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Reservoirs for Water Supply Under Climate Change Impact—A Review

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Abstract
Arid region water reservoirs have different characteristics and solutions from humid regions with the most water shortage in the world socio-economically. This paper outlines possible implementation methodologies, procedures and guidance for water storage in natural and artificial reservoirs for better operation and management rules taking into account the impacts of climate change. The literature is full of methodological applications regarding the impact of climate change on the hydro-meteorological records, but the same is not available in reservoirs (surface and underground), which is the scope of this paper. In addition, reservoir structures offer the necessary mitigation and adaptation activities against the effects of climate change to design, construct, maintain, operate or increase their existing capacity. To increase groundwater reservoir capacity in local aquifers, precipitation, associated flooding and flash flooding should be diverted to artificial groundwater recharges through precipitation and surface runoff harvesting activities. Definitions of fully or partially penetrating underground dams are also explained. The real groundwater feeding application is offered from the Kingdom of Saudi Arabia as arid region representative. Finally, a series of recommendations are presented for the future design and management of reservoirs.

Keywords Climate · Groundwater · Harvesting · Impact · Reservoir · Sedimentation

1 Introduction

The arid and semi-arid region drainage basins (catchments) called "wadi" imply that there is not enough vegetation, but the surface is covered with either rock outcrops or alluvial deposits, especially by Quaternary deposits. Humid areas adjacent to arid and semi-arid regions are subject to desertification, and such occurrences must be addressed with special treatment by vegetation, afforestation and reforestation studies

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and practices. Future wastewater reuse and desalination are likely possibilities to support water supply in semi-arid and arid regions (Ragab and Prudhomme 2002; Abufayed et al. 2002).

The literature is full of global warming and change impact on the environment, ecosystem and different components of the hydrological cycle (Boé et al. 2009; Kundzewicz and Döll 2009; Sohoulande Djebou and Singh 2016; Mohorji et al. 2017). Many semi-arid and arid regions such as the eastern Mediterranean basin, western USA, southern Africa, northeastern Brazil and Arabian Peninsula are exposed to the effects of climate change and these regions are destined to experience scarcity in water resources. Climate models show that such regions are hotspots for the impact and variability of climate change in the twenty-first century (Salinger 2005; Bates et al. 2008; Fearnside 2012; Lionello and Scarascia 2018; Abatzoglou and Parker 2018; Maure´ et al. 2020; Norouzi 2020). In arid and semi-arid regions, climate impact studies related to engineering water structure design, maintenance, operation and management are extremely rare in addition to inadequate mitigation and adaptation activities related to water reservoirs (Şen 2020; Ahmad and Butt 2019; Yifru et al. 2021). Uncertain climate change and its impacts lead to additional reservoir constructions, large dykes, levees, etc. should not depend on future scenarios, but with societal ability improvements to deal with current problems (Kundzewicz et al. 2018). DeNicola et al. (2015) gave examples of mitigation and adaptation measures that can help reduce the burden on traditional water resources (surface and subsurface reservoirs), including desalination, wastewater recycling and reuse, and food outsourcing or "virtual water trade". It is recommended to pay attention to the climate change impact of engineered water structures by considering the future projections based on climate scenarios together with the outputs of the General Circulation Model (GSM). Recently, Grill et al. (2019) detailed the reservoir's significant impact on global water scarcity and stress issues.

The main reservoirs in arid and semi-arid regions are for groundwater recharge, local water supply, crop growth, flood control and artificial recharge alternatives via injection wells (Sharda et al. 2006; De Laat and Nonner 2012; Abdalla and Al-Rawahi 2013; Şen et al. 2013). In these regions, floods are often flush and thus the correct identification of water level record or peak discharge with maximum level is aggravated by siltation (Farquhason et al. 1992). River morphology and riparian vegetation adapt to constantly changing discharge conditions; this makes it difficult to distinguish long-term development driven by natural discharge variation from the impacts of flow variation due to climate change and variability (Oorschot et al. 2018).

Reservoirs are of small scale with significant surface water coverage (Kummu and Varis 2007; Haberts et al. 2014, 2018). Their impacts on the global and local hydrological cycle cannot be ignored (Ogilvie et al. 2019). Reservoirs are built for single or multipurpose services. Evaporation is one of the main factors of water loss, and therefore, surface water bodies in surface reservoirs must be diverted to groundwater reservoirs at any speed. A new model presented by Meziani et al. (2020) estimates evaporation losses from five dam reservoirs in the arid and semi-arid regions of Algeria based on air temperature, atmospheric pressure and wind speed at 2 m above ground.

Due to the recent effects of climate change, flash flood effects have increased in many areas all over the world (Youssef et al. 2009). The biggest problem is the lack of data in distinguishing the effects on hydrological and environmental conditions before or after dam reservoir construction (Vázquez-Tarrío et al. 2019; Yang et al. 2014). Frequently, the historical meteorological, climatological and hydrological records are extended by some stochastic process on the basis of the assumption of stationary, implying that the future is a statistical reflection of the past. Such an assumption does not take into account the impacts of climate change on variables, and therefore, future operation and management of such reservoirs provide incomplete estimates as stationarity dies (Milly et al. 2008).

