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Review Article

Climate change and challenges of water and food security

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Abstract

Water and food security are the key challenges under climate change as both are highly vulnerable to continuously changing climatic patterns. Studies have predicted that the average global temperature may increase by 1.4–5.8 °C and there would be substantial reduction in fresh water resources and agricultural yield by the end of the 21st century. Approximately 75% of the Himalayan glaciers are on retreat and will disappear by 2035. Moreover in Africa (Sub-Saharan Africa) by 2050 the rainfall could drop by 10%, which would reduce drainage by 17%. Majority of the fresh water resources has already been depleted and there is reduction in agricultural production globally with escalation in population and food demand. Some of the prominent climate change impacts are, growing deserts, and increase in the magnitude of floods and droughts. An extreme decline in crop yields in arid and semi arid areas globally has caused food shortages and a manifold increase in food inflation. Countries of Africa, Middle East, Arab and Asia have close economic ties with natural resource and climate-dependent sectors such as forestry, agriculture, water, and fisheries. This manuscript highlights groundwater recharge by utilization of wastewater using the Soil Aquifer Treatment (SAT) method in irrigation and the significance and methods of artificial recharge of groundwater. This paper also presents easily and economically feasible options to ensure water and food security under climate change and recommend formation of effective adaptation and mitigation polices and strategies to minimizing the impact of climate change on water resources and irrigation.

Keywords: Climate change; Water security; Food security; Adaptation & mitigation techniques

Contents

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1. Introduction

Water and food scarcity are the biggest problem globally and it severely affects the arid and semiarid regions/countries. Climate change has resulted in increases in globally-averaged mean annual air temperature and variations in regional precipitation and these changes are expected to continue and intensify in the future (Solomon et al., 2007). The impact of climate change on the quantity and quality of groundwater resources is of global importance because 1.5–3 billion people rely on groundwater as a drinking water source (Kundzewicz and Döll, 2009). As per the fourth IPCC assessment report the knowledge of groundwater recharge and of levels in both developed and developing countries is poor. There has been very little research on the impact of climate change on groundwater' (Kundzewicz et al., 2007).

Study of Global Climate Models (GCMs) projects significant changes to regional and globally averaged precipitation and air temperature, and these changes will likely have associated impacts on groundwater recharge (Kurylyk and MacQuarrie, 2013). IPCC report (2008) predicts that the climate change over the next century will affect rainfall pattern, river flows and sea levels all over the world. Studies show that agriculture yield will likely be severely affected over the next hundred years due to unprecedented rates of changes in the climate system (Jarvis et al., 2010; Thornton et al., 2011). In arid and semi-arid areas the expected precipitation decreases over the next century would be 20% or more. The accelerated increase in the greenhouse gases (GHG) concentration in the atmosphere is a major cause for climate change. As per the IPCC (2007) report, the maximum growth in the emission of greenhouse gases (GHG) has occurred between 1970 and 2004, i.e. 145% increase from energy supply sector, 120% from transport, 65% from industry, 40% from change in land use patterns and during this period global population increases by 69%. As per the WMO (2013), the world experienced unprecedented high-impact climate extremes during the 2001–2010 decade that was the warmest since the start of modern measurements in 1850. Moreover, survey of 139 National Meteorological and Hydrological Services and socio-economic data and analysis from several UN agencies and partners conducted by WMO concluded that floods were the most frequently experienced extreme events over the course of the decade. The amount of energy reaching the earth's atmosphere every second on a surface area of one square meter facing the sun during daytime is about 1370 Watts and the amount of energy per square meter per second averaged over the entire planet is one quarter of this (IPCC, 2007A). The global mean temperature has increased by 0.74 °C during (Fig. 1) the last 100 years. Furthermore studies conducted by Indian Space Research Organization (ISRO) after the study of 2190 Himalayan glaciers revealed that approximately 75% of the Himalayan glaciers are on the retreat, with the average shrinkage of 3.75 km during the last 15 years (Misra, 2013). These findings raise serious concerns over the accelerated retreat of glaciers in the Himalayan Mountains because it will increase the variability of water flows to downstream regions and threaten the sustainable water use planning in the world's most populous Ganga Basin. Studies (de Wit and Stankiewicz, 2006; Anthony Nyong, 2005) predict that by the year 2050 the rainfall in Sub-Saharan Africa could drop by 10%, which will cause a major water shortage. This 10%

decrease in precipitation would reduce drainage by 17% and the regions which are receiving 500–600 mm/year rainfall will experience a reduction by 50–30% respectively in the surface drainage.

So, far much attention has been given to climate change adaptation as an anticipatory and planned process, managed through new policies, technological innovations and development interventions (Adger et al., 2005). But these policies and strategies are far from implementation and most of the fresh water resources are depleting at a very fast rate due to unprecedented escalation in demand from domestic, irrigational and industrial sectors. Impact of climate change such as depletion of water resources (Shallow & deep aquifer depletion) and decline in agricultural production has increased and has escalated food inflation globally and there is an acute shortage of food in many poor African and Asian countries, where people cannot afford expensive food and are dying of starvation. The condition is extremely severe in continents like Africa, where most of the northern portion is extremely dry. Western India, Middle East and Arab Countries, where most of the domestic, irrigational and industrial demands are met by Surface and groundwater are facing severe crisis due to depletion of water resources.

This condition can only be improved by increasing the crop yield and preventing further depletion of water resources. The paper highlights the best suitable methods, which are easily and economically feasible and can ensure water and food security under climate change if implemented properly. The manuscript also suggests a road map for long-term and near-term strategy for minimizing the impact of climate change on water resources and agriculture.

2. Present status of water resources

There are large uncertainties among the nations vulnerable to climate change impacts over the availability of water resources in the future. In 1955, only seven countries

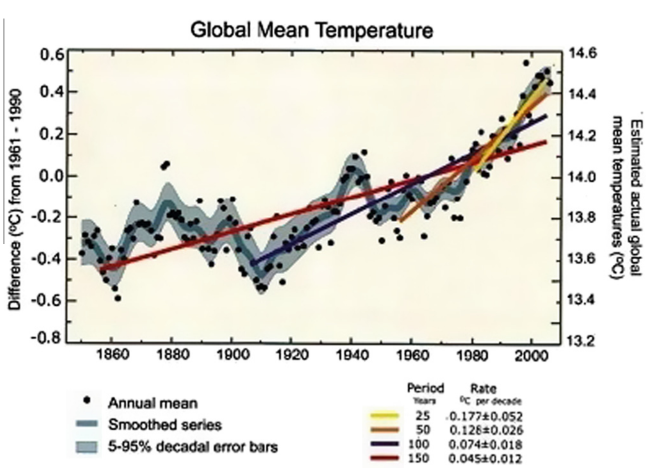

Fig. 1. Global mean temperature during the last 100 years (source: IPCC, 2007A).

