts of floods, water harvesting in upstream areas presents a very effective way of reducing floods, sediment transportation, and deposition in downstream areas.

At the same time, almost nothing has been undertaken to reduce the impacts of urbanization on decreasing groundwater recharge and at the same time increasing flood water quantities and their damaging effects. Sediments eroded from areas not yet built in urbanized areas still reach the road networks and water courses causing increases in the sediment load of floods. Adequate regulations and their implementation in that concern are still missing and should be in place as soon as possible. Also, mining and quarrying activities are causing disturbances in the natural landscape by excavating and piling up of mining by-products increasing herewith the erodibility of rock cuttings and hence sediments transported along wadis. Although the regulations condition that quarrying and mining industries should rehabilitate their activities' sites, very big violations are still there.

Household liquid wastes

In Jordan, household wastewater is either sewered to a wastewater treatment plant or disposed of into cesspools, depending on the presence of a sewerage system in the vicinity. Both, ways with impacts on the local surface and groundwater resources due to the wastewater contents on diseases-causing organisms, relatively higher concentrations of nitrates, phosphates salinity, and recently pharmaceutical residues than the supply waters [20,21]. Therefore, Household wastewater in Jordan poses a considerable health challenge for communities and nations alike. Addressing the impacts of household wastewater necessitates substantial investments in treatment costs, expertise, and the development of safe reuse strategies. Given the complexity and resources required, mitigating the adverse effects of household wastewater demands a comprehensive approach

that encompasses not only effective treatment processes but also the implementation of sustainable and safe methods for its reuse.

Cesspools are generally leaky and the wastewater infiltrates through, reaches the groundwater bodies and if the flow time to the groundwater and the type of aquifer pores do not allow for the total removal of bacteria and viruses the leaked wastewater contaminates the groundwater [22].

Remediation measures

Undertaken: Jordan's early encounter with the impacts of untreated wastewater on the health and the environment led the country to construct its first wastewater treatment plant in 1945 to treat Salt City wastewater. Successively then more such plants were constructed and expanded to serve around 65% of all households in the country. By now, most wastewater treatment plants in Jordan are working on mechanical principles, produce an effluent with a BOD5 concentrations of less than 30 mg/l. Some of the treatment plants produce a BOD5 of more than 30 mg/l due to hydraulic overload and to higher organic matter concentration in the incoming wastewater.

Jordan's dire need for water imposed a necessity for the reuse of treated wastewater in agriculture, generally after mixing it with flood and base flow water collected in dams and weirs. The treated wastewater quantities became enough to cultivate at least around 260,000 dunums with Alfalfa and various trees such as olive and apple. The introduction and expansion in wastewater treatment and reuse have protected the health of the population, and the environment, and produced more agricultural products. As an example of the quality of treated wastewater the composition of Khirbet es Samra wastewater treatment plant effluent, the largest in Jordan, is given in Table 2.

Needed: Certain current wastewater treatment facilities require both expansion and rehabilitation due to overload issues, whether in terms of quantity or quality. There is a pressing need for the establishment of new wastewater treatment plants in certain villages and towns to safeguard public health, protect the environment, and preserve surface and groundwater sources in their vicinity. Given the relatively small size of some of these villages, their wastewater poses a contamination risk to vital water sources. Implementing decentralized wastewater treatment and reuse schemes can effectively address these concerns and fulfill the purpose of ensuring the sustainable management of wastewater in these communities. Gradually, Jordan should introduce in its wastewater treatment plants provision for treating upcoming pollutants such as pharmaceutical residues.

Industrial liquid wastes

According to their qualities, industrial wastewater can be classified into (a) High salinity effluents, (b) High organic loads effluents, (c) High trace elements effluents, (d) High contents of other specific substances such as phosphates and ABS and (e) A combination of any group of a-d. Practically, these wastewaters are treated, untreated, or semi-treated. More than 90% of industries in Jordan possess own wastewater

Table 2: Composition of the Effluent of the Khirbet es Samra wastewater treatment plant (mg/l) (MWI Open files).

