

Environmental Impacts of Irrigation

**Nathaniel A.
Nwogwu**

*Federal University of
Technology Owerri,
Nigeria;
Auburn University US*

Oluwaseyi A. Ajala

*Punjabi University India;
University of
Ibadan, Nigeria*

Ifeoluwa F. Omotade

*Federal University of
Technology Akure, Nigeria*

Toju E. Babalola

*Federal University
Oye-Ekiti, Nigeria*

Temitope F.

Ajibade and

Kayode H. Lasisi

*Federal University of
Technology Akure, Nigeria;
University of Chinese
Academy of Sciences,
PR China;
Chinese Academy of
Sciences, PR China*

Bashir Adelodun

*University of Ilorin, Nigeria;
Kyungpook National
University, South Korea*

Fidelis O. Ajibade

*Federal University of
Technology Akure, Nigeria;
University of Chinese
Academy of Sciences,
PR China;
Chinese Academy of
Sciences, PR China*

7.1	Background.....	167
7.2	Soil Degradation, Erosion, and Sedimentation.....	169
	Erosion • Surrounding Area Impact • River Morphology and Configuration • Channel Structures • Sedimentation • Soil Salinity • Soil Properties	
7.3	Water and Air Quality	174
	Toxicity • Pollution • Anaerobic Effects • Gas Emission • Groundwater Salinity	
7.4	Hydrology	176
	Flow Characteristics Alteration • Flood Characteristics Alteration • Water Table Level Change • Dam Siting and Operation Impacts	
7.5	Biotic and Ecological Effects.....	181
	Biodiversity and Landscapes • Impacts on Biotas and Habitats • Water Bodies • Pests, Weeds and Animal Diseases	
7.6	Ensuring Environmental Quality and Sustainability: Sustainable Ways and Techniques to Mitigate Negative Impacts of Irrigation on the Environment	182
7.7	Conclusion	183
	References.....	184

7.1 Background

Irrigation is instrumental in increased agricultural production (Kukul and Irmak, 2020; Usman and Gerber, 2019; Burney et al., 2010; Asayehegn et al., 2012). Like every other developmental stride, irrigation projects bring about social, economic, and environmental changes. Development targets achievement of positive and sustainable change, though some conflicting factors may arise due to development. To improve the well-being of both human and the environment, the developmental program should be evaluated before implementation to ensure minimal adverse social and environmental impacts while delivering its purpose (Hassanvand et al., 2017). Gone are the days when ecological degradation was ignored (Perret and Payen, 2020). In this regard, more awareness has been supported to educate people on better irrigation and

drainage practices. Although the advantages of irrigation prevail over its disadvantages and costs, it is still necessary to discuss those adverse impacts that come with it. This would help decision/policy makers, irrigators, and farmers adopt ideal irrigation plans, designs, and management practices that could promote ecological sustainability. The need to establish lasting benefits and reduce adverse effects prompted the support of the concept of sustainability. Regarding agricultural development, water is generally insufficient in different regions of the world, yet agriculture is recorded as one of the significant withdrawals of water.

In addition, freshwater is not evenly distributed across the globe. For this reason, with increasing human population and human activities that require water has led to the continuous search for enough quality water to carry out these activities. The problem of water scarcity has prompted people in various parts of the world, especially the middle east, to resort to the use of wastewater (treat and untreated or poorly treated) for irrigation as a means of ameliorating their situation (Guadie et al., 2021; Thiruchelvel et al., 2020; Al-Reyami et al., 2020). This reutilizing of wastewater has earned importance recently, particularly in the arid and semi-arid areas (El Moussaoui et al., 2019; Villamar et al., 2018; Ofori et al., 2021). Although many studies have suggested some benefits of wastewater reuse in irrigation, the confirmation of its appropriateness and general acceptance for irrigation is still a debate among researchers. This is owing to the various drawbacks associated with wastewater irrigation. Therefore, the problem with wastewater reuse is that while trying to solve water scarcity in agriculture, it equally brings about harmful effects to both human and the environment (Guadie et al., 2021; Gohil, 2000; Rehman et al., 2019). This is likely to manifest with the continuous use of wastewater (e.g., municipal wastewater) as it would lead to heavy metal accumulation in the irrigated area, plants, and groundwater (Thiruchelvel et al., 2020). For instance, when there is a high level of heavy metals in agricultural soils and crops, the lives of the consumers of the farm produce (crops and vegetables) are threatened (Chaoua et al., 2019). Moreover, due to low expertise and funding, many developing countries still irrigate their farms with untreated or unwell-treated wastewater, which could be dangerous to the environment, health, and economy (Adewumi and Ajibade, 2019). A study on the environmental impacts of wastewater for irrigation at Dhamar City, Republic of Yemen, carried out by Rageh et al. (2017) suggested that direct use of wastewater is not suitable for irrigation because of the risks it presents to the environmental resources (Al-Reyami et al., 2020). Therefore, it is imperative to treat wastewaters from chemical contaminants, pathogens, and salinity to avoid the adverse effects it would present on the groundwater and soil conditions (Al-Reyami et al., 2020). Generally, it is necessary to conduct wastewater characterization to determine the possibility of using such wastewater for irrigation without jeopardizing human and environmental health (Ajibade et al., 2014a,b; Braga and Varesche, 2014; Ilori et al., 2019; Adewumi and Ajibade, 2019). Soil characteristics should also be considered while resorting to wastewater irrigation.

To evaluate the imports of any anthropological exploitation practice on the environment and establish effective actions to prevent and lessen negative impacts and enhance encouraging results, a formal process known as environmental impact assessment (EIA) is adopted. The EIA offers such benefits as predicting problems, figuring out ways to avoid the issues, and enhancing the positive impacts of a particular project (Dougherty et al., 1995). The adverse environmental effects of irrigation take some time to surface (Yusuf, 2008); hence, ecological impact assessment of every project should be carried out, bearing in mind the eruption of its adverse impacts in the future. This is imperative as it is inevitable that anything that affects the environment would directly or indirectly affect lives as well.