were found to be with water stressed conditions. In 1990 this number rose to 20 and it is expected that by the year 2025 another 10–15 countries shall be added to this list. It is further predicted that by 2050, 2/3rds of the world population may face water stressed conditions (Gosain et al., 2006). Majority of the Arab countries depend on the international water bodies for their requirement. Arab countries do not have any major source of water; they have to depend on natural precipitation and water conservation techniques. Nile river basin is the home of approximately 190 million people of Ethiopia, Eritrea, Uganda, Rwanda, Burundi, Congo, Tanzania, Kanya, Sudan and Egypt. Since majority of nations of the Nile river basin are among the top 10 poorest countries of the world therefore it is absolutely difficult for them to adopt any strategy of water management, which require investment. The Middle East and the OSS (Observatory of the Sahara and the Sahel) regions, which have the least natural water resources, both in absolute terms and in relation to its population (UNESCO, 2004) will be affected severely. Table 1 shows the world's natural renewable water resources as compared to OSS region.

The use of strong technological equipment such as deep tube wells and high-powered pumps for the abstraction of groundwater in majority of the vulnerable countries resulted in continuous unsustainable drawdown of aquifers. These pumps allowed faster drafting from aquifers, rivers, canals etc. and disturb the natural equilibrium of recharge and discharge. The country like India where the population is increasing in an unprecedented rate is likely to be water scarce by 2050. The water requirement in India by 2050 will be in the order of 1450 km^3, which is significantly higher than the estimated water resources of 1122 km^3 per year. Therefore to meet the shortfall requirement, it is necessary to harness additional 950 km^3 per year over the present availability of 500 km^3 per year (Gupta and Deshpande, 2004). Table 2 shows the basin wise water present in India. As per the study of the Ministry of Water Resource (MOWR) Govt. of India, the estimated irrigation return flow (RF) from the surface and groundwater irrigation is likely to be 223 km^3 per year in the year 2050 for higher population growth rates giving 133 km^3 per year. The total recyclable wastewater is estimated to be 177 km^3 per year in 2050. Taking all these important factors into consideration, Gupta and Deshpande (2004) estimated the total resource availability in 2050 for higher population growth shown in Table 3.

Africa which is one of the world's driest continents is facing a very severe water crisis. Over 90% of Sub-Saharan Africa agriculture is rain-fed, and mainly under smallholder management (Batino and Waswa, 2011). As per the WHO/UNICEF report more than one billion people still use unsafe drinking water. The African river system identifies three river systems (de Wit and Stankiewicz, 2006) i.e. the areas receiving very low rainfall have virtually no perennial drainage (dry regime), then the areas with an intermediate range in which drain-

Table 1
World's natural renewable resources (rounded off figures) (source: UNESCO, 2004).

Geopolitical regions (Groups of Countries)	Total average internal and external resources (km^3/year)	Portion coming from outside of the region (external resources) (km^3/year)	Relatively constant portion (Surface and groundwater) (km^3/year)
OSS region**	520	113	~200
Europe	1900	10	600
Ex-USSR (the former USSR)	4400	430	1400
North America (USA and Canada)	6700	0	1700
Latin America (including the Caribbean)	13,000	3	4000
Africa, excluding the OSS region (but including the Madagascar)	3500	0	1200
Near the Middle East	480	17	100
Indian sub-continent and south east Asia	6600	1000	1600
China (including Mongolia and North Korea)	2800	0	1000
Japan and 'four dragons'	700	0	200
Australia and Oceania	2000	0	300
Total (without overlap)	42,600		12,300

OSS region**: Arabic Maghreb Union (AMU) countries: Algeria, Egypt, Libya, Mauritania, Morocco and Tunisia. Permanent Interstate committee for drought Control in the Sahel (CILSS) countries: Burkina faso, Cape Verde, Cad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger and Senegal. Intergovernmental authority on Development (IGAD) countries: Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda.

age density increases with increasing rainfall (intermediate rainfall regime) and the areas of high rainfall (high rainfall regime). The dry regime covers the largest area of the African continent i.e. approximately 41%, but most important is the intermediate rainfall regime which covers approximately 25% because this is the area where changes to precipitation would result in serious changes in drainage supply. Further as predicted by an ensemble of global climate change models by the second part of this century, climate change would directly affect African countries, 75% of which belongs to the intermediate stage. Fig. 2 shows the present rainfall regimes in t Africa and Fig. 3 shows the expected changes in the precipitation by the end of the 21st century on the basis of the composite of 21 leading fully coupled GCMs adapted by IPCC for forecasting purposes (CSAG, 2002). The studies conducted by several researchers predict that the crop yield will decline and the crop water demand will increase in the African continent especially in the dry land farms. A net 2.5 °C rise in temperature in Africa will result in a decline of net revenues from agriculture by US$ 23 billion (Kurukulasuriya and Mendelson, 2007). Thus it has become necessary now to take very seriously the impact of climate change on the present water resources and take necessary actions without any further delay.

3. Strategic challenges

Water conservation is one of the oldest activities practiced by old civilization to fulfill the required demand for water for irrigated agriculture and domestic needs in the arid and semi-arid regions. In ancient times the recharge movement initiated by the local communities was aided and supported by emperors. The approaches that support farming communities to self-mobilize and self-organize for participatory learning and action could lead farmers to enhance their uptake of better technologies and improved use of farm-level resources in the wake of increased climate change and variability (Mapfumo et al., 2013). One of the most important facts of water resource management is that the conservation of water resources costs far less and it is more sustainable than treating non-potable and waste water and supplying it for the required needs. Further majority of water conservations strategies are relatively easily and economically feasible as compared to the water treatment plants. Therefore good strategies for artificial recharge to groundwater and conservation of water resources are necessary. Further, the irrigation system must be designed, installed, managed, and maintained properly, because it wastes lot of water. Modern irrigational equipment should be used and their regular maintenance is essential. Table 4 shows the performance of some of the water management strategies after considering global warming effects.

There are several key challenges related with policy and strategy making that have to be confronted. Some of the important challenges are as follows:-

(i) Collection of information and data and their sharing among countries related with climate change and its impact on water resources. It is necessary because water resource management requires, systematic and well planned actions based on accurate scientific data.
(ii) Majority of the countries have varying hydrological conditions, therefore adaptation of the same policies and strategies by each country is not possible. The policies and the action plan will be different for each country based on its hydrological conditions.

Table 2
Basin wise water in India (km^3/year) source: MOWR (1999).