<i>Khirbet es Samra</i>	<i>pH</i>	<i>PO₄</i>	<i>T-N</i>	<i>NO₃</i>	<i>NH₄</i>	<i>TDS</i>	<i>TSS</i>	<i>COD</i>	<i>BOD₅</i>	<i>E. coli</i>
	7.7	8.3	15.2	28.6	6.2	982	9	42	8.5	27

Table 3: Analyses of the solid waste leachates, and the liquid waste pool, southeast of Amman (in meq/l).

Parameter	Temp °C	EC (µS/cm)	pH	NO ₃ ⁻	HCO ₃ ⁻	CO ₃	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
Old dump	14.6	138.000	8.46	12.09	6.09	0	11.5	150	7.3	8.6	142	23.22
New dump	14.4	5.500	8.10	0.062	4.48	0	1.9	34.1	2.4	3.2	37.6	1.18
Waste pool	15.6	18.560	8.68	89	3.50	0	4.88	158.9	7.71	9.77	154.3	2.65

treatment plants and many of these produce effluents which comply with regulation and standards, some do not, and some others produce semi-treated wastewater.

Industrial effluents are disposed of by (a): Diversion into a domestic wastewater treatment plant, especially Khirbet-es-Samra, (b) Discharge into nearby wadis, (c) Use in irrigation in the surrounding of the effluent-producing industry, and (d) Transport to a collection pool or infiltration and/or evaporation in a spreading basin. Around half of the industries discharge their pretreated effluents to domestic wastewater treatment plants. Others, which wastewater contains substances that might pose a threat to the treatment processes of domestic WWTP are not allowed. They discharge their effluents to the nearby wadis. Some discharge their effluents to pools and spreading basins where they infiltrate or evaporate.

Industrial effluents contain high salinity or high organic load or both. Only a few of them have high trace element concentrations such as lead mercury iron etc. and very few high concentrations of specific parameters such as pharmaceutical residues, and agrochemicals.

Remediation measures

Undertaken: Jordan demonstrates commendable progress in the domain of household wastewater treatment and reuse, along with anticipated expansions in this sector. A crucial and effective regulatory measure is the requirement for industries to obtain licenses only after establishing the essential facilities to treat industrial wastewater to a degree that permits its discharge into the household sewerage system or along wadi courses. This stringent condition ensures responsible industrial practices, safeguarding both public health and environmental integrity.

Needed: Some chemicals present in industrial wastewater continue to enter domestic wastewater treatment plants, necessitating novel considerations for regulations, management, and treatment strategies. Notably, these chemicals encompass emerging pollutants such as pharmaceutical residues utilized in households, industries, agriculture, and medical centers.

In this concern, regulations and handling of pharmaceuticals are very effective ways in reducing their quantity that reaches the water resources (e.g.: Returning unused pharmaceutical to pharmacies to be dealt with in an engineered way, or separation of hospital wastewater from that of household wastewater to be treated on its own). In

that concern, worldwide experience can be consulted. In addition, innovation of other techniques and measures, more suitable to the climatic and water conditions in Jordan, can still be developed.

Solid wastes

Solid waste disposal: Solid waste in Jordan generally consists of about 49.5% food waste, 25.9% cartons, 6.5% plastics, 3.3% glass, 2.5% metals, and the rest of the natural materials; wood, earth, stones, construction refuse, etc. [23]. Because solid wastes in Jordan do not undergo systematic separation, they contain all types of solid wastes such as medicaments, batteries, trace elements, plastics, paints, mineral oils, insecticides, pesticides, and some industrial solid wastes.

The generally applied methodology of handling solid waste in Jordan is collecting the un-separated solid wastes by trucks to the disposal site where they become compressed to consolidate and in most disposal sites covered by a few centimeters of soil and then reconsolidated. When compared with open uncovered dumping sites such a procedure restricts the entry of air into the solid wastes, prohibits immediate burning and combustion and improves the landscape, but it does not prohibit biochemical reactions whether aerobic or anaerobic, which produce decomposition gases and liquid leachates that diffuse into the air or reach the surface and groundwater resources of the surrounding areas. Solid wastes deposited in disposal sites react with rainwater or compaction water, subsequently leaching into the ground and surface water bodies, leading to contamination.