Generally, evaluating how sustainable an irrigation project can be is dependent upon the availability of local water and other water uses, the historical background of how irrigation systems have developed, and the peculiar attributes associated with particular irrigation practices considered (Baldock et al., 2000). Factors such as topography, rainfall characteristics, type of source available, and soil profile are essential in the selection of an irrigation scheme (Asawa, 2005). Also, combined use of surface and ground waters for irrigation is considered to yield maximal efficiency and benefits (Asawa, 2005). Different irrigation types are in use in the various parts of the world concerning the various determining factors and economic considerations. Therefore, environmental impacts attributed to irrigation

would also vary with county and country (Baldock et al., 2000). Agriculture is considered a high consumer of water globally; in some cases, polluted water is used to meet the agricultural demand in irrigation (Ajibade et al., 2021). Baldock et al. (2000) further classified the ways by which irrigation affects the environment into four basic categories, viz.:

- i. Direct impacts on water sources: irrigation affects the quality and quantity of surface and ground waters.
- ii. Direct impacts on soil: irrigation affects the quality (via pollution) and quantity (via erosion) of the soil.
- iii. Direct impacts on biodiversity and landscape: irrigation displaces earlier habitats. It creates new ones, either by debasing or preserving the existing habitats and affecting the diverseness and constitution of landscapes.
- iv. Secondary impacts resulting in intensified agrarian production from irrigation (e.g., an increase in fertilizer usage).

These effects may take a gradual process to unfold (for instance, reduction in certain species as a result of contamination) or manifest dramatically (as can be seen when a valley gets flooded and thus creates a reservoir for irrigation, or when there are canal formations in a river which reduce and destabilize the flow of such river) (Baldock et al., 2000). Although irrigation has numerous advantages to both the environment and agricultural production, this chapter focuses more on the adverse impacts of irrigation to the environment and other components therein.

7.2 Soil Degradation, Erosion, and Sedimentation

Soil degradation is one of the significant environmental impacts of irrigation. It is, therefore, important that proper monitoring and management of irrigated soils are regularly done to help proffer solutions to the various soil degradation issues associated with multiple types of irrigation practices. There are varieties of agricultural activities resulting from an increase in intensified production that can lead to depletion of soil fertility. For instance, monocropping without enough time to fallow, rise in soil salinity resulting from continuous irrigation, reduced organic matter (OM) content of the soil, and increase in soil toxicity resulting from increased use of agrochemicals (e.g., fertilizers, pesticides, and herbicides), all contribute to soil degradation (Baldock et al., 2000; Dougherty et al., 1995; Tilman et al., 2002). In addition, irrigating with wastewater and using polymer-based fertilizers and pesticides often contribute to microplastic pollution in agricultural soils, thereby degrading the soil health and quality (Kumar et al., 2020).

FAO (1992) affirms that about 0.5% (i.e., about 5–7 million ha) of arable land becomes unproductive yearly due to soil degradation. Soil degradation as a result of irrigation covers many aspects of environmental degradation, including erosion, sedimentation, soil salinity, alteration of soil properties, and river morphology. Among these environmental impacts, soil salinization remains the primary cause of soil being unproductive. It affects production in many ways, such as in crop selection, crop germination, and yield, and making the soil tough to work on (Dougherty et al., 1995). Therefore, it is necessary to evaluate irrigation water quality and its compatibility with a particular soil type before irrigation is carried out to avoid or reduce associated adverse environmental impacts if not adequately assessed (Ayers and Westcot, 1985). For instance, a low-quality water might be good for irrigation on a sandy or permeable soil while such water could be considered unsafe for irrigation on clayey soil. Such difference in choice or acceptability of a particular water quality for a type is important. These soil degrading impacts of irrigation are discussed one after the other as follows.

7.2.1 Erosion

The exposure of irrigated lands to erosion is highly dependent on the type of irrigation adopted (Dougherty et al., 1995). The regular introduction of water into an area makes it wetter, hence making

it get saturated when there is a raindrop. This in turn reduces the absorption or infiltration of rainwater into the soil, thereby building up more runoff which carries both soil particles and essential nutrients alongside. Aspects such as field size, stream size, gradient, and field layout do not change easily and they have a significant influence on erosion rates (Dougherty et al., 1995). Irrigation is a technical project that needs to be implemented and handled with adequate care to avoid extreme environmental hazards. Like other agricultural practices, irrigation affects soil structure and soil erodibility; therefore, proper irrigation practices should be adopted to eliminate soil degradation from irrigation. For instance, the ancient in-field patterns for managing water involving inadequate land development (cut and fill) practices by waterway embankments could lead to severe local erosion at the upper-end of the watered land and simultaneously causing sedimentation at the middle- or lower-end areas of the farmland. Moreover, the field's microtopographic configuration will be altered, which may result to uneven distribution of water on the irrigated field. The increased erosion rate common in some irrigation projects' surrounding is often due to increased economic activities which the project attracts.