In many regions, water resources planning, design, operation and maintenance can be developed against the effects of climate impact with dam reservoir construction, groundwater feeding facilities, precipitation and runoff collection possibilities. Adham et al. (2011) considered the effect of climatic change on groundwater quality around subsurface dam areas by using numerical simulation for sustainable groundwater development from subsurface dams constructed in the south islands of Japan where limestone is the underground geology. Shuai et al. (2020) studied the implications for biogeochemical processes and contamination plume migration in the river corridor on the basis of hydro-geomorphic factors. Natural flow regimes and connectivity of basins and sub-basins are altered by dam reservoirs (Grill et al. 2019). The climate change and global warming cause to serious water shortage worldwide, especially in arid and semi-arid regions. Selection of the optimum location is the most important issue, which requires a set of positive and negative criteria (Dortaj et al. 2020). Lu et al. (2021) studied the interaction between groundwater and surface water in cases of river floods and noticed that the lateral inflow is the recharge of groundwater to surface water as partial exchange between surface and groundwater. Recently, Bulti (2021) indicated that the hydrological properties of a river basin are extremely affected by the construction of a dam.

The main purpose of this review paper is to reveal the deficiencies in arid and semi-arid region reservoir water potentials under the impacts of climate change and variability. It outlines methodologies for water potential enhancement possibilities through various methodologies and techniques. Climate change impact role is indicated in all aspects regarding arid and semi-arid region reservoirs. A field application of the runoff discharge project is described from the Kingdom of Saudi Arabia. Finally, a list of recommendations is presented for better hydro-meteorological study improvements for water resources in these regions. The novelty of this study is in the presentation of overall reservoir water storages under climate change impacts as concise review from the literature, and the explanation of partially submersible subsurface dams and their roles in groundwater recharge are explained in detail in the following sections.

2 Climate Change Impact in Arid and Semi-Arid Regions

The natural environment cannot cope with self-purification processes to digest greenhouse gas (GHG) emissions, which appears to be a global problem due to three different geographical factors. First, the wealth of human existence determines the distribution of housing, industry, trade centers and motor vehicle transportation among these centers. The second factor is the natural phenomenon in the atmosphere and hydrosphere that controls local and temporal changes in climate, weather and quality, since emissions to these spheres are either diffused in various forms or carried by the wind. The intersection between emissions and spheres can be modified by local relief factors (geomorphology).

As a result of global warming and associated climate change impacts, both temperature and precipitation changes should be considered for hydrological impacts through General Circulation Models (GCMs) for at least the next 30 to 50 years. On this line, Bao et al. (2019), Scheepers et al. (2018) and Bussi et al. (2018) stipulated an increase in precipitation and runoff in many dry land drainage areas. On the other hand, some authors have stated that annual runoff will decrease in some regions (Nerantzaki et al.

2020; Shrestha et al. 2018). Therefore, it is well known that climate forecasts are quite uncertain and there is still some confusion in the literature.

Studying rainstorm characteristics and developing time distribution models (cumulative precipitation hyetographs) for these regions using procedures similar to those by Huff (1967, 1986) and (Hogg 1980) is the first contribution of such research projects. Figure 1 shows the locations of arid and semi-arid regions less than 250 mm and up to 250 mm-500 mm, respectively.

According to Cambridge Dictionary, the troposphere is the lower atmosphere (troposphere) so it experiences a positive lapse rate (negative temperature change with altitude). All meteorological and climatological activities take place in this sphere. It has a special composition of oxygen, nitrate, carbon dioxide (CO_2), water vapor and ideal gases. A schematic representation of the troposphere Hadley cells is shown in Fig. 2 near the equator in the Northern Hemisphere. Deserts are atmospheric subsidence belts over which dry air movements take place. In the troposphere, global climate change impact occurs as the impact of climate change, and thus water-related events change temporally and spatially.

The most important cycle around the equator is the Hadley cell in the tropics, and climate change affects the size of this cell as a result of expansion due to the annual average temperature increase. The average thickness of the troposphere is about 10 km at 15°C at mean global temperature. According to the Paris Agreement, it is planned that the preferred average temperature increase should not exceed 1.5°C or be at a maximum of 2°C. These temperature increases represent the world average temperature stabilization at 16.5°C and a maximum of 18°C. It is well known that gases expand as the temperature increases, and so with approximate reasoning, it is possible to make a very simple calculation. If the troposphere thickness is 10 km at 15°C, the expansion in the troposphere thickness at 16.5°C and 18°C is approximately 1 km and 2 km, respectively. On the other hand, the lateral expansion of the Hadley cell can be calculated, provided that the earth is considered as a sphere, whose equatorial circumference is equal to 40,000 km. Therefore, the length from the equator to longitude 30° is about 3,330 km. A similar proportionality calculation results in lateral expansions of approximately 330 km and 666 km at 1.5 °C and 2 °C temperature increases, respectively. Lateral expansion is expected to approach 33° latitude at its maximum.