Sl. No.	Basin	ASW	AMR	EUSW	RGW	SGW
1	Indus	73.30	58.60	46.00	26.50	1338.20
2a	Ganga	525.00	401.30	250.00	171.60	7834.10
2 (b + c)	Brahmaputra + Meghana	585.70	477.50	24.00	35.10	1018.50
3	Godavari	111.40	107.10	76.30	40.60	59.40
4	Krishna	78.10	61.00	58.00	26.40	36.00
5	Cauvery	21.60	18.90	19.00	12.30	42.40
6	Pennar	6.70	6.20	6.70	4.90	11.10
7	EF*: Between Mahanadi & Pennar	33.50	15.30	13.10	18.80	41.30
8	EF: Between Pennar & K. Kumari	16.50	16.00	16.50	18.20	66.00
9	Mahanadi	66.90	60.20	50.00	16.50	119.70
10	Brahmani – Baitarni	33.00	32.60	18.30	4.10	43.40
11	Subarnaretha	12.80	9.70	6.80	1.80	10.80
12	Sabarmati	3.80	3.40	1.90	3.20	28.20
13	Mahi	11.00	10.70	3.10	4.00	12.60
14	WF: Kutchh, S'tra, luni	15.10	13.60	15.00	11.20	113.20
15	Narmada	46.00	36.90	27.50	10.80	18.40
16	Tapi	16.90	16.20	15.00	8.30	7.50
17	WF: Tapi & Tadri	87.40	80.30	11.90	17.70	11.20
18	WF: Tadri to K. Kumari	113.50	97.80	24.30	0.00	0.00
19	Inland drainage: Rajasthan	0.00	0.00	0.00	0.00	0.00
20	MR: B'desh and Myanmar	31.00	24.80	0.00	0.00	0.00
Total		1889.20	1548.10	683.40	432.00	10812.00

* EF: East Flowing; WF: West Flowing; MR: Minor Rivers; K. Kumari: Kanyakumari; S'tra: Saurashtra; B'desh: Bangladesh; Available Surface Water (ASW); Average Monsoon Runoff (AMR); Economically Utilizable Surface Water (EUSW); Replenishable Groundwater (RGW); Static Reserve of Groundwater (SGW).

Table 3
Water resources availability based on low and high population growths for 2050 (km^3); source: Gupta and Deshpande (2004).

Water available during 2001	Water required during 2050	Anticipated water deficit	Possible measures to meet the deficit				
			EUSW+GW in excess of 1998	Recyclable waste water	Irrigation return flow	RAGWR	Water availability
500	973–1450	473–950	SW = 420 GW = 202 Total = 550**	103–177*	33–133	125	1311–1485

RAGWR = Retrievable Artificial Groundwater Recharge; EUSW = Economically Utilizable Surface Water; GW = Groundwater.
* Ignored water quality issues.
** After considering 17% decline in storage for surface sedimentation.

(iii) Climate change has increased the frequency and intensity of the natural calamities and now it has become necessary to invest in the study of these natural calamities and their future impacts and prepare a comprehensive plan to minimize their impact on countries.
(iv) Among all the challenges the biggest challenge is the financing of the climate change study related projects and the adaptation of their recommendation because these investments are not profitable.
(v) Many poor and developing countries are unable/hesitant to construct expensive infrastructure required to meet climate change related challenges because of imperfect information and data about intensity of climate change impact on their country.

To minimize the impact of climate change on water resources it is necessary to understand and evaluate the vulnerability of water resources to global warming impacts. After understanding these impacts only policies and strategies should be formed and implemented. All efforts should be made to present future impacts by reducing greenhouse gas emission

4. Water security under climate change

In most developing countries, especially African and Asian, there are urgent needs to understand the dynamics of local climate and make predictions to respond to climate variability and change. The economies of most developing countries depend heavily on climate-sensitive sectors such as water, agriculture, fisheries, energy and tourism, climate change therefore poses a serious challenge to social and economic development in developing countries. (Munang et al., 2013). The shortage of water can be augmented from wastewater utilization after suitable treatment (FAO, 2012). Some of the techniques like artificial recharge and use of unconven-

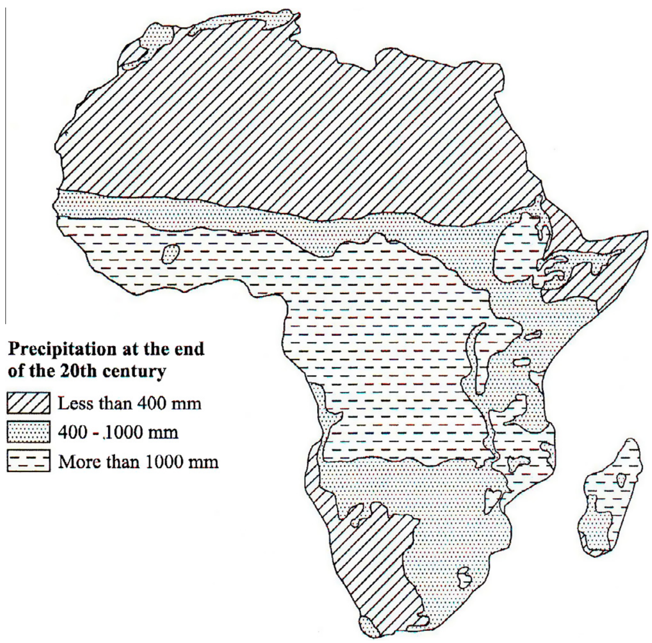

Fig. 2. Precipitation in the African continent at the end of 20th century (source: de Wit and Stankiewicz, 2006).

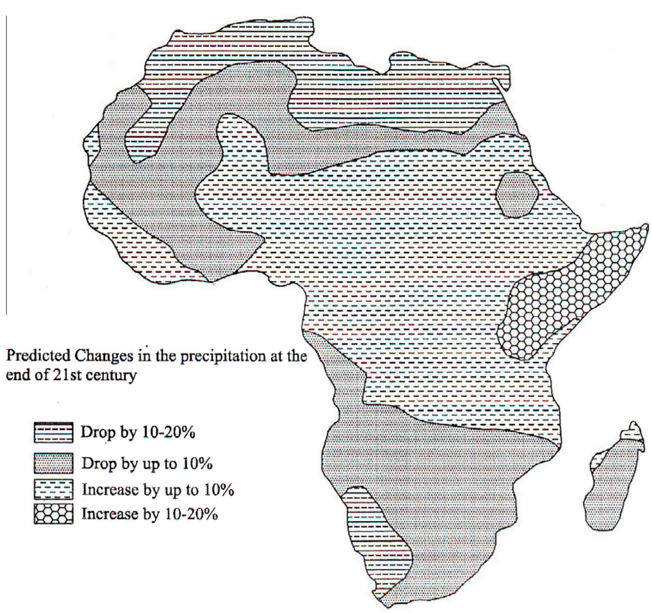

Fig. 3. Predicted changes in the precipitation in the African continent due to climate change at the end of the 21st century (source: de Wit and Stankiewicz, 2006).

tional water (reuse of wastewater after recycling) are effective solutions to minimize the impact of such problems. The unconventional water can play a major role in the management of water resources and agricultural activities in dried and semi dried areas. Recycling and reuse of wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes and replenishing a groundwater aquifer (groundwater recharge) can help in minimizing the impact of climate change on crop yield and water resources. Recycled water for irrigation requires less treatment than recycled water for domestic purposes and till date no documented case of human health problems has been reported by the use of unconventional water for irrigational purposes. Through the natural water cycle the earth has recycled and reused water for millions of years. Water recycling by giving technological support can speed up these natural processes. Usually the recycling of unconventional water may be classified as planned recycling and unplanned recycling.