In Jordan, solid waste disposal sites are found distributed all over the country and their sites have not been exposed to sophisticated environmental, health, and astatic impact assessment. Hence, they do not fulfill present-day criteria. In addition, most solid waste disposal sites are located along wadis courses, in land depressions and abandoned quarries, or in karst holes, hence forming a direct threat to the ground and surface water resources in their vicinities.

Many studies worldwide discussed the impacts of solid waste disposal on surface and groundwater resources [24]. The problem is that once the impacts are detected in the composition of the surface or groundwater bodies the repair becomes very difficult or even impossible.

Examples of the composition of leachates in solid waste disposal sites are listed in Table 3. In practice, in semi-arid

and arid areas many years of compaction and burial are required until the solid wastes generate leachate. These are generally composed of calcium, magnesium, sodium chloride, sulfates, nitrogen compounds (such as ammonia, nitrate, and nitrite), and bicarbonates. Peak concentrations of the various parameters are reached after many years of deposition and compaction. In addition, once it is reached it continues at the same level for many tens or hundreds of years, even if the disposal stops [24].

Remediation measures

Undertaken: Intended separation of solid waste and specific treatment of their composing materials is not practiced in Jordan. But, scavengers collect metals, plastics, batteries, carton, glass bottles, and others and hence, some unintended separation takes place and the solid wastes become less dangerous. For dangerous materials, a special disposal site has been constructed in Jordan, Swaqa Hazardous Waste Disposal Site, at around 70 km southeast of Amman in the desert area. This is an engineered disposal site, thought of to protect humans, the environment, and the ground and surface water resources of its surroundings. In some big solid waste disposal sites, decomposition gases are collected to produce energy, which has become a profitable business [25].

Needed: Existing solid waste disposal sites should undergo rigorous impact assessment studies in relation to their effects on health, air, surface and groundwater resources, and landscape. Rehabilitation programs including excavation and recycling of the content of these sites should be planned and implemented. Recent worldwide developments in the handling of solid wastes advocate a slogan of “Zero Waste”, or recycling all solid wastes. That is also because solid wastes collection, separation, and recycling have become commercially beneficial.

All activities concerning solid wastes should start by separating their production sites into food remains, plastics, glass, metals, paper, or combinations of them transporting them to beneficiation centers, and recycling them into usable forms.

Groundwater overexploitation

Since about 3 decades, the water supply of Jordan depends mainly on extracting groundwater. The groundwater of Jordan consists of two types, namely, renewable groundwater, which receives recharge water on a regular basis, and non-renewable water, which might receive some recharge water, but it's natural discharge or outflow equals or is more than the recharged amounts and its average age is measured in tens to many hundred thousand years.

Since about 4 decades, Jordan has been over-extracting its renewable and nonrenewable groundwater resources. The impacts are manifested in the drop in groundwater levels by 1-10 m/year, reduction in or ceasing of spring discharges, mobilization of saltwater in aquifers towards fresh groundwater bodies, and deteriorating water quality [26-28]. These impacts have their rigorous percussions on the socio-economic life in the country such as: Reduced water supply to

household during the last few years from 85 l/c.d to around 73 l/c.d, reduced water quality, which may negatively reflect on human health, declining agricultural productivity due to decreasing irrigation water quantities and higher water salinity, larger investments in the purification of increasingly deteriorating water quality and reduced availability of the natural resources for future generations.

Jordan's worsening water situation has driven the country to the brink of collapsing water supply system, where all available surface water has been developed and used, renewable groundwater has become overexploited and nonrenewable groundwater has been mined at very high rates. That is in addition to the total exploitation of the unconventional treatment and reuse of almost all waste water. Rationing in household water use has, considering the standard of living in the country, become inelastic and any further decrease in the daily household consumption will be reflected in worsening public health situation. Figure 12 shows the decline in groundwater levels in one of the groundwater monitoring wells.