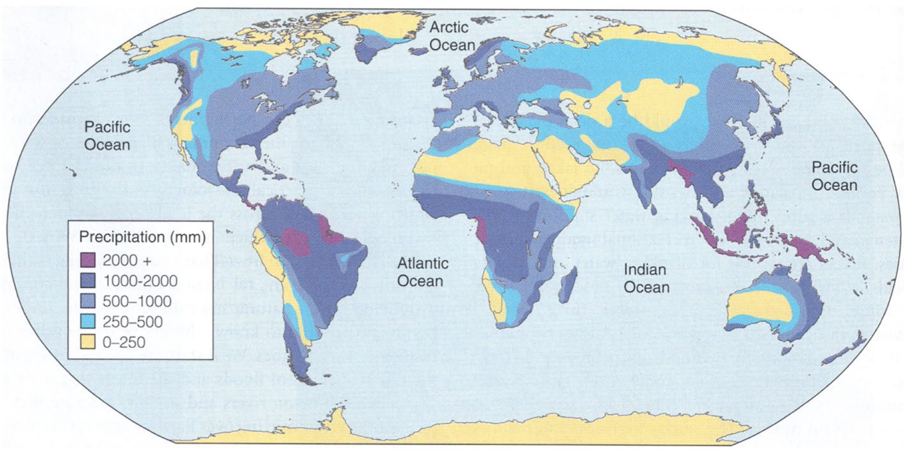

Fig. 1 Global distribution of precipitation (After Pipkin et al. 2014)

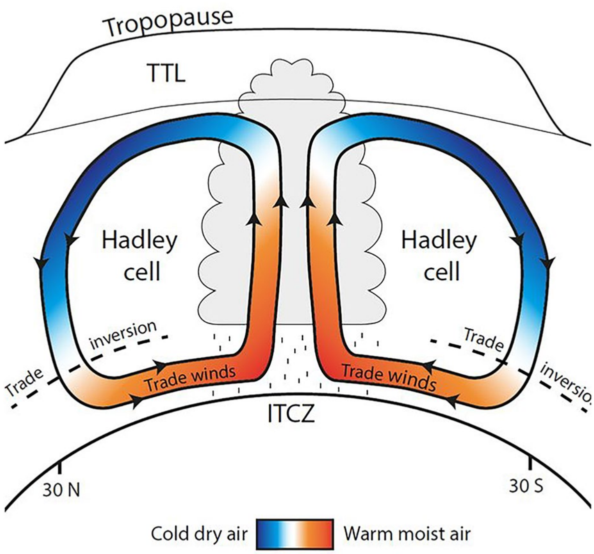

Fig. 2 The Hadley cell within the troposphere around the equator

Especially for arid and semi-arid regions, IPCC (2007, 2013) reports mention necessary adaptation and mitigation recommendations regarding scarce and extremely valuable water resources. The same reports indicate that some arid regions, such as the southern parts of the Arabian Peninsula, will receive more precipitation, and therefore, water harvesting (rainfall and runoff) procedures are important for surface and preferred subsurface artificial groundwater recharge alternatives. In addition, it is recommended to pay attention to the climate change impact of engineered water structures by considering future GCM model projections (Şen et al. 2013; Almazroui et al. 2019). In many dry land locations, increases in precipitation intensity and frequency will support groundwater recharge through water harvesting structures. Especially, in arid and semi-arid regions the increase in precipitation events and the resulting flash floods should be directed to artificial groundwater recharge potential areas in order to increase groundwater reservoirs.

Hydro-meteorological and hydro-engineering structures should allow for possible climate change impacts, but little professional guidance on these issues is available in many regions. Reliable and sustainable studies are needed to assess the relative costs and benefits of demand management and non-structural management operations such as water use efficiency or prohibition of new floodplain development in the context of changing climate impacts. Relying solely on traditional dam reservoir management interventions is a mistake for the following reasons:

1. In some regions, climate change impacts are likely to produce occasional hydrological conditions and extremes of different magnitudes than existing reservoir systems can manage.
2. Climate change impacts may produce similar types of variability, but outside the range in which the existing reservoir and infrastructure is designed and built to cope.
3. Relying solely on conventional methods and techniques assumes that sufficient time and information will be available before the onsets of major or irreversible climate impacts to allow reservoir managers to respond approximately,

4. These approaches assume that no special effort or plan is required to guard against surprises and uncertainties.

The potential regional climate change impacts can lead to increases in frequency and magnitude of drought and flood events, and long-term changes in average renewable water resources through changes in temperature, precipitation, humidity, wind intensity, vegetation, soil moisture and runoff (Solomon et al. 2007).