4.1. Unplanned recycling

It occurs usually in the cities located near the banks of the rivers. These cities take water from rivers to fulfill their demands of domestic and industrial purposes. Cities discharge their wastewater in downstream and draw water from upstream and after recycling it is reused.

4.2. Planned recycling

Planned recycling of wastewater is developed with the goal of beneficially reusing a recycled water supply. Many cities established a water recycling master plan to utilize precious water resources. Under such a plan, all the water-related measures are examined for wastewater recycling and all activities within the city are carried out (establishment of efficient water and wastewater systems within the city) following the master plan. The objectives of such recycling master plan include the creation and nurturing of a water cycle that has a minimal impact on the environment.

Another important way of reusing the unconventional water is through artificial recharge of the dried aquifer systems with partially treated water. Such type of aquifer recharge is only possible where the subsurface lithological conditions and the groundwater condition are favorable, a high degree of upgrading can be achieved by allowing sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated lithology (Vadose Zone) then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses and other microorganisms (Fadlelmawla et al., 1999).

This type of artificial recharge to groundwater with wastewater can be very useful to prevent depletion of groundwater in arid and semiarid areas, where precipitation is extremely low and almost no rechargeable water is available. This process is also called Soil-Aquifer Treatment (SAT). Several practical applications of SAT technology are available throughout the world. One of the biggest is at Whittier Narrows, Los Angeles, USA, which has a recharge area of approximately 279 ha forms a small basin is divided into 15 sub-basins. The scheme disposes of 750 Ml/day using only about one third of the basin during normal operation. The major objective of the scheme is to replenish groundwater for local abstraction and only 16% of the recharge is renovated wastewater. No measurable impact has been detected on either groundwater quality or human health (Nellor et al., 1985).

Artificial recharge with wastewater is totally depending on the properties of the subsurface lithological conditions. The areas where Vadose Zones are not supportive (hard rock areas, older alluvial plain with thick clay and silt layers) for groundwater recharge, artificial recharge structures, like horizontal shaft and vertical shaft, equipped with artificial set of lithologies (Figs. 4 and 5) can be very effective. Artificial lithologies are equipped with geotextiles that perform both separation and filtration functions and improve the performance of recharge structures manifold. These structures usually vary in shape and size and can be used in construction in hard rock and older alluvial plains also. These structures are very effective if formed up to the depth of shallow aquifers (Misra et al., 2013). Moreover the purification mechanisms through an artificial set of lithology is much better than the natural conditions.

4.3. Utilization of wastewater for groundwater recharge

The artificial recharge to groundwater with wastewater depends on a number of factors such as porosity, permeability, hydraulic conductivity, transmissivity and the most important stratigraphical arrangement. In majority of the cases the subsurface sequencing of the layers and the aquifer depth creates problems. Thus the selection of the possible locations for the construction of artificial recharge facility should be established taking care of factors such as suitable site, infiltration capacity, hydrogeological conditions, systematic planning and environmental considerations. Based on these considerations Soil-Aquifer Treatment (SAT) facility can be established.

4.3.1. Identification of suitable area

Identification of a suitable area for such recharge schemes should be demarcated very carefully. Such areas should be as far as possible with any urban settlement and be a micro or mini watershed. Demarcation of areas should be based on the following criteria. (a) A minimum of 20 m depth to the groundwater levels with continuous declining trends is required to allow for geopurification processes (infiltration and absorption) before the infiltrating wastewater reaches the groundwater. This much of depth also allows for groundwater mounding during the recharge process without affecting the infiltration process (RIGW, 1999). (b) Where groundwater quality is good and there is no alternative source of water (c) where discharge from wells and hand pumps are inadequate.

4.3.2. Infiltration capacity of the Vadose Zone

Infiltration capacity of the Vadose Zone is a very important factor that governs the rate of saturation of the zone of aeration. Therefore the lithological zones with an infiltration rate of 0.30 m/day or more are most suitable.

4.3.3. Hydrogeological consideration

Integration of data obtained from field, laboratory analysis and simulation methods are generally used to develop an understanding of the hydrogeological system as a basis for predicting potential consequences. Some of the important considerations that are important for such projects are as follows

(i) The aquifer characteristics at the recharging site must have good hydrogeological conditions such as storage coefficient, availability of storage space and permeability.

(ii) Young alluvium buried channels, alluvial fans and sand dunes etc. are some of the best places for recharge.

(iii) In hilly terrain and hard rock areas, fractured, weathered to semi weathered and cavernous rocks are the best sites for recharge.

4.3.4. Planning & management consideration

Planning and management of artificial recharge projects need careful consideration of several water management objectives, water routing capabilities, economics, off-site effects and different other factors. Water requirement for irrigation purposes can be fulfilled by geopurified wastewater, if it is carried out with systematic planning. A large amount of wastewater is generated in urban areas. After partial treatment this water can be used for artificial recharge of groundwater aquifer, which can be exploited for irrigational purposes. For creating partial treatment facility near the recharge and discharge area planning should be based on hydrogeological consideration and based on easily and economically feasible techniques.

4.3.5. Appropriate spacing

It is also important that there should be appropriate spacing between the two recharge structures. Because when the recharge water begins to merge with the existing groundwater, a mound will develop that drastically reduces the recharge rate. Further if many recharge structures are placed side by side the hydraulic gradients of these recharges will become zero due to superposition, due to this the mound will continue to grow and the recharge rate will drop more quickly (Chatdarang, 2001). Therefore two recharge structures should be at least 1000 m away from each other for getting good results.

4.3.6. Environmental consideration

It is very important to carry out a detailed environmental impact assessment of each selected location and project before the implementation, which includes mitigation and monitoring planning. The most important factor for environmental consideration is that in any circumstances the selected site should not be within or upstream of a groundwater drinking community and no recharge should be planned where groundwater is flowing into the river.

Table 4
Performance of water management strategies after considering the Global warming effects (source: Nelson, 2007).