Furthermore, Ofori et al. (2021) affirm that wastewaters have more OM content compared to other sources of irrigation water (e.g., groundwater), and this has made wastewater a good and valued source of irrigation water since it could be rich in OM necessary for plant growth and yield. An increase in the soil OM content improves soil compatibility, soil erodibility, soil buffering capacity against acidification, nutrient cycling, and availability of nutrients such as nitrogen, phosphorus, and sulfur (Murphy, 2015). However, it has been reported that sodium adsorption ratio (SAR), an important factor considered in irrigation, relatively increased in wastewater irrigated soils those irrigated with conventional irrigation water (Ofori et al., 2021). SAR helps to show how sodium ions affect the soil structure (Marchuk and Rengasamy, 2010). Some adverse effects on both crops and soil occur when SAR becomes high in the ground, viz. decreased crop growth and increase in plant toxicity (Maqsood et al., 2015), calcium deficiency in plants (Imran et al., 2010), reduction in dissolved organic carbon (OC) sorption (Mavi et al., 2012), reduced soil fertility and agricultural productivity, damage to soil structural stability (Ofori et al., 2021), and decreased soil permeability and hydraulic conductivity (Arienzo et al., 2012; Oster et al., 2016). Therefore, proper design, good choice of irrigation type/water with regards to the soil type and topography, moral land development, irrigation frequency, and good water management practices associated with surface irrigation methods (e.g., use of gates, siphons, and checks) can be effective in reducing erosion and water distribution hazards on irrigated fields.

7.2.2 Surrounding Area Impact

As earlier said, irrigation is a development project, leading to a rise in anthropogenic activities within the surrounding establishment, especially in developing nations. This increase in human activities could result from the increased economic activities associated with irrigation development in an area. For instance, farmers and their families may engage directly or indirectly in irrigation activities. Irrigation development promotes anthropogenic activities such as grazing due to the increased number of livestock, and the exploitation of forest resources, mainly for wood in the surrounding areas. These activities, in turn, make the soil more prone to erosion since the vegetation is adversely affected, negatively affecting the area's fertility and ecology.

Moreover, clearing more significant non-irrigated parts of the watershed results in rise in the water table downstream; for areas that have high salinity levels in groundwater, more recharge may lead to more excellent salt points in the streams and increase the degree of pressure in the lower watered parts of the field, thereby hindering leaching; this occurrence has been reported in South-eastern Australia, and it could be controlled by planting deep-rooted crops and trees in the upland areas (Dougherty et al., 1995).

To eliminate these associated problems, necessary plans and actions that can take care of such problems that might come up should be put in place from the outset of the project. This could be the provision of allowance for farm animals, firewood, or veg plots within the surrounding area of an irrigation scheme, and protecting unprotected expanses may be required.

7.2.3 River Morphology and Configuration

River morphology deals with the movement, direction, and shape of rivers and how they change in these aspects over time as controlled by rain, other weather conditions, floods and sediment transport. The capacity and shape of a river are a function of its current, the bed and bank material, and the sediments transported by the current. More energy and sediment loads go with the fast-flowing river than with a slow-moving one. Therefore, sediments settle more in reservoirs and deltas where flow velocity weakens (Khan et al., 2014). On the other hand, a river is said to be in a regime when the flow is moderately constant such that it is not erosive and the same time not slow to cause deposition of sediment (Dougherty et al., 1995). Khan et al. (2014) further stated that when the sediment transport capacity of the flow becomes greater than the sediment input to the river, channel bed erosion develops, while the reverse leads to channel bed aggradation. However, this condition changes with time. When flow reduces, river morphology is affected as the capacity of the flow to carry sediments reduces leading to their deposition in the slower moving reaches, thereby causing shrinkage of the river channel, and the reverse becomes the case for fast flow. Similarly, for a section where sediment balance is altered probably by reservoir or scouring of a dregs controlling structure, river morphology is significantly affected. Petts and Gurnell (2005) suggested that riparian vegetation equally influences river morphology since plants growth along the river floodplains leads to narrower channels. Also, when water is released from a reservoir, scouring may occur which would result in the dropping of the bed level proximately downriver of the dam which can be seen as an opposite of the possible resultant impact of low flow. It can be deduced that the major causes of change in river morphology within the area of irrigation scheme are erosion and sedimentation. Therefore, alteration of river morphology would affect the downstream uses such as navigation, withdrawal for drinking, industry, and irrigation. It may also have a great negative effect on the river ecology.

7.2.4 Channel Structures

Exposure of canal to impairment is greatly associated with alteration of the channel morphology and regime condition (Dougherty et al., 1995). This is because there would likely be some problems of siltation, and others related to pump and filtration operation at the intake structures resulting from increased suspended sediments. Water withdrawal assemblies may get blocked by sediments or water may be left beyond their reach. Furthermore, the debasement of the channel equally endangers the wholeness of the hydraulic structures (e.g., intakes, headworks, flood protection) and bridges; when structures are newly constructed, existing neighboring constructions are affected since the flow condition is changed or affected (Dougherty et al., 1995).

7.2.5 Sedimentation

Sedimentation is unavoidable in irrigated areas as they are very vulnerable to erosion. It is a global issue that affects both the irrigation systems design and the operational performance (de Sousa et al., 2019). Ensuring enhanced water and sedimentation management in irrigation is imperative to ensure sufficient water supply as well as to promote food production (Kisi, 2012; Kusu et al., 2009). As earlier discussed, irrigated area gets wetter, hence reducing its capacity to absorb rainwater. This often leads to building up of runoff which flows along with sediments. Also, in an event of over-irrigation, runoff may be observed causing scouring on the field. These sediments are thereafter transported downstream and even to the river and reservoir bed, causing reduction of the river and reservoir capacity as well as blockage of hydraulic channels (de Sousa et al., 2019). In addition, irrigated areas are commonly having less wind-protecting vegetation and this sometimes allows for wind erosion blowing soil particles which in turn fill the canals (Dougherty et al., 1995). Failure of irrigation structures can occur when the dregs load of the water source exceeds the volume of the irrigation waterways for transporting the sediments.