In general, the importance of seepage and flooding for groundwater recharge in many regions is not evaluated in view of the climate change impacts. Many IPCC reports consider wetland drainage basin areas, but the concept of dry land wadi and freshwater resources are not adequately covered (Kundzewicz et al. 2018). The following points have not been well studied in terms of climate change impact studies for any region.

1. Climate change scenario productions should be carried out temporally and spatially.
2. Keeping the water balance in the optimum solution position by including the variability as well as the climate change impacts.
3. Extreme events (flood and drought) should be given primary importance in order to reduce damage to human life and property.
4. The combined effects of land use, land change, climate trends and variability should be adapted for better water resources reservoir managements.
5. Intensities, frequencies, return periods of extreme events should be followed in the light of local standard principles, scientific and technological methodologies.
6. In the assessment of surface and groundwater reservoirs, precipitation and runoff harvesting should be taken into account where appropriate, based on climate change and surface characteristics, demographic and geological aspects, and variability effects.

2.1 Climate Change Impact on Groundwater Resources

The climate change impacts on stream flow and groundwater recharge vary regionally depending on climate scenarios, largely following changes in precipitation forecasts. Studies on how groundwater will respond to climate change have recently begun with human activities (Green et al. 2011; Taylor et al. 2013). Even small changes in precipitation can lead to big variations in groundwater recharge in many regions (Sandstrom 1995; Woldeamlak et al. 2007). Not only fluvial flow changes, but also summer and spring flow shifts towards winter cause increased competition for water reservoir storage (Payne et al. 2004) and may lead to summer water shortages especially in arid and semi-arid regions (Tague et al. 2008).

In general, vadose zone humidity responds rather slowly to continental climate changes (Glassley et al. 2003; Phillips 1994). Climate change is among the most important effects on water resources as a result of precipitation variability (Kundzewicz et al. 2007; Ouysse et al. 2010). They are particularly vulnerable to climate change, where groundwater reservoir storage potential is quite low. Also, where present groundwater resources are available, settlements become more vulnerable to climate change, especially, if groundwater supply is not in balance with abstraction (van der Gun 2010). Groundwater reservoirs support water demand levels over long periods of time, provided that critical climate variables are predicted with reliable methodologies over long periods and managed safely (Gurdak et al. 2008; Herrera-Pantoja and Hiscock 2008; Jyrkam and Sykes 2007).

It should be noted that water resources in arid and semi-arid regions are more vulnerable to climate change and variability (Aguilera and Murillo 2009; Barthel et al. 2009; Novicky et al. 2010). For example, drought durations and intensities may be more permanent in these regions (Giertz et al. 2006). Existing surface water reservoir dams can play an important role in balancing water demand (Sharda et al. 2006). The precipitation pattern changes spatially and temporally, which generates groundwater quality variability and even salinization problems (Gurdak et al. 2007, 2008).

Groundwater reservoirs are the main source of freshwater, but unfortunately, there is still little interest or study on the possible effects of climate change on these freshwater resources. Aquifers especially in arid and semi-arid regions are filled by flooding from permeable recharge surface areas through the main flow channels of Quaternary alluvial deposits, which are also porous media, solution spaces in fissured and fissured rocks, dolomite or limestone geological setups. Groundwater recharge areas should be cleaned from fine silt build-up or cleaned periodically after each flood event. Also, flood plains are among the most important groundwater recharge locations, and therefore, their areal extends should be limited by considering future projections and climate change impacts.

Combined with climate change and the associated hydrological cycle, groundwater recharge is also interactively coupled with the following events:

1. As a result of climate change, changes are also expected in precipitation, evapotranspiration and runoff recharge. It is possible that increased precipitation intensity will lead to more runoff and less groundwater recharge.
2. Sea level rise can lead to increased saltwater intrusion into coastal and island aquifers, depending on the relative positions of sea and groundwater table levels.
3. Change in precipitation refers to changes in CO_2 concentrations that can affect the dissolution of carbonate rocks and thus the formation and development of karst groundwater aquifers.
4. Changes in natural vegetation and crops can affect nutrition as reflections of climate change impacts.
5. Increased flood events contribute to unconfined aquifers in many regions and thus affect groundwater quality especially in Quaternary alluvial aquifers in arid and semi-arid zones.
6. Changes in soil organic carbon can affect infiltration properties on aquifers and consequently slow groundwater recharge.

These mentioned factors indicate that groundwater-focused organizations must deal with global climate change issues in order to protect groundwater resources from the climate change impacts.

Potential sites for conventional reservoirs in ephemeral streams are often small and often have high construction costs per unit storage volume, if developed. The effects of reservoirs in arid regions are more effective on hydrological cycle functions than humid regions (Deng et al. 2016).