More effective	Not affected	Less effective
● Landscape conservation	● Wastewater recycling	● Traditional river diversions
● Conservation rate structures	● Interior water conservation	● Traditional groundwater pumping
● Agricultural water conservation	● Groundwater cleanup	● Traditional surface storage facilities
● Water marketing		● Ocean water desalination*
● Urban storm water management		
● Saltwater groundwater intrusion barriers to protect coastal aquifers		
● Water system reoperation		
● Interagency collaboration and integrated water management strategies		
● Floodplain management		
● Watershed Restoration		

* Given existing energy requirements.

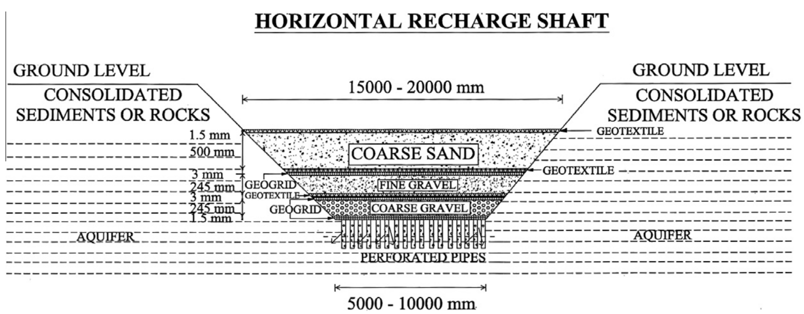

Fig. 4. Design of horizontal shaft structure equipped with artificial set of lithology suitable for hard rock areas, older alluvial plains and places with high surface runoff.

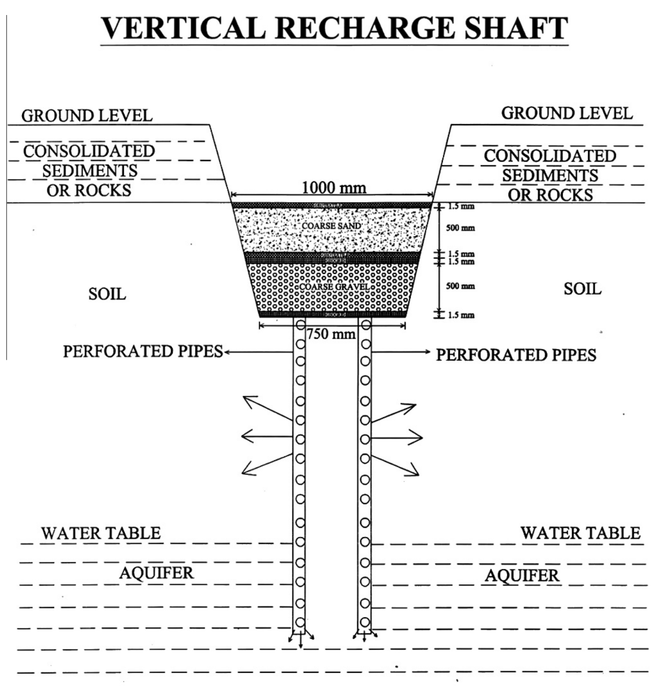

Fig. 5. Design of vertical shaft structure equipped with artificial set of lithology suitable for hard rock areas and older alluvial plains and places with low surface runoff.

4.4. Artificial recharge methods

Artificial recharge methods were specially design for uses in the arid and semi arid regions of the world. These recharge methods include three (Sakthivadivel, 2007) important components (i) Area of the watershed to produce runoff (ii) a storage facility (soil profile, surface reservoirs or groundwater aquifers); and (iii) a target area to beneficially use the water (agriculture, domestic or industry). According to O'Hare et al. (1986) some of the important factors, which are considered for artificial recharge are (a) Availability of wastewater (b) Quantity of source water available (c) Resultant water quality (after reactions with native water and aquifer materials) (d) clogging potentials (e) Underground storage space available (f) Depth of underground storage space (g) Transmission characteristics of the aquifer (h) Applicable methods (injection or infiltration) (i) Legal/institutional constraints (j) Costs (h) Cultural/social considerations. The programs of the artificial recharge are usually conducted in four phases.

4.4.1. Feasibility studies

The feasibility study is the detailed evaluation of the entire recharge project that includes planning, demarcation of the area for recharge, groundwater levels and their declining trend, precipitation over the demarcated area, available quantity of water, study of the geological conditions, hydrological variability within the aquifer, chemical mixing of surface waters with native groundwater, the nature of probable migration of recharged water and economical feasibility of the entire project.

4.4.2. Analytical and testing

Analytical and testing programs are based on the results of the feasibility analysis. The test programs are usually designed, using different existing facilities. This work includes, analysis and testing of quality of water and the pre-treatment required, conveyance system required to bring the water to the recharge site, chemical and physical modeling of recharge options, detailed chemical analysis of co-mingled waters that have different initial chemical signatures, measurement of infiltration capacity of soil and recharge rates.

4.4.3. Designing and operation

Design of the recharge structure is based on the outcome of the feasibilities, analytical and testing studies. If the design is not compatible with the existing ground environment, then the operation of the recharge structure will completely stop within few days. This phase includes the works like designing of injection wells, induced recharge structures; recharge shafts with filter, and different land improvement and watershed management techniques.

4.4.4. Project implementation

Successful implementation of any recharge project is based on the results of the above mentioned three phases of the project. Usually project implementation phase consists of full scale program parameters that include site for well/shaft/infiltration ponds if required, major future options for sourcing of surface water, planning of different recharge management techniques during regular operations and continuous monitoring and maintenance of entire working mechanism of the project.

4.4.5. Cost of recharge structures

Cost of any recharge structure depends upon the source water treatment, source water transportation, resistance to siltation and clogging and the most important stability of recharge structure. The cost of construction, operation, monitoring and maintenance usually depends on the design of the recharge structure and its compatibility with the existing ground environment. Generally the construction and operational costs of the recharge structure is far less than those required for domestic water supply using tankers. Table 5 shows the capital cost and operational cost of various recharge structures.

4.4.6. Environmental impact

Usually recharge structures do not show any harmful environmental affects if its design, operation, maintenance and monitoring are carried out following standard feasibility study recommendations. While planning the recharge structures, the environmental considerations include, ecological effects on soil, hydrologic and aquatic ecosystems, effects on the species and most important the possible effects on people's use of water resources for recreation. Majority of the recharge methods which use surface infiltration systems for recharge and depend on subsurface lithological infiltration rate are very susceptible to clogging by suspended particles, chemical impurities and biological activities. The clogged top layer of the rechargeable ground surface reduces its infiltration rate. Thus clogging of infiltration systems of the artificial recharge structures is a major operational problem. The clogging causes water logging problems that led to several environmental hazards such as soil salinity, loss of vegetation covers/irrigated area. Further due to water logging, water borne diseases, infectious diseases and several diseases spread by mosquitoes are common and often create panic situations.