Some commonly known irrigation schemes that have been reported to be challenged by high sedimentation problems are: Coromandel region in New Zealand (Ballantine et al., 2014; Marden and Rowan, 2015), Khoshi river system and Sunsari Morang Irrigation Scheme in Nepal (Depeweg and Paudel, 2003; Paudel, 2010), Elkhorn Slough Watershed and Upper North Santiam River Basin, Oregon in USA (Ouellet-Proulx et al., 2016; Spear et al., 2008; Urich and Bragg, 2003), Jatiluhur irrigation system, at Bekasi Weir Irrigation Scheme in Indonesia (Sutama, 2010), Magdalena river in Colombia (Higgins et al., 2015), and Iguatu Experimental Watershed in Brazil (Santos et al., 2017). In Africa, most pronounced irrigation schemes in terms of high sedimentation issues include: Southwest Kano Irrigation Scheme in Kenya (Ochiere et al., 2015), Metahara Scheme in Ethiopia (Ali et al., 2014; Bishaw and Kedir, 2015; Munir, 2011), Gezira Irrigation Scheme in Sudan (Osman, 2015), in suburban tropical basin in Congo (Lootens and Lumbu, 1986), and irrigation schemes in South Africa (de Sousa et al., 2019).

In order to arrest this menace as well as avoid the high cost of desilting canals and reservoir, some effective designs, planning and sedimentation monitoring tools should be employed from the onset of the project. For instance, the installation of sediment excluders/extractors at the headworks can assist in mitigating sedimentation and failure of irrigation canals.

7.2.6 Soil Salinity

Increase in soil salinity is one of the major environmental problems caused by irrigation (Manasa et al., 2020; Fathizad et al., 2020; Pulido-Bosch et al., 2018; Singh, 2018, 2021). FAO (2020) (as cited in Singh, 2021) affirms that over 3% of the global soil resources have been affected by salt. Many researchers have identified the common means by which soil salinity is increased on an irrigation scheme (Dougherty et al., 1995), and they include:

- i. *Accumulation of salt content in the soil resulting from salts in the irrigation water*: irrigation water often has some salt content; part of the water introduced on the field is absorbed by plants, some infiltrate into the soil, and the other evaporate into the atmosphere. This water redistribution occurs while its salt content remains on the field but some infiltrate with water through the soil profile. Hence, the salt content of the irrigated soil increases with time as irrigation continues.
- ii. *Use of agrochemicals*: soil salinity increases from the increased use of solutes or agrochemicals in the form of natural or artificial fertilizers, pesticides, etc. as not all the constituent salts would be used by crops.
- iii. *Movement of naturally occurring salt in the soil*: salts occurring naturally in the soil may form solution with soil water or exist naturally as salty groundwater. Such challenge is more pronounced in the desert or dry zones where occurrence of leaching is almost impossible. In areas with both high groundwater level and salinity, water rises by capillarity and evaporates into the atmosphere while salts are left on the soil surface or within the subsoil.
- iv. *Change or transfer of irrigation method*: humidity/salinity bridge may occur when there is a change from rainfed to irrigation of a single crop, or change from one to dual irrigation. The bridge is usually created between the deep groundwater and the salt-free surface layers of the soil. Careful soil monitoring is suggested in this regard especially when the irrigated regime is increased.

Moreover, increase in groundwater salinity may exist as result of waterlogging. However, saline groundwater is mainly pronounced in coastal areas. Salinization in soil and water resources is commonly caused by poor irrigation and drainage systems or practices in arid conditions (Perret and Payen, 2020). Fortunately, proper land development (cut and fill) and properly sustained drainage networks could help efficiently in ensuring even water distribution as well as mitigating salinity effects. Furthermore, the position of the freshwater and saline water boundary within the coastline is dependent upon the hydraulic potential of the freshwater (Dougherty et al., 1995). For lower water table, the boundary moves inland as the pressure decreases. This consequently leads to high increase in salinity of freshwater which adversely affects the soil, crop yield, local ecology, and exposes the people using such water (especially