Narr et al. (2019) noted that reservoirs hold little water, but reduce flood hazards in many drainage basins. Especially, earthen dams and Quaternary alluvial surface geology layers cause high seepage, which contributes to groundwater reservoirs as a recharge (Jin et al. 2018). The accumulation of permeable water in the substratum protects the permeable geological formation against evaporation losses.

3 Sub-Surface Dams

The impact of climate change on engineering structures (dams, reservoirs, embankments, canals, culverts, etc.) has been explained in more detail by sedimentation effects on engineering structures (RAE 2011; Almazroui et al. 2019).

According to IPCC (2007, 2013) reports, there are differences in the effects of climate change in arid, semi-arid and humid regions. Single reservoirs in arid regions are very sensitive to climatic and hydro-meteorological extreme events, because adaptive flexibility may not have been considered in their design. Short-term hydro-meteorological changes have increasing trends in the frequency and intensity of droughts and floods. Accordingly, surface and subsurface reservoirs should be planned and designed in appropriate types, shapes and sizes against the climate change impacts.

Especially in arid and semi-arid regions, any reservoir operation and management, water availability, variability and reliability are important keys. As new reservoirs tend to be larger than old ones, both positive and negative impacts become evident and conflicts arise, because the climate change impact is not considered in most such reservoirs. While extra reservoir storage facilities can increase confidence, they can also generate additional problems depending on system management. The concept of reservoir sustainability should focus on construction, management and rehabilitation under possible climate change impacts depending on location (George et al. 2016).

Floods that occur from time to time, especially sudden floods, threaten dam safety and cause an increase in reservoir sedimentation. The safety of existing dams needs to be reassessed in light of current conditions and possible future climate change impact scenario projections. Feasibility and impact studies on future dam reservoirs should allow for hydrological uncertainties in a warming world.

Small reservoir dams are common in arid regions and have the advantages of operational efficiency, flexibility, proximity to the point of use and require relatively few experts for management. Large surface reservoir dams have the advantage of greater efficiency over available water inflow than small reservoirs, and their efficiency is generally more reliable. Small scale dams are usually less than 15 m high, but reservoir dams greater than this height are in the large scale category. In arid regions, large-scale dams are few, whereas small-scale ones predominate, because domestic and irrigation needs are entirely dependent on these reservoirs.

Ishida et al. (2011) presented reviews of basic information about sub-surface (underground) dams, their construction around the world, and the problems associated with the sustainable use of groundwater. Foster and Tuinhof (2004) provided more detailed information on subsurface dams to increase groundwater storage in basement land. In desertification areas, subsurface dam construction possibilities are presented by Fujiwara and Fujita (2006). The importance of reservoirs on global hydrological systems is presented by Grill et al. (2019) and they also mentioned that underground reservoirs hold more than 70% of the runoff worldwide.

Runoff harvesting is an effective way to collect and then use water through fairly simple hydraulic structures such as small dams, ditches, pits, roof collections and terraces. On the other hand, the effects of climate change on socio-economic developments are very important especially concerning the water resources aspects in the twenty-first century (Abu-Zeid and Shiklomonov 2003).

While various methodologies have been proposed to meet water demand other than the well-known rainfall harvest, in recent years surface water (runoff) harvesting applications for groundwater recharge augmentation have begun to emerge through small-scale surface dams with groundwater flow beneath and injection well systems behind the surface dam itself. On the other hand, there are sub-surface dam alternatives as shown in Fig. 3.

As can be seen from this figure, there are two types of groundwater recharge dams: full burial (Fig. 3a) and partial penetration (Fig. 3b). The choice of each type depends on the geological, hydrogeological explorations and geophysical prospection studies. Groundwater withdrawal from sub-surface reservoirs can be balanced by groundwater replenishment during rainy periods in arid and semi-arid regions (Alley 2001).

4 Advantages and Disadvantages of Reservoirs

For over thousands of years, reservoirs have allowed people to collect water when it is plentiful and store it for dry periods, and these structures have become part of the social environment. Dams are essential social infrastructures to prevent flood hazards and increase