4.5. Rain water harvesting

In rain water harvesting the source of recharge water is rainfall only, while in the case of artificial recharge structures it could be rainwater, surface runoff, river or canal water or wastewater. Rain water harvesting can be defined as receiving, collection, storage, and use of rainwater for domestic, industrial and irrigational purposes. Besides its application domestic, industrial and irrigational purposes it may be effectively utilized to recharge groundwater aquifers.

Several types of rainwater harvesting structures can be constructed based on the type of catchment surface used (after Kahinda and Taigbenu): (1) in situ rainwater harvesting structures, where the system uses part of the target area as the catchment area, for instance construction of small ridge and furrow structures in agriculture fields (2) ex situ, rainwater harvesting structures where the system uses an uncultivated area as its catchment area, for instance diversion of surface runoff water into a collection basin (3) domestic rainwater harvesting structures, where the system collects water from rooftops, courtyards, compacted or treated surfaces, store it in tanks for domestic uses.

5. Agriculture and food security

According to the Food and Agriculture Organization (FAO) of the United Nations, in most recent estimates, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to over a billion (FAO, 2009). Majority of the world's hungry population are in South Asia and Sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to

Table 5
Construction and operational costs of Artificial recharge methods (source: UNEP International Environment Centre, 2004).

Artificial recharge structure type	Capital cost/1000 m^3 of recharge structure	Operational cost/1000 m^3/year
Injection well (alluvial area)	$551	$21
Injection well (hard rock)	$2	$5
Spreading channel (alluvial area)	$8	$20
Recharge pit (alluvial area)	$515	$2
Recharge pond or percolation pond (alluvial area)	$1	$1
Percolation tank (hard rock area)	$5	$1
Check dam	$1	$1

steadily degrading resource bases, weak markets and high climatic risks (Vermeulen et al., 2012). As per the current knowledge and options for supporting farmers, particularly smallholder farmers, in achieving food security through agriculture under climate change actions in following (Vermeulen et al., 2012) areas should be taken:

(a) Accelerated adaptation to progressive climate change over decadal time scales.
(b) Management of agricultural risks associated with increasing climate variability and extreme events.
(c) Mitigation actions that involve both carbon sequestration and reduction of emissions.

5.1. Adaptation of advance agriculture practices

Adaptation of advance technologies can help in making the framing more easy and productive task. The good agricultural practice involves providing adequate water to plants so that excess standing water can be prevented. Excessive amounts of water can cause poor aeration of the root system leading to inhibition of plant development; therefore avoiding water stress is particularly important in arid regions. Further use of GPS tractors, along with sprayers can minimize the farming cost. These tractors can accurately drive themselves through the field after receiving the correct work plan in their computer system. Moreover the pressurized irrigation with sprinklers is extremely useful in increasing the water use efficiency in modernizing the agriculture system. Furthermore adaptation of mobile technique can play a big role in monitoring and controlling crop irrigation systems. With these instruments a farmer can control his irrigation systems from a phone or computer instead of driving to each field. The major challenge is to accelerate the adaptation of modern techniques in irrigation with which the crop productivity cannot be increased. Fig. 6 shows the framework for agricultural water management in the context of the climate change.

5.2. Crop breeding

Adaptation of plant breeding can improve the quality, performance and diversity of crops with the objective of developing plants better adaptable to human needs. Studies show that for overcoming abiotic stresses in crops, the crop breeding technique has been proved to be an effective means of increasing food production (Evenson and Gollin, 2003), and mitigating climate change effects (Burney et al., 2010). Crop breeding techniques not only enhance the crop quality and yield and but also increase the tolerance of environmental pressures like soil salinity, high temperature and drought conditions. Therefore large scale adaptation of crop breeding is essential to ensure food security.

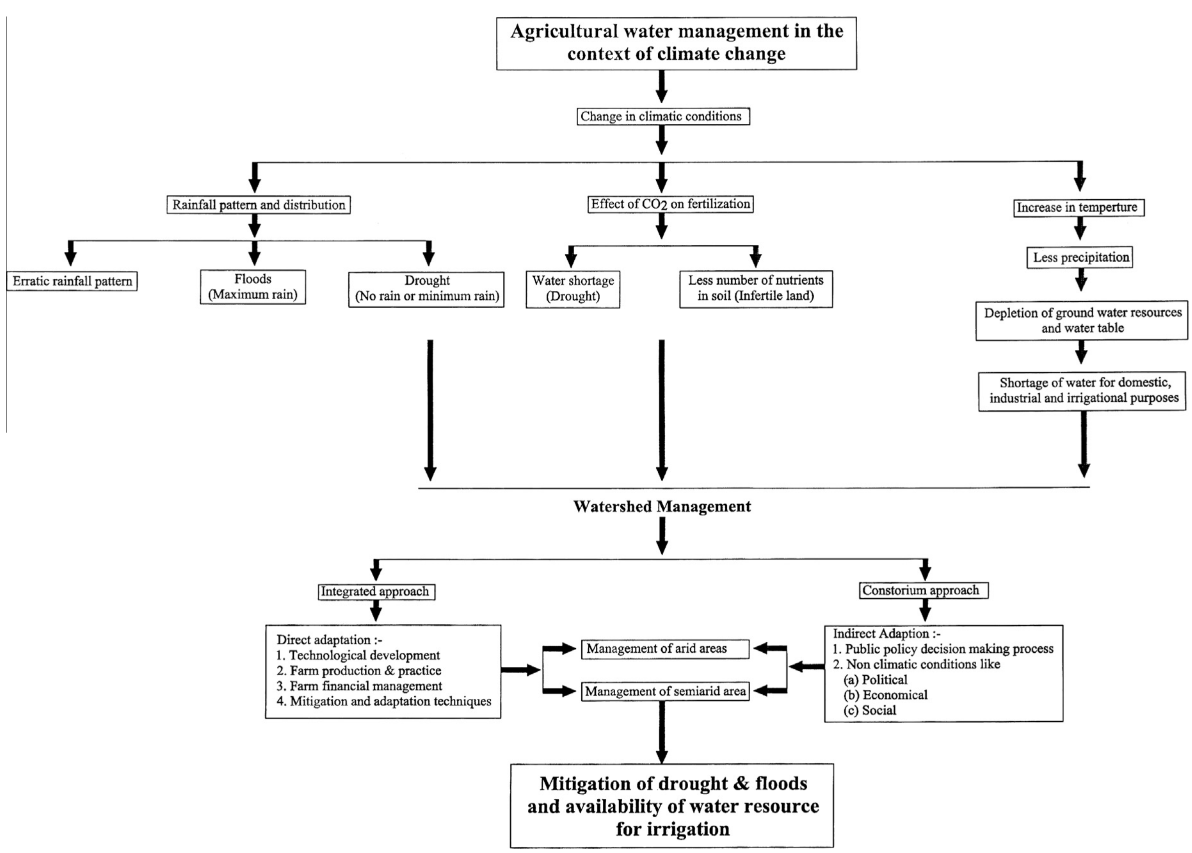

Fig. 6. Proposed framework for agricultural water management in the context of climate change.