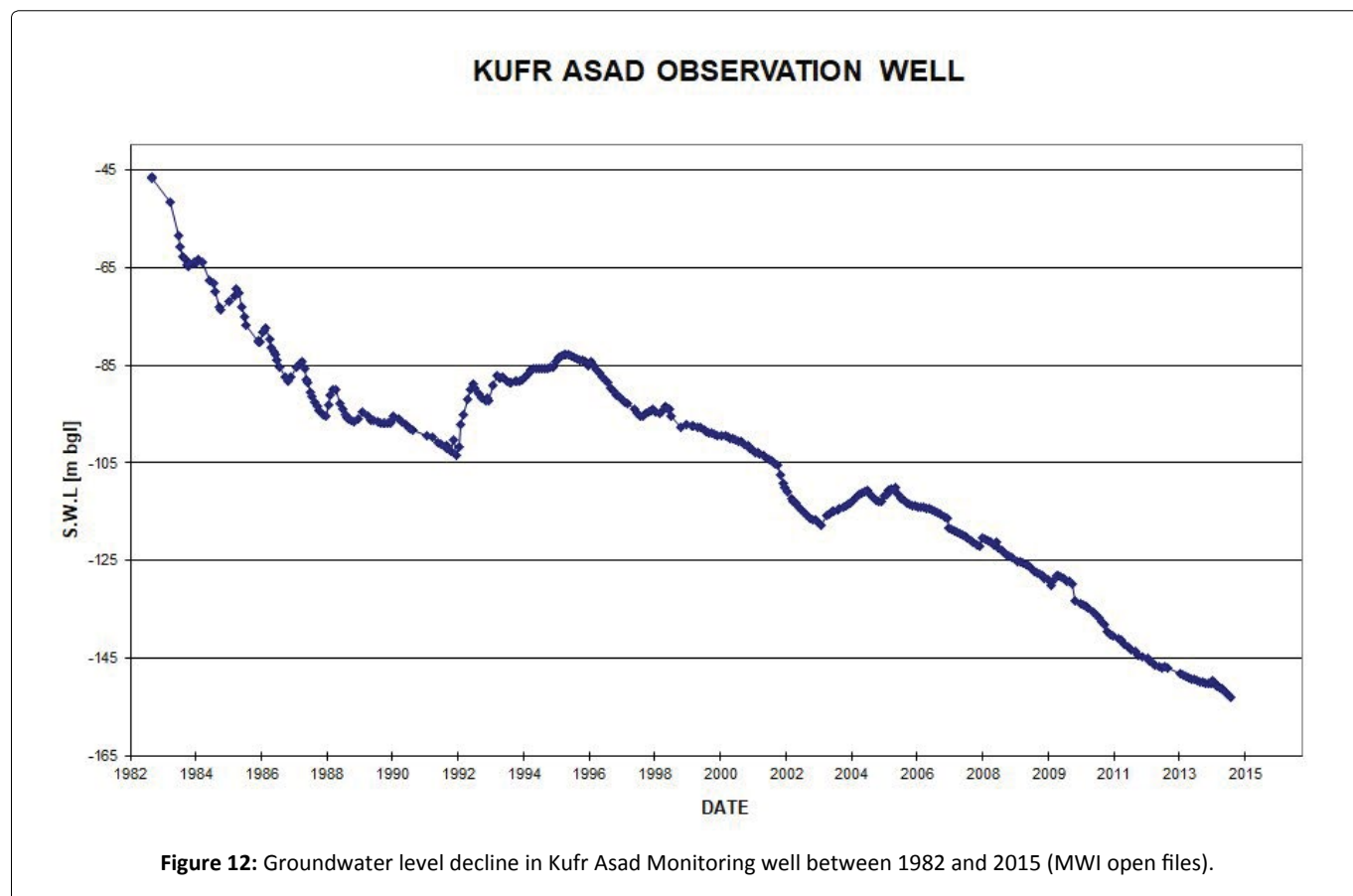
Remediation measures

Undertaken: The country has rationalized its household water uses to a very high degree, implemented rationing and improving water use efficiency in the irrigation sector, recycled industrial wastewater, built appropriate water harvesting systems of dams, weirs, ditches, and pools. But all that has not and cannot solve the water shortage problem of the country.