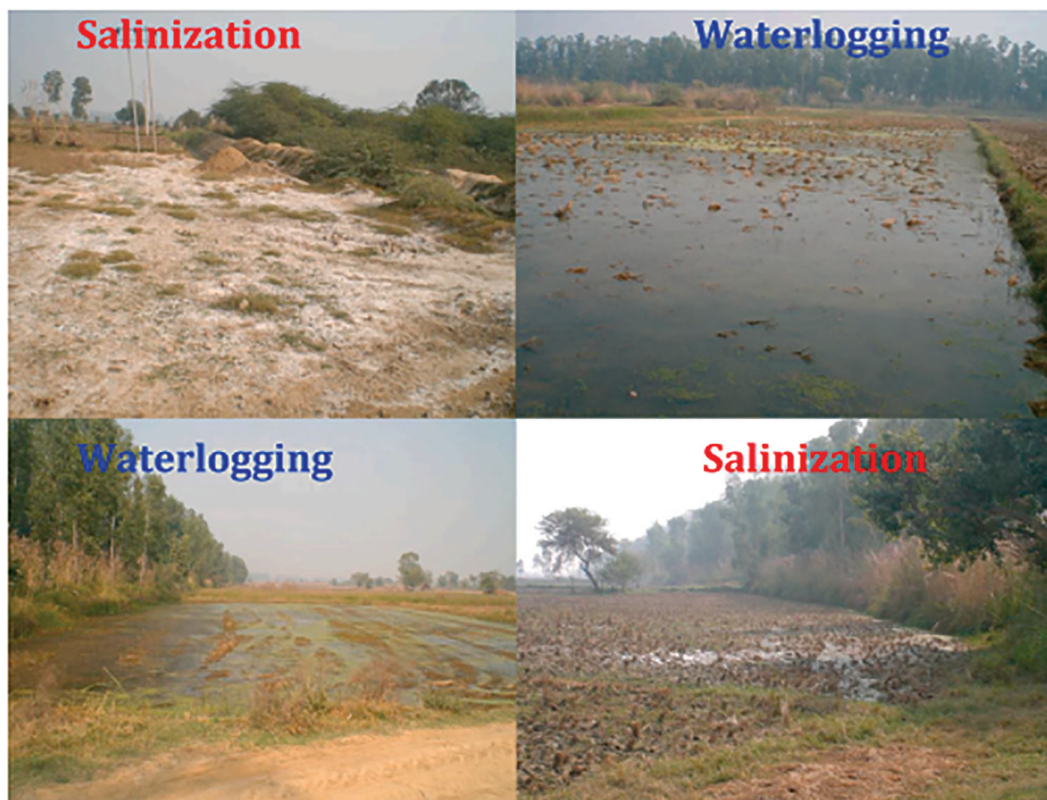


FIGURE 7.1 Soil degradation resulting from waterlogging and salinization in irrigated areas (Singh, 2021).

for drinking) to health risk. Also, the use of wastewater for irrigation increases rate of salinization at 0–30 cm and 30–60 cm depths of the soil, although the salinity of freshwater irrigated soils is relatively low, especially at the deep soil layers (Khanpae et al., 2020). In a similar way, Niemeyer et al. (2020) reported that irrigation with produced water negatively affects the soil habitat function, and aquatic testing with leachates showed likely impacts to adjacent water bodies. Figure 7.1 shows soil degradation because of waterlogging and salinization in irrigated areas.

7.2.7 Soil Properties

Irrigation water affects soil structure and other soil properties, especially when long-term irrigation regimes is practiced; these effects of irrigation water on the soil properties are dependent upon the water quality, method of application, and nature of the irrigated soil, and may be beneficial or negative (Adejumobi et al., 2014), but wastewaters (treated/untreated) have been reported to cause more adverse effects than tap-water (Ofori et al., 2021). The buildup of salts in the soil is capable of causing permanent impairment to the soil structure crucial for irrigation and crop productivity; such negative impact is observed more in clayey soils where the presence of sodium causes the failure of soil structure (Dougherty et al., 1995). This effect brings about some difficulties such as rendering the area less productive for growing crops, making the soil difficult to work, and making reclamation difficult (if not impossible) for reclamation by standard techniques. However, the practice of mixing irrigation water or soil with gypsum prior to irrigation is employed to lessen the sodium content and effect in sodic soils (Dougherty et al., 1995).

In some areas (e.g., coastal swamps), acidification may be a great problem. The transition from rainfed to irrigated crop production needs adequate availability of nutrient as some amount of water and nutrients are lost through the soil cross section. If proper attention is ignored, the irrigation project becomes inefficient. When the water loss through the soil profile gets high, there would likely be an increased loss of beneficial cations. Also, a reduction in soil pH may lead to inability of plants to absorb nutrients and/or a rise in heavy metals presence in the soil; similarly, decrease in soil pH may equally cause a decrease in OM content of the soil and this consequentially leads to degradation of soil structure as well as decrease in soil fertility. For instance, a study carried out on the soils of the Omi Irrigation Scheme, Kogi State, Nigeria after 13 years of its operation showed that there was a change (reduction) from the initial neutral soil pH level (pH=6.65–7.00) to at the beginning of the scheme to slightly acidic pH level (pH=6.53–6.60) (Adejumobi et al., 2014). They equally observed a significant increase in some biological, physical and chemical of the soil including cation exchange capacity, OM, and OC. Hence, proper attention and monitoring should be given in this regard as remedying soil deterioration and acidification complications is very expensive.

7.3 Water and Air Quality

The environment and human health are affected by the quality of air. Therefore, efforts are being made globally to develop various ways to improve the quality of air. The largest environmental health risk is air pollution. It is a global crisis that has become increasingly significant in recent times and will continue well into the future. Poor air quality directly affects all living things. Some air pollutants contribute to greenhouse gas (GHG) emission and disrupt the processes in the ozone protective layer. It is thus necessary to protect this resource by ensuring that it is of the highest possible quality.

Water is another vital natural resource. Though the earth surface seemingly has an abundance of water, only some portion of the global water available is usable, making it a limited resource that must be used carefully. Water is used for varying purposes; its quality must, therefore, be determined before use. Furthermore, regular monitoring of the different sources of water is required to assess its quality.

7.3.1 Toxicity

Toxicity usually occurs when certain salts present in irrigation water are taken up by plants and accumulated in the leaves, causing damage to the plants. A high concentration of boron, chloride, and sodium in irrigation water leads to toxicity and harm plants. The concentration of salts in irrigation water that would lead to toxicity differs depending on the crop sensitivity. Testing of water can assist in ascertaining any components that might be toxic to plant.

Wastewater reuse in irrigation agriculture has recently become common in areas where water shortages are more pronounced (low-income, arid and semi-arid countries) (Hajjami et al., 2012). Particularly in the developing countries, reuse of untreated wastewater is becoming widespread (WWAP [United Nations World Water Assessment Programme], 2017). Wastewater irrigation is gaining broader recognition in many parts of the world because of its many advantages, water scarcity, and climate change. However, aside from the multiple benefits of this resource, reuse water also comprises heavy metals that create problems for agricultural production (Alghobar and Suresha, 2017). Therefore, long-term reuse of industrial or municipal irrigation wastewater can contribute to toxic pollutant accumulation in agricultural soils and plants (Singh et al., 2010). A study by Arora et al. (2008) suggested that irrigating farmlands with wastewater led to a high concentration of heavy metals in the growing plants' edible portions (Arora et al., 2008).

Excessive heavy metal deposition on agricultural soils by irrigating with wastewater is dangerous to the lives of inhabitants who consume crops grown in polluted areas (Chaoua et al., 2019). Toxicity effects on human health by heavy metal intake through food is already a concern reported worldwide (Malan et al., 2015).