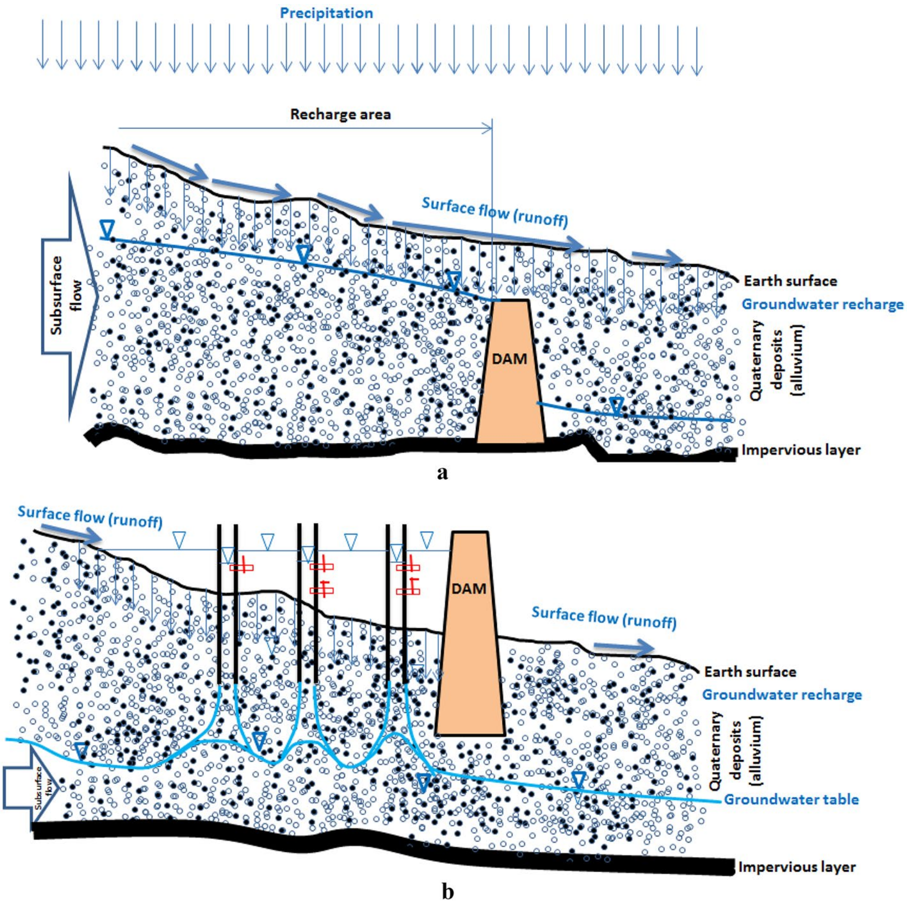

Fig. 3 Subsurface dams **a**) complete, **b**) partial

resilience to catastrophic droughts. In arid regions, they adjust to seasonal variations and irregularities in precipitation and runoff, and therefore seek to provide water resources in an almost balanced temporal order whenever possible.

Reservoir structures have a number of advantages, in addition to agriculture, food and environmental activities, to provide the water necessary for the continuation of human life in different regions, especially with water scarcity and stress reduction studies. Other benefits of sub-surface dams are that they are not exposed to siltation and precipitation problems, they do not have significant evaporation losses, and they can be easily refilled by direct or indirect (flow) seepages (Şen 2008). Underground (sub-surface) dams have the advantages of storing water without sinking, preventing evaporation, providing clean and safe water, greater stability and safety than surface dams, not requiring extensive maintenance, and no downstream danger even after the sub-surface dam breaks, water renewability after every rainfall event, there is no danger of deterioration due to natural (like earthquake) or man-made disasters.

The benefits of reservoirs include water supply, hydropower generation, flood control, irrigation, navigation, recreation, etc. requires dealing not only with their benefits, but also with undesirable effects. In the early stages, impacts on the safety of the dam and downstream were considered (Adamo et al. 2020), but recently environmental impacts have also weighed in on the planning, design, construction and operation and maintenance phases in addition to the climate change and variability impacts.

Social, environmental and political issues related to reservoirs have been specified by the World Commission on Dams as a New Decision-Making Framework, including the selection and design of dams and reservoirs (Doğan 2002). In decision-making, the same Commission proposed equity, efficiency, sustainability and accountability in dam selection or rejection, dam processes and reservoir options to address water supply–demand, water power, flood control and other issues.

As for the disadvantages of dam reservoirs, overgrowth of plants for various reasons is called eutrophication (Nazari-Sharabian et al. 2018), which is stimulated principally by the excess plant nutrients, namely, carbon dioxide, nitrogen and phosphorus. Discharges of such nutrients originate from municipal and industrial sources in addition to agricultural and urban runoff. Eutrophication depends on reservoir morphology, solar radiation penetration, water temperature, dissolved oxygen (DO) concentration, and water movements as a result of transport and dispersion (Nazari-Sharabian et al. 2018). On the other hand, climate change directly or indirectly affects eutrophication as a result of the relationship of meteorological factors with available nutrients (Whitehead et al. 2009). Furthermore, disadvantages include limited water reservoirs due to difficulty in site selection, subsurface geological, geophysical and hydrogeological exploration, and restrictive pore volume of 30 to 35% maximum of the entire reservoir Costanza-Robinson et al. 2011. Also, disadvantages include cutting and depletion of downstream groundwater and salinization of groundwater due to successive recharge washes.

5 Application

The application of this methodology is carried out in the Al-Ghat Dam, which is an earthen dam with a height of 11 m, a length of 250 m and a reservoir storage capacity of 1.0×10^2 m^3, in the drainage basin within the Kingdom of Saudi Arabia, 220 km north of Riyadh

City. The drainage area is approximately 43 km^2 and the main channel length is 82 km; behind the small earth dam are vertical standpipe feeders as injection wells, as in Fig. 4, where their bottom ends are in permeable Quaternary alluvial deposits in wadi subsurface high permeability natural channels.