Needed: The traditional method of augmenting water supply through the development of surface and groundwater resources was depleted long ago, as there are no substantial amounts of such resources left for further development. Rationing has already been implemented to the maximum extent possible. Therefore, radical changes towards a balanced resources/demand equation have become inevitable for a continual yield of water resources to also guarantee the functioning future generations' water supply systems. And that is, in the case of Jordan, the only possible as secure solution by desalinating sea water at Aqaba, the only seashore area of Jordan, on Jordanian territory, under Jordanian authority, and in Jordanian hands. At present, Jordan is firmly planning to desalinate seawater at Aqaba and the hope is to start the project within a few months, in early 2024.

Soil and Landscape degradation

Man-made soil and landscape degradation in Jordan results mainly from mining and construction industries, which are activities causing changes in the landscape and in the soil and rock stabilities. Open cast mining and quarrying of phosphate, building stones, gypsum, clays and the construction of roads, buildings, bridges, etc. are the main man-made factors leading to soil and landscape degradation. The by-products of all these industries are disposed around their mining sites and lay bare against rain, wind, and sun and hence are exposed to erosion, transportation by winds to other areas and flood water to become deposited along



wadis or in dam lakes. The effects are stronger erosion, of rocks and soils than under natural conditions, larger sediment loads of flowing water, and faster siltation of dams and water harvesting facilities (Table 4). In addition, they result in increased chemical weathering of the byproducts due to larger rock and soil grain areas' exposure to weathering and their dissolution in rain and flood water, hence increasing salinities in the water of dams and along wadi courses. Knowing that some of the dissolved soils and rocks contain dangerous substances, which become transported with the water such substances are: Uranium, selenium, phosphates and other trace elements in the phosphate and oil shale mining byproducts. Construction of road networks and borrowing areas of construction materials are, in addition to the above, not rehabilitated and that adds to the erosion and transportation problems and lead to rock toppling and undercutting, also damaging the landscape.

Remediation measures

Undertaken: Although regulations of quarrying and mining processes state that excavations created by these activities should be rehabilitated to avoid their environmental impacts and landscape degradation, very few mining and quarrying enterprises adhere to the regulations. And the land is left without rehabilitation. Fines, in some cases, are collected from the violating enterprises, but the collected money is not spent on rehabilitating the quarrying, mining or borrowing sites.

Needed: Certain regions of the Jordanian landscape,

including the Badia and desert areas, have undergone significant disruption due to mining, quarrying, rock excavation, and the construction of road networks and buildings. These areas require substantial rehabilitation efforts. The necessary regulations obliging the industrial activities leading to soil disturbance exist in Jordan and should be strictly applied to all such activities. The collected fines for not abiding to the regulations should be spent on rehabilitating the disturbed sites.

In addition, planting of trees and desert plants, regulation of grazing activities, and terracing of slopes will help in alleviating soil erosion, and in the conservation of soil moisture. The benefits of that are giving back to the soil its life-giving functions and fitness for human habitat.

Discussion and Conclusion

The present situation

Jordan, like other countries worldwide is living a stage of a combination of natural and man-made environmental deterioration, which is expressed in the following manifestations:

1. Accelerated land and soil erosion, transportation and deposition leading to landscape deterioration and loss of agricultural soil.
2. Climatic changes reflected in increasing temperatures, decreasing precipitation and increasing rainfall intensity and hence occurrence of vehement floods.

Table 4: Main information on the major dams in Jordan (JVA open files).