7.3.2 Pollution

Pollution is the contamination of the environments with harmful substances to the health and well-being of its inhabitants. Pollutants are toxic substances produced in higher-than-average concentrations, which harm our ecosystems. Pollution of water is a global crisis faced by both developing and developed countries; it undermines economic development and the socio-environmental resilience and well-being of billions of people (Mateo-Sagasta et al., 2017). Due to excessive water pollution and global scarcity of water resources, protecting river water quality is very critical (Dwivedi and Shikha, 2016).

Irrigation has often been linked to water pollution caused by runoff and leaching of salt, pesticides, and fertilizers (Mateo-Sagasta et al., 2017). In many regions, the return flow of irrigation is a significant cause of water pollution as it impacts water quality for subsequent uses (e.g., domestic, industrial, and supply for irrigation). More so, institutions like the US Environmental Protection Agency consider irrigation to be the critical cause of water pollution (US EPA, 1992).

Use of polluted water from waste, agricultural, or industrial sources in irrigation adversely affects soil quality, increases the number of trace elements present in plants and soils, and harbors harmful pathogens (Allende and Monaghan, 2015; Hass et al., 2010). Polluted water is a potential cause of both direct and indirect contamination of agricultural produce (Singh et al., 2018), which contributes to increased soil and water degradation (Islam et al., 2018). Contaminants in soils are leached to the unsaturated zone in regions where over-irrigation is practiced, where they can lead to geogenic contaminant mobilization and possibly raise the levels of contaminants in local groundwater (Nolan and Weber, 2015).

7.3.3 Anaerobic Effects

Appropriate irrigation management is needed to maintain adequate soil moisture in the active root zone for optimal development of crops. Soil moisture in the crop root zone is increased above field capacity by over-irrigation. This excessive water application disrupts the soil's oxygen balance, inundates roots, lowers uptake of plant water, and thereby stresses plants (Irmak and Rathje, 2008). The restriction of oxygen in the soil leads to anaerobic conditions, affecting plant development and OM constituents. Shortage of oxygen in the soil profile damages the root, shoots, and germinating seeds they support (Vartapetian and Jackson, 1997), which are not adapted to this type of environment. Providing a medium for plant growth is an important function of soil; therefore, changes in its physical and chemical characteristics have a significant effect on the production of root biomass and, hence, on plant vegetation (Pierret et al., 2007). For the optimal development of plants, air and water have to be available in adequate proportion within the soil. The anaerobic condition affects both the chemical and biological properties of the soil, subsequently impacting biological activities, leading to many microbes not being able to survive without oxygen. The reduction of O_2 and the related mechanisms affect plant survival, growth, and functioning in waterlogged soils (Pezeshki and DeLaune, 2012). An increased population of putrefying microorganisms producing toxins and high levels of soil-borne diseases are also anaerobic effects caused by poor irrigation management.

7.3.4 Gas Emission

Intensified agriculture has proved to play an important role in increasing food production through different irrigation practices (important et al., 2020). Irrigation increases the production of crops; however, its operation also increases machinery and energy demand, which consumes significant fossil energy quantities and potentially contributes to GHG emissions (Pimentel and Pimentel, 2003). According to the Intergovernmental Panel on Climate Change, 2014 (IPCC, 2014), irrigation increases the agricultural impacts of global warming which is a major contribution of GHG. Increase in soil water content, C mineralization, respiration, and microbial activity of soils by irrigation can increase CO_2 and N_2O emission

(Sainju et al., 2012). Soils flooded by over-irrigation can release N_2O and CH_4 emissions through the process of denitrification and anaerobic decomposition of OM in the soil (Sainju et al., 2012).

Furthermore, the common practice of continuous flooding irrigation, used for growing rice, releases a significant quantity of CH_4 . Continuous flooding leads to anaerobiosis condition in the soil, causing anaerobic breakdown of complex organic substrates by methanogens and the release of CH_4 (Islam et al., 2020). Aggravating climate change by increase in GHG emissions, through intensified agricultural practices, results in reduced agricultural productivity (Hu et al., 2019). Various other negative effects on the environment include loss of biodiversity, pollution of water, soil erosion, and degradation.

7.3.5 Groundwater Salinity

Roughly 30% of water withdrawn globally for irrigation is estimated to flow back to rivers and groundwater via conveyance losses and return flows (irrigation water above plant need, drained from the soil and returned to ground/surface water) (Scanlon et al., 2007). The quality of groundwater is impacted by return flow as it is usually composed of dissolved salts, concentrated by evapotranspiration. Irrigated agriculture has critical impacts on groundwater quality and can change the quantity of groundwater resources (Bouwer, 1987). Groundwater salinization in irrigated soils can occur by: concentration of salts through the uptake of plant water; irrigation with wastewater, saltwater intrusion due to pumping of groundwater; leaching down of salts into groundwater (Suarez, 1989; Van Weert et al., 2009). Several studies have also shown that intensive abstraction of groundwater for irrigated agriculture has led to the deterioration and depletion of aquifers globally (Faunt et al., 2016; Pulido-Bosch et al., 2018; Wada et al., 2010).

The salinity of groundwater occurs when the level of concentration of dissolved solids is over a pre-defined limit (total dissolved solids, or a thousand milligrams of dissolved solids in a liter of water, mg/L) (Freeze and Cherry, 1979). Saltwater intrusion is a common issue for coastal aquifers worldwide, mainly where groundwater abstraction is substantial (Werner et al., 2013). Over-exploitation and poor management have raised the risk for saline water intrusion, which can harm agricultural productivity of coastal crops by salt accumulation, resulting in harmful effects on soils and plants (El-Fadel et al., 2018). High salts concentration in groundwater increases salts content in the root zone, thereby exerting an osmotic effect on plants, causing them to expend and consume more energy in extracting water rather than using it for plant development and hence stunting plant growth (Blaylock, 1994).