In case of flooding, surface water storage takes place in the reservoir of the small dam. To prevent evaporation, water has to be artificially replenished to the lower surface via injection pipes, shown in Fig. 5 at various stages behind the dam water levels.

Figure 5a shows three fountain injection pipes at different levels while in Fig. 5b the same pipe is under full surface water impoundment after precipitation and upstream runoff. On the right, after the injection of relatively clean (not affected by sedimentation) surface water, it is diverted from the upper fountain to the lower surface, while the water level drops below this fountain. Thus, the second fountain from the top starts injecting into the subsurface dam reservoir.

6 Recommendations

There are many gaps, uncertainties and unanswered questions for arid, semi-arid and arid regions, which can be summarized as follows:

1. Cost effectiveness of various climate change impacts such as flood, drought, mismanagement.
2. There are few studies in the IPCC (2001, 2007, 2013) reports that summarize potential response strategies and summarize considerations of how water managers might respond in practice, particularly in arid and semi-arid regions.
3. IPCC reports highlighted different trends in different parts of the world and even in sub-areas of the same region, but such differences were not taken into account through regional water resources management. Climate change is expected to affect regional integrated water resources planning, operation and maintenance.
4. Although soil moisture is related to possible climate change, infiltration capacity for underground water resources, reservoir storage and groundwater feeding possibilities

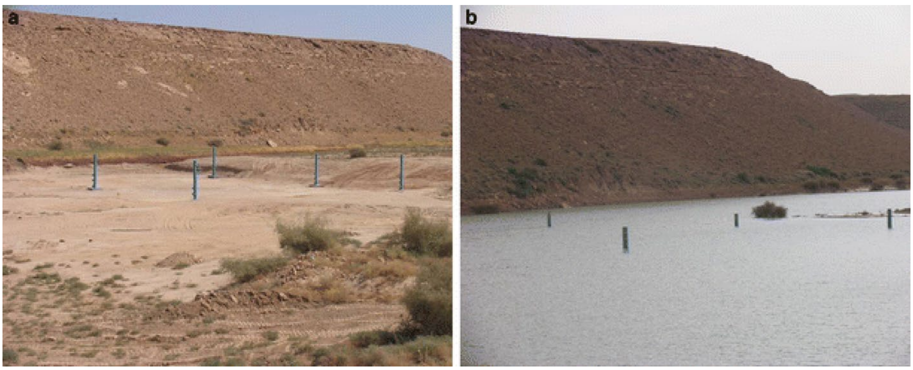

Fig. 4 Ghat site **a** before the storm rainfall and **b** after the storm rainfall