Dam name & Year of construction	Designed Storage MCM	Real Storage m ³	Dead storage m ³	Sediments m ³	% of sediments	Annual sed. Rate	Catchment km ²	Lake Area km ²	PPT mm/year
Al-Wehdah, 2006	110	106,362,891	3,637,109	NA	NA	NA	5590	3.75	350
Wadi Al-Arab; 1986	16.8	16,789,000	3,200,000	2,900,000	17.2%	0.44	262	0.8	350
Ziglab 1967	3.9	3,964,300	NA	335,700	8.6%	0.15	106	0.3	150
Kufranjah, 2016	7.8	7,800,000	420,305	NA	NA	NA	99	NA	NA
King Talal, 1977	75	67,003,900	NA	18,000,000	24%	0.52	3700	4.8	250
Al-Karamah, 1997	55	55,000,000	55,000	2,000,000	3.6%	0.0005	62	5	150
Wadi Shueib, 1969	1.7	1,254,959	423,294	900,000	52.9%	0.98	178	0.3	300
Al-Kafrain, 1967	8.5	8,452,287	45,063	1,900,000	22.4%	0.4	163	0.8	300
Zarqa' Ma'in, 2017	2	2,000,000	0	NA	NA	NA	182	0.14	200
Al-Wala, 2002	25.3	25,105,134	422,844	4,600,000	18.2%	0.87	1770	0.86	200
Al-Mujib, 2003	29.8	24,718,788	3,774,160	6,500,000	21.8%	1.09	4380	1.6	200
Al-Tannur, 2001	14.7	14,308,400	500,000	2,500,000	17%	0.77	2160	0.84	250
Al-Lajjon, 2015	1	1,000,000	67,494	NA	NA	NA	46	0.13	215
Al-Karak, 2017	2	2,000,000	93,964	139,982	7%	1.17	170	0.194	NA

3. Tectonic activities expressed in earthquakes and volcanic eruptions with their damaging effects.
4. Water pollution and its effects on the environment, the surface and groundwater resources, and the biodiversity.
5. Urbanization, industrialization and agricultural activities with increasing use of all types of pharmaceuticals, fertilizers and industrial chemicals, with all their solid and liquid wastes discharged treated or untreated into the environment.
6. Water resources overexploitation, degradation, and exhaustion.
7. Declining biodiversity as a result of water quality degradation and water resources development, which left no water for faunal and floral organisms to survive.

The impacts of the above man-made and natural deteriorations are not restricted to their immediate manifestations, but they have cascading effects on each other and on human health, air quality, natural resources continuation, and next generations shares in them, land productivity and on many others natural set-up elements. But these cascading effects will not be discussed in this article because they are a very big undertaking that deserves a special investigation for each case on its own.

Remediation measures

Undertaken programs: Jordan has adapted a number of policies and implemented many programs to minimize the impacts of man-made and natural deteriorations of its environment challenges such as:

1. Flood control expressed in the construction of dams, weirs and water harvesting facilities in the upper reaches of catchment areas.
2. Recording and observation of earth movements through earthquake observation stations distributed all over the country, which are not merely used as earthquake observation stations but are also useful in registering any other earth movement, which may be caused by underground volcanic activity, tectonic rock movements, or major natural or man-made explosions.
3. In what concerns water pollution, Jordan has constructed many tens of major centralized wastewater treatment plants to serve cities, towns, or several villages, that is in addition to decentralized wastewater treatment plants serving universities, hospitals military camps, single villages or small settlements, industrial wastewater treatment plants, and irrigation return flow drainage systems. In addition, the treated wastewater has been allocated for used in irrigation after mixing with flood or base flow water or recycled within the same industry. The adapted policy for waste water treatment and reuse has been a major factor in protecting human and environmental health, securing an additional non-conventional water source for industrial and irrigational uses and increasing agricultural production.
4. Municipalities and village administrations in Jordan collect all types of solid wastes un-separated and are buried in solid waste disposal sites. The collection process functions in an adequate way, but the burial and burial sites do not fulfill present day appropriate

policies of zero waste. Solid waste disposal sites, especially those constructed without appropriate environmental impact studies represent health and environmental time bombs.

5. The natural water scarcity in Jordan has been challenged by: Constructing dams, weirs and other water harvesting facilities, water rationing for household uses, recycling of industrial water, wastewater treatment and reuse, reducing physical and administrative losses of water supply systems, desalination of brackish water, introduction of irrigation water saving technologies, and new seeds and new types of crops, which use less water than conventional crops. All that helped the country to use its water in an efficient and safe way. But, the exploitation was extended to the non-renewable and fossil groundwater resources of the country, which has been causing not only the exhaustion of these resources and the deterioration of their qualities, but in the loss of the present and future generation of their strategic water reserves. Nonetheless, the water supply situation of the country is becoming more critical with the passage of time.