Several past studies also found evidence that high salt concentrations have a detrimental effect on agricultural potential by lowering crop yields and causing additional costs for salinity management (Foster et al., 2000; George et al., 2008; Lee and Howitt, 1996).

7.4 Hydrology

Water is an essential aspect of the ecosystem, about 70% of the earth is covered with water while only about 2.5% is freshwater available for human use. Out of the 2.5% of freshwater available about 30% is found in groundwater and 70% in rivers, lakes, and glaciers (Salas et al., 2014). This is why a comprehensive understanding of hydrology which is the science that encompasses the existence, occurrence, distribution, properties, and storage of water above, on, and below the earth's surface is of utmost important in order to enable conservation of water resources and best management practices for its sustainability in the ecosystem. A process by which water flows continuously from the earth surface and water bodies to the atmosphere is known as hydrologic cycle. Figure 7.2 shows the hydrological cycle illustrating how water is circulated through the ecosystem. The limited availability of freshwater has resulted to its competitive demand, which has widely been increasing, thereby making it difficult to satisfy water for human consumption, agricultural practices, and other uses (Omotade et al., 2019). Globally, agriculture is the largest demand for water (OECD, 2010; Wallace, 2000) because water use in agriculture is for cultivation of crops and rearing of livestock; United States Geological Survey (USGS) reports that

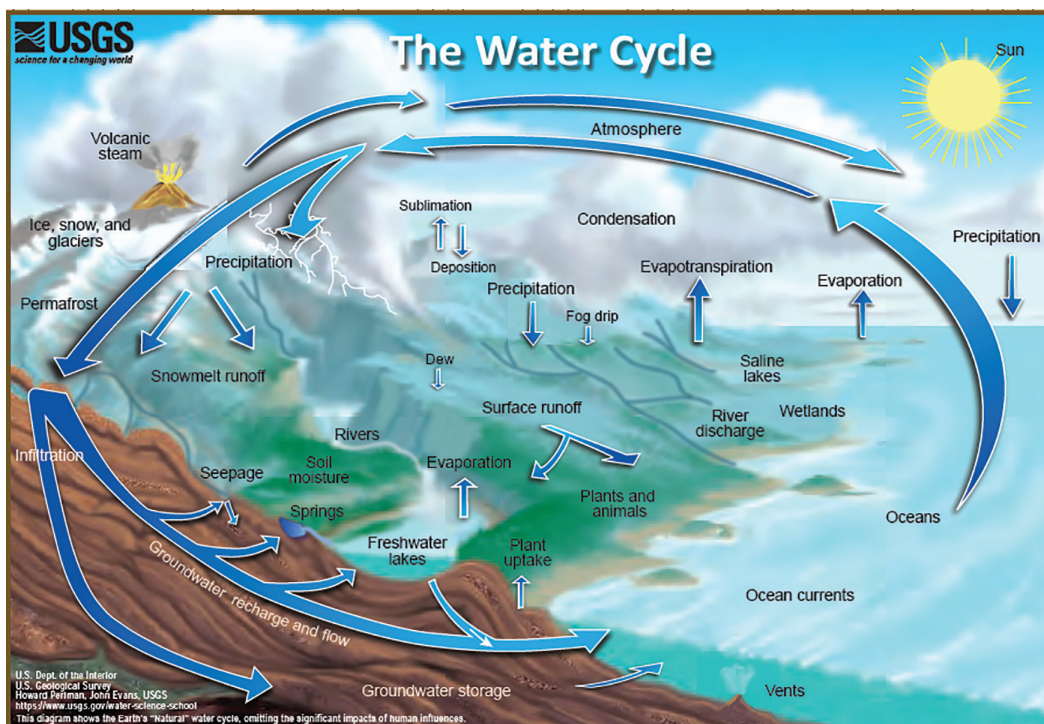


FIGURE 7.2 Hydrological cycle (Water cycle, 2020).

agricultural irrigation alone accounts for about 65% of the global freshwater available (Abunnour et al., 2016). Irrigation is important because it contributes to increase in agricultural production through the supply of water to crops to supplement limited rainfall and in dry regions to enable optimum yield. Recognizing the environmental impacts of irrigation on the hydrological cycle is important in ensuring effective management of groundwater resources and in the enhancement of optimum agricultural productivity (Foster et al., 2018).

7.4.1 Flow Characteristics Alteration

Irrigation affects the flow characteristics of rivers and groundwater discharge, because whenever new irrigation schemes are constructed or old schemes rehabilitated, the hydrological regime will be altered (Dougherty et al., 1995). During the process of fertigation, irrigation results in contamination of surface water through return flow and pollution of groundwater through seepage. This is because irrigation is an anthropogenic factor in the hydrological cycle which makes it highly significant in carrying salt and various contaminants in soil and water (Holy, 1993). Litskas et al. (2010) reported an increase in the concentration of nitrate due to the use of fertilizer during irrigation. This outcome impairs water quality, and decreases the sustainability of agricultural ecosystem and the environment (Holy, 1993) as highlighted in Figure 7.3. Also, poor sustainability of irrigation systems leads to aquifer exhaustion by abstraction of irrigation water, salinization, or contamination of water by minerals. Intrusion of salt into river bodies and infiltration of water with high content of salts endanger neighboring soil water and cause deterioration of watercourses (Foster et al., 2018; Holy, 1993). Impaired water quality in the downstream regions will have negative impacts on human health, recreation amenities, and make the ecosystem vulnerable (Brown and Harris, 2005).