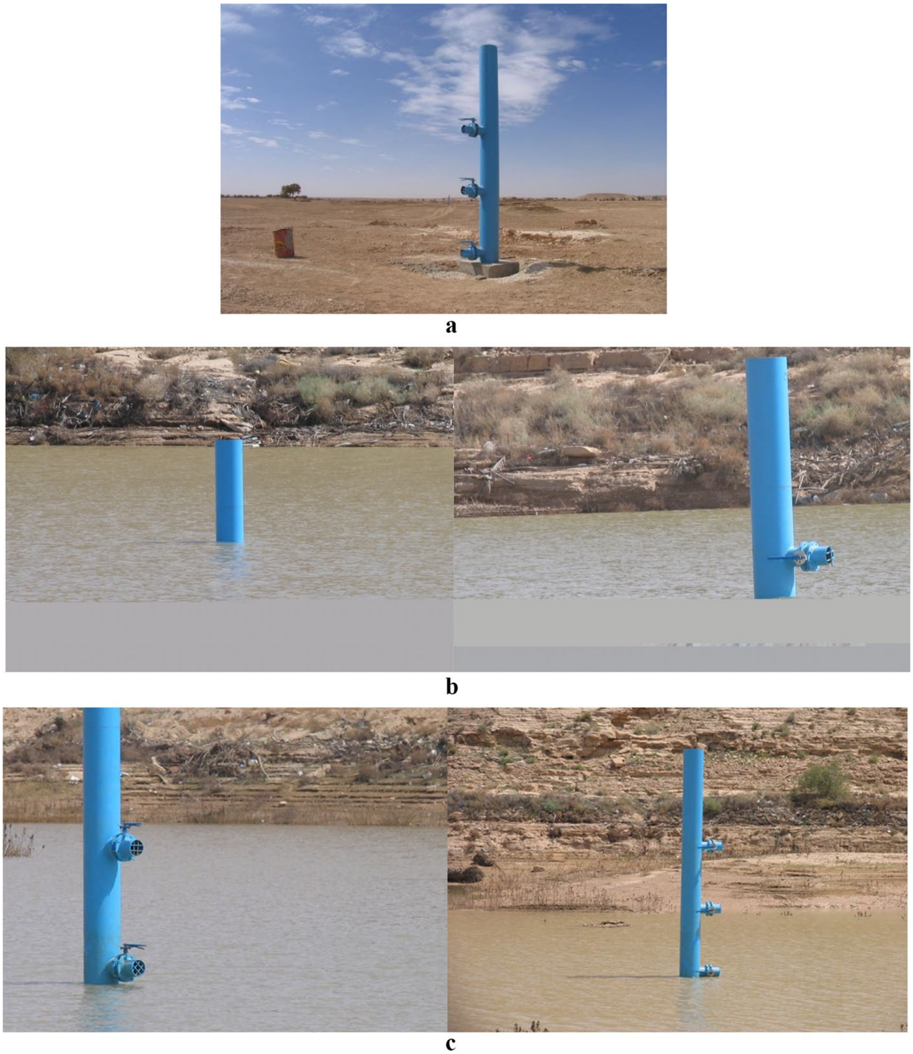

Fig. 5 Injection pipe posistions in dry and wet (flooding) cases

is not considered as one of the important hydrological components with the perspective of increase or decrease in groundwater storage in annual and ten-year time periods.

5. Significance of seepage and flooding for groundwater recharge is not assessed by climate change impact assessment.
6. The possibilities for artificial groundwater recharge development can be strengthened due to the climate change impacts. Especially, in the fractured media and karstic region (solution cavity) groundwater recharge may be associated with climate change.
7. In IPCC reports, drainage basin areas are considered as they appear in humid regions, but arid and semi-arid wadi concepts and freshwater resources are not well addressed.
8. Estimation of groundwater recharge rate using carbon-14 isotopes has been mentioned, but in arid and semi-arid regions, a similar estimation, even with chloride concentra-

tion, is not considered outside of local studies (Subyani and Şen 2006). In arid regions, the chloride mass balance approach should also be focused on for recharge estimates.

9. Considering record breakings and climate variability in addition to the trend as climate change indicators should be closely considered in future studies.
10. Inadequate coverage of flash floods in arid and semi-arid regions in terms of climate change.
11. Sedimentation is mentioned very briefly in IPCC reports, but more detailed studies are needed for sediment yield rates in arid and semi-arid regions.
12. Adaptive real-time reservoir and freshwater distribution should be presented with an effective management project.
13. Adequate coverage of multi-purpose, multi-dam operation and management studies in the arid region.
14. Since climate change affects all socio-economic sectors, the preparedness action plan requires a multidisciplinary approach, institutional arrangements, inter-agency communication and information exchange. Decision makers should depend on reliable data and conclusions for different optimization action priority scenarios.
15. Increasing the use of alternative water resources such as reuse of municipal wastewater and desalination of sea water/brackish water.
16. Improve monitoring efforts to improve weather, climate and hydrological modeling data to help understand water impacts and management strategies.
17. Promote rainwater harvesting techniques to store rainwater as an alternative source and use artificial ditches, contour bundling, gully plugging, control dams and weirs to capture rainwater and increase water availability for agricultural use.
18. Public awareness on climate change especially in arid and semi-arid regions is still at a developmental stage.
19. How to identify suitable sites for groundwater recharge (natural or artificial) rainfall and runoff harvesting?
20. Considering the climate change impacts based on relevant climate scenarios for future water availability, supply and demand possibilities,
21. Development of a future regional database on water resources, including extreme events (droughts and floods).
22. The waste water reuse and desalination in semi-arid and arid regions can contribute significantly to water supply resources.

7 Conclusions

Except for a limited amount of surface water (runoff) in arid and semi-arid regions, surface and groundwater reservoirs are important sources as confined and unconfined aquifers. In these regions, renewable groundwater reservoirs are mostly in Quaternary alluvial deposits in different valleys. These deposits act as porous media for groundwater reservoir storages, which are naturally or artificially filled after surface water impoundments behind the dams and are transferred to subsurface (underground) reservoirs as artificial recharge plants before significant evaporation losses due to extremely dry conditions in desert areas. Different climate change scenarios show increases in precipitation frequency, occurrence, intensity and amount, expressing similar increases in runoff, and therefore, not only classically known precipitation harvesting, but also runoff harvesting possibilities arise for groundwater reservoir storage increments. This paper describes the necessary runoff harvesting possibilities in addition to its implementation in the Riyadh region of the Kingdom of Saudi Arabia. In the light of the explanations in this review article, it is hoped that more conscious and possible practices can be made for future water sustainability especially in arid and semi-arid regions societies under the effects of continuous climate change and variability. In addition, a number of recommendations are proposed for better planning, operation and management and maintenance in arid, semi-arid and humid regions.

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Consent to Participate This is a single author article.

Consent to Publish From my side I give the permission to publish this work.

Competing Interests There is no competing interest and no conflict.

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