Needed programs

While numerous policies, programs, and projects have been enacted in Jordan to mitigate the effects of both natural and man-made environmental degradation, a more extensive set of initiatives is still necessary to achieve a balanced equilibrium between degradation and rehabilitation.

The mitigation measures to alleviate the impacts of natural and man-made degradations can still be undertaken, such as minimizing erosion and transportation of eroded materials, avoiding construction in the vicinity of tectonically active structures and adequately studying these structures and their movements to predict their future behavior. Old buildings and buildings constructed in discordance with the valid earthquake-resistant building codes must be revisited and analyzed on their resistance to earthquakes and flooding and to carry out any necessary measures to increase their resistance. There is also a deemed necessity to control the abundance of the valid building codes during the construction of new buildings. In addition, measures can be undertaken to alleviate the impacts of eventual volcanic eruptions such as avoiding major construction projects in the vicinity of potential volcanic eruption sites, observation of activities related to potential eruption, and intensified studies on volcanoes and their re-eruption probability. Examples of mitigation measures can be taken from those of Vesuvius and Etna volcanoes.

Measures against climate changes by intensive use of advanced technology such as sophisticated water harvesting programs to collect the floodwater of natural and urbanized areas and to divert it to be stored in surface water storage facilities such as weirs, pools, cisterns or to recharge it into aquifers. Improved agricultural engineering management of rainwater stored in the soil (Green water), protected farming (Greenhouse), drip and sub-soil irrigation, and improved

seeds among others can be very effective in challenging climate changes.

Decreasing groundwater recharge and increasing flood water and sediment load quantities due to urbanization require adequate regulations and their implementation policies and programs. Mining and quarrying excavating and piling up of mining by-products must undergo the regulations and the condition of quarrying and mining licenses, according to which the cities of their activities should be rehabilitated gradually before moving to other sites.

Some existing wastewater treatment plants need expansion and rehabilitation because they have become overloaded qualitatively or quantitatively. There is an urgent need for the establishment of new wastewater treatment facilities in certain villages and towns to safeguard public health, preserve the environment, and protect surface and groundwater sources in their vicinity. Given the relatively small size of some of these villages, where wastewater contamination poses a threat to vital water sources, the implementation of decentralized wastewater treatment and reuse schemes can effectively address these concerns and fulfill the intended purpose.

Industrial chemicals reaching domestic wastewater treatment plants need new thinking, regulations, management, and treatment such chemicals are upcoming pollutants of pharmaceutical residues used in households, industry, agriculture, and in medical centers. In this concern, regulations and handling of pharmaceuticals are very effective ways of reducing the quantity that reaches the water resources (e.g.: Returning unused pharmaceuticals to pharmacies to be dealt with in an engineered way, or separation of hospital wastewater from that of household wastewater to be treated on its own). In that concern, worldwide experience can be consulted. In addition, innovation of other techniques and measures, more suitable to the climatic and water conditions in Jordan, can still be developed.

The conventional way of increasing the supply of water by developing surface and groundwater resources has been exhausted, because there are no appreciable amounts of such resources to be developed and water use rationing has been stretched to its utmost limits. Therefore, radical changes towards a balanced resources/demand equation have become inevitable for a continual yield of water resources to also guarantee functioning future generations' water supply systems. That is, in the case of Jordan has become only possible through desalinating sea water at Aqaba, the only sea shore area of Jordan, on Jordanian territory, under Jordanian authority, and in Jordanian hands. At present, Jordan is firmly planning to desalinate seawater at Aqaba and the hope is to start the project within a few months, in early in 2024.

Parts of the landscape in Jordan, even in the Badia and desert areas have been strongly disturbed by mining, quarrying, rock borrowing areas, and construction of road nets and buildings and they need to be rehabilitated. The necessary regulations obliging the industrial activities leading to the disturbance exist in Jordan and should be strictly applied to all such activities. The collected fines for not

abiding with the regulations should be spent on rehabilitation the disturbed sites.

In addition, planting of trees and desert plants can help in alleviating soil erosion, and conservation of soil moisture. Terracing of slopes will also be a very effective soil erosion and water harvesting technique.

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