5.3. Climate forecasting for crops

Erratic climatic conditions and their variability with time play an important role in the crop production and overall yield. Most of the crop failures worldwide are associated with either a lack or excess of rainfall. Precise climate forecasting can reduce the risks of crop failure and also help in the pre and post decision making processes for better agricultural yield. Several studies have evaluated the potential benefits of using seasonal climate forecasts on the decision making process in agriculture (Jones et al., 2003; Hansen, 2002). Further the nature of the forecasting also influences the ability of farmers to respond like farmers are more concerned about within-season characteristics of rainfall rather than the total seasonal rainfall amounts. The value of forecasts diminishes if information is received after the number of pre-planting decisions are made, therefore the forecasting should be in time and specific.

5.4. Managing food security

Managing food security and its sustainable development is one of the biggest challenges worldwide. Majority of the world's poor population lives in South Asia and Sub-Saharan Africa countries, nearly 1.7 billion people (Chen and Ravallion, 2007) and out of this, approximately for 860 million people there food security. Countries are not able to provide sufficient quantities of nutritious food to these people so that they can live healthily. It is strongly believed that there is enough food in the world to feed everyone adequately but the problem is distribution and management. Therefore development and implementation of a food security plan is necessary that must include procedures for handling threats, product tampering, and product storage and distribution plan along with a monitoring procedure. Moreover there should be a corrective action that prevents products from entering commerce.

5.5. Reduction in farming cost

Artificial recharge can play a major role in minimizing the farming cost. There are a number of examples that proof its utility in irrigation sector. In 2000, the International Water Management Institute (IWMI) carried out a study in India on the project "Madhya Ganga Canal Project (MGCP)", which occupies lower Ganga canal command area in central ganga plain. The study was carried out on Lakhaoti Branch canal of the MGCP, which spreads over 205.6 thousand hectares and covers the area of western Uttar Pradesh (UP) in India. Under this experiment excess river water was used to recharge the groundwater via earthen canals. The experiment was successful in raising the groundwater table to 6.6 meters and brought down the cost of pumping for irrigation from Rs. 4500 per ha meter to an economical level of Rs. 2700 per ha meter. The conclusion of this study is that the prevailing practices of supplying water only during summer/dry seasons need to be changed. In fact during monsoon such supplies should be carried out to help farmers to grow water intensive crops, this way both irrigation and recharge of groundwater will take place.

The construction of structures like "ooranies" is another example. These are big or small types of dugout tanks and ponds constructed thousands of years ago in very large numbers (more than 500,000) in the Peninsular India. These "ooranies" were constructed to fulfill the demand for water for agriculture and domestic purposes. There are several shallow dug wells near these tanks which are recharged with tank water. Further many wells which are used for drinking purposes, located near the tank and tank beds are artificially recharged from the tank into these wells to provide a clean water supply throughout the year with natural filtering (DHAN foundation, 2002). The structures like "ooranies" if formed in large scales especially in the arid and semiarid areas, the problems of water scarcity for domestic and irrigational purposes can be solved up to some extent despite drastic changes in climate.

6. Conclusion and recommendation

Climate changes have started showing its impact on water resources and agricultural yield worldwide. Majority of the countries in arid and semiarid areas totally depend on precipitation and rivers originating in tropical and temperate regions. The overall water stress is continuously increasing and due to climate change a sharp decline in precipitation is expected in these regions. Studies also predict reduction in frequency and escalation in the intensity of rainfall, which will result in frequent drought and floods. Unsustainable depletion of groundwater will likely be worsened by reduced surface water infiltration in arid and semiarid areas and the increase in intrusion of salt water to coastal aquifers from sea level rise will further reduce the availability of usable groundwater.

Agricultural sector and food securities are threatened and if the basic adaptive measures such as changes in crop pattern, crop breeding and types and innovative technologies, which use less water are not used global food production especially in arid and semi-arid areas will further decline. The present situation in the majority of the arid and semiarid countries is not satisfactory. These countries are not able to fulfill the required demand for water and food for people. The implementation of recycling and reuse of wastewater is a good option in these countries. Groundwater recharge using artificial recharge structures and Soil Aquifer Treatment (SAT) systems equipped artificial set of lithologies through wastewater can help in minimizing the impact of climate change on water resources and agricultural yield.

The present study recommends the following measures to minimize the impact of climate change on water resources and crop yield.

- Regions which are most vulnerable to climate change, should adapt strategies to manage climate change risk. Easily and economically feasible techniques and strategies should be formed in the countries falling under this category. The strategies will vary from one country to other depending on their hydrological conditions.

- Countries with arid and semi arid regions should be encouraged to invest and finance research projects related to climate change studies and data collection related to water.
- Improvement in irrigation infrastructure should be carried out in all vulnerable countries to cope with climate change risks. Farmers should be trained for alternative livelihoods in areas expected of severe impact of climate change.
- Programs related to groundwater development such as rainwater harvesting, watershed management, formation of artificial recharge facilities with waste-water and rainwater should be implemented on a large scale in all vulnerable areas.
- Artificial recharge of groundwater with partially treated wastewater can be an added advantage to reuse policies of water in all arid and semi-arid countries. This technique has proven advantages over the direct application of treated wastewater.
- Agricultural sector requires large amounts of water, which will definitely affect water availability for domestic and industrial requirements in future. Therefore more emphasis should be given to watershed development and upgrading rain fed agriculture through rainwater harvesting and artificial recharge systems.
- Multi-disciplinary approach and advanced techniques should be adopted in the evaluation of vulnerability of different water resources and their associated systems that add to global warming.
- Approximately with 90 percent certainty IPCC report revealed that emission of greenhouse gases is responsible for current global warming trends. Therefore all possible efforts should be carried out for reducing green-house gas emission—particularly carbon-dioxide released through the burning of fossil fuel.
- Global warming affects the environment of the entire world. Thus for minimizing the impact of climate change on water management public awareness and involvement are needed. Hydrologists can play an important role in increasing the awareness with discussions with students, business groups, corporates and communities through conferences.

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References

Adger, W.N.N.W. Arnell, Tompkins, E.L., 2005. Successful adaptation to climate change across scales. Global Environ. Change Part A 15, 77–86.

Anthony Nyong. 2005. Abstract in Impacts of Climate Change in the Tropics: The African Experience. Avoiding Dangerous Climate Change (Meteorological Office, Exeter, UK, 2005) (www.stabilisation2005.com).

Batino, A., Waswa, B.S., 2011. New challenges and opportunities for integrated soil fertility management in Africa. In: Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., Kihara, J. (Eds.), Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts, Vol. 1. Springer, Dordrecht, The Netherlands, pp. 3–20.

Burney, J.A., Davis, S.J., Lobell, D.B., 2010. Greenhouse gas mitigation by agricultural intensification. Proc. Natl. Acad. Sci. U. S .A. 107 (26), 12052–12057.

Chatdarang, V. 2001. Artificial recharge for conjunctive use in irrigation: The San Joaquin valley, California: (M. Tech Thesis); Massachusetts Institute of Technology, June 2001, USA.

Chen, S.; Ravallion, M. 2007. Absolute poverty measures for the developing world, 1981–2004. World Bank, Development Research Group, Poverty Team.

CSAG, 2002. Assessments of Impacts and Adaptations to Climate Change: Africa Climate Change Scenarios: Vol. 1 (2002) (www.csag.uct.ac.za).

de Wit, Maarten, Stankiewicz, Jacek, 2006. Changes in surface water supply across Africa with predicted climate change. Science 311, 1917–1921.

DHAN foundation, 2002. Revisiting tanks in India, National Seminar on conservation and development of Tanks. New Delhi India.

Evenson, R.E., Gollin, D., 2003. Assessing the impact of the green revolution, 1960 to 2000. Science 300, 758–762.

Fadlelmawla A, M. Abdel-Halen and Vissers, M. 1999. Preliminary plans for artificial recharge with exclaimed wastewater in Egypt; 9th Biennial Symposium on Artificial recharge of groundwater, Tempe, AZ, June 10–12.

FAO, 2009. The State of Food Security in the World. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2012. Wastewater treatment and use in agriculture. http://www.fao.org/docrep/T0551E/t0551e07.htm.

Gosain, A.K., Rao, Sandhya, Basuray, Debajit, 2006. Climate change impact assessment on hydrology of Indian river basins. Curr. Sci. 90 (3), 346–353.

Gupta, S.K., Deshpande, R.D., 2004. Water for India in 2050: first-order assessment of available options. Rev. Pap. Curr. Sci. 86 (9), 1216–1224.

Hansen, J.W., 2002. Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric. Syst. 74 (3), 309–330.

IPCC. 2007. Fresh water resources and their management climate change 2007; Impact, adaptation and vulnerability. Contribution of working group-II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press: Cambridge, UK.

IPCC. 2007A. Climate change, The physical science basis; Working group I contribution to the fourth Assessment report of the Intergovernmental Panel on Climate change; Summary for policymakers, Technical Summary and frequently asked questions.

IPCC. 2008. Climate change and water, Intergovernmental panel on climate change technical report IV. June 2008.

Jarvis, A., Ramirez, J., Anderson, B., Leibing, C., Aggarwal, P. 2010. Scenarios of climate change within the context of agriculture. In: Climate Change and Crop Production. CAB International.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., Ritchie, J.T., 2003. DSSAT cropping system model. Eur. J. Agron. 18, 235–265.

Kahinda, J.M., Taigbenu, A.E., 2011. Rainwater harvesting in South Africa: challenges and opportunities. Phys. Chem. Earth 36, 968–976.

Kundzewicz, Z.W., Döll, P., 2009. Will groundwater ease freshwater stress under climate change? Hydrol. Sci. J. –J. Des. Sci. Hydrol. 54, 665–675.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., et al., 2007. Freshwater resources and their management. In: Parry, M.L., Canziani, O.F., Paluticof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contributions of the Working Group II to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 173–210.

Kurukulasuriya, P., and Mendelsohn, R. 2007. A Ricardian Analysis of the Impact of Climate Change on African Crop Land, Policy Research Working Paper (4305), The World Bank, Washington DC.

Kurylyk, Barret L., MacQuarrie, Kerry T.B., 2013. The uncertainty associated with estimating future groundwater recharge: a summary of recent research and an example from a small unconfined aquifer in a northern humid-continental climate. J. Hydrol. 492, 244–253.

Mapfumo, P., Samuel, Adjei-Nsiah, Mtambanengwe, Florence, Chikowo, Regis, Giller, KenE., 2013. Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. Environ. Dev. 5, 6–22.

Misra, A.K., 2013. Global climatic variations and its impact on Indian hydrological conditions. Int. J. Eng. Sci. Res. Technol. 2 (2), 148–158.

Misra, A.K., Manav Wadhwa, Ankur Shivhare, Anupriya Gupta, Nikita, 2013. Design and testing of artificial recharge structures equipped with geosynthetic materials for arid and semi arid areas. Adv. Water Resour. Prot. 1 (4), 53–57.

MOWR. 1999. Integrated water resources development-a plan for action. Report of the national Commission for integrated Water Resources Development plan; Ministry of Water Resources, Government of India, Vol. 1, pp. 515.

Munang R, Johnson N. Nkem, ZhenHan. 2013. Using data digitalization to inform climate change adaptation policy: Informing the future using the present; Weather and Climate Extremes; http://dx.doi.org/10.1016/j.wace.2013.07.001i.

Nellor, M.H., Baird, R.B., Smyth, J.R., 1985. Health effects of indirect potable water reuse. J. Am. Water Works Assoc. 77, 88–96.

Nelson, B. Monty Schmitt, Ronnie Cohen, Noushin Ketabi. 2007. Water Management Strategies to Weather the Effects of Global Warming; NRDC reports Department, 40 West 20th Street, New York, NY 10011, USA.

O'Hare, M.P., Fairchild, D.M., Hajali, P.A., Canter, L.W. 1986. Artificial recharge of Groundwater. Proceedings of the second International Symposium on Artificial Recharge of Groundwater.

RIGW/IWACO. 1999. Artificial recharge pilot projects at El-Bustan area, Egypt. Final report; Recharge institute for groundwater, Egypt.

Sakthivadivel Ramaswamy. 2007. The Groundwater Recharge Movement in India; www.iwmi.cgiar.org/.../Ground_Water/.../Giordano_1845931726-Chapter10. pdf.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., et al., 2007. Climate Change 2007: The Physical Science Basis. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Thornton, P.K., Jones, P.G., Ericksen, P.J., Challinor, A.J., 2011. Agriculture and food systems in sub-Saharan Africa in a 4 °C+ world. Philos. Trans. R. Soc. A: Math. Phys. Eng. Sci. 369 (1934), 117–136.

UNEP. 2004. http://www.unep.or.jp/ietc/publications/techpublications/TechPub-8e/recharge.asp.

UNESCO. 2004. The water resources in the OSS (Observatory of the Sahara and the Sahel) countries; evaluation, use and management; International Hydrological Programme. Published in 2004; 7, place de Fontenoy, 75352, Paris 07 SP.

Vermeulen, S.J., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G.C., Thornton, P.K., Wollenberg, E., 2012. Options for support to agriculture and food security under climate change. Environ. Sci. Policy 15, 136–144.