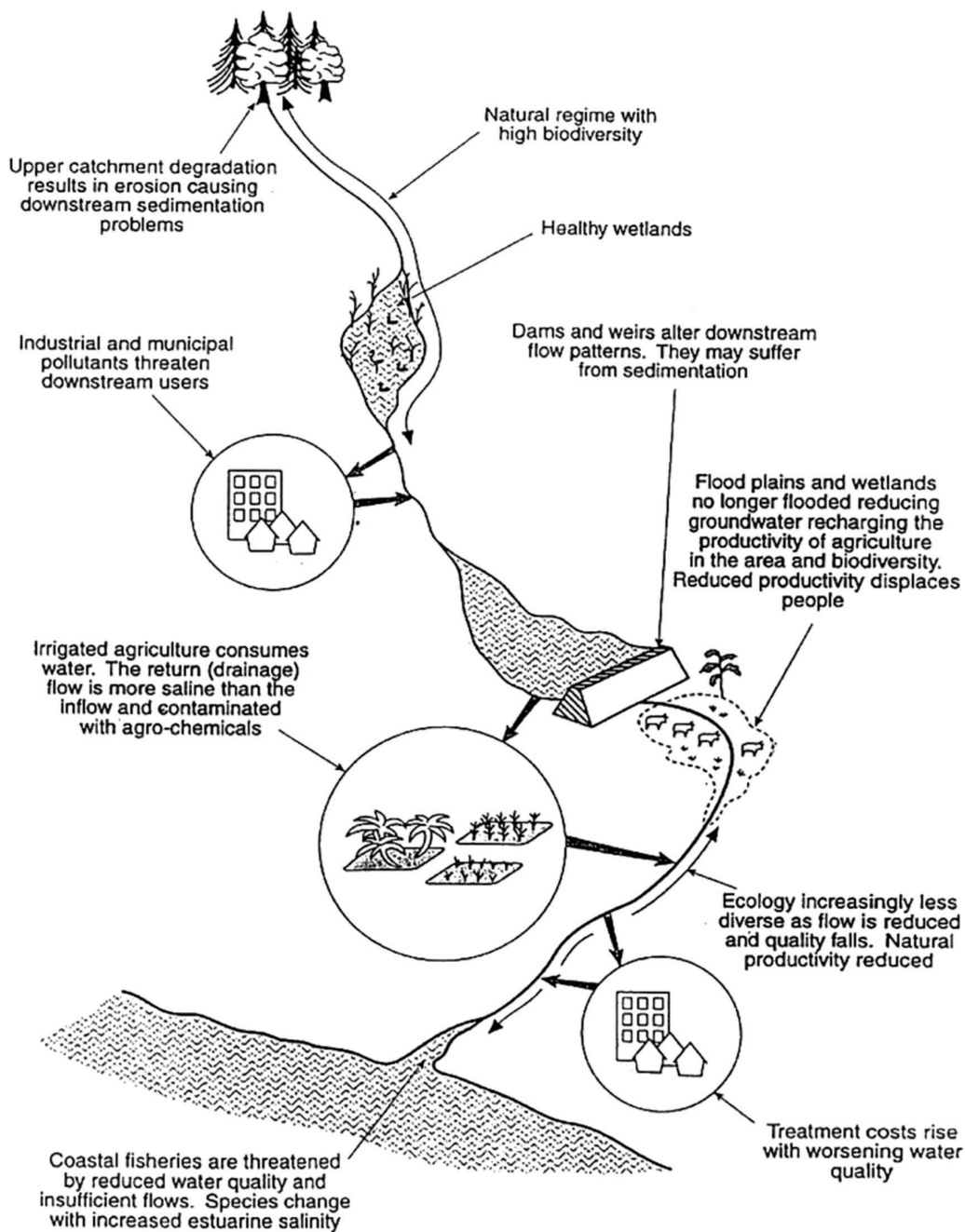


FIGURE 7.3 Origins and effects of poor water quality in a river body (Dougherty et al., 1995).

Continuous groundwater-based irrigation also negatively affects the flow between surface and groundwater, which results in drawdown and other issues, including soil compaction, hence, creating a disturbance of natural flow regimes as a result of the altered active and passive groundwater recharge zone (Foster et al., 2000; Leduc et al., 2001). More so, water flow is altered through the reduction of soil water infiltration capacity, which is as a result of solid particles present in irrigation water which thus

influence the aeration rate of the soil. In the process of construction of irrigation systems on the land area, vegetative cover and top soil are removed, thus causing adverse effects on the hydrological balance in the watershed. Massive irrigation projects have the possibility of causing environmental disturbances as a result of changes in the hydrology and limnology of river basins. In addition, diverting water for irrigation use reduces river base flow which results in reduction in water supply for downstream users, and thereby increase in the pollution rate from municipal and industrial at the downstream; these pose health hazards.

7.4.2 Flood Characteristics Alteration

Flood can be defined as the presence of excess water on land as a result of high flow or overflow of water in an established watercourse (Magami et al., 2014). During rainfall or irrigation, excess water remains after infiltration and evaporation have taken place when the soil, streams, and artificial reservoirs are fully saturated with water; this excess water moves along the land surface as runoff. Most times, flood occurrences are caused by natural factors, but in some cases, anthropogenic (man-made) factors such as irrigation can also cause flooding. Human activities such as dam construction, irrigation, bridges, and others have impacted on free flow of water in the drainage channels, rivers, and streams (Aderogba, 2012). Altered flood regime can have adverse effect and negative impacts on the environment, as it reduces groundwater recharge through floodplains and causes loss of periodic or permanent wetlands. Irrigation schemes can lead to reduction in the amount of bare ground, thereby making an area to be prone to flooding. Also, it can affect the natural drainage pattern, thereby causing localized flooding. Flow alteration as a result of human activities emanating from dam construction, stream channelization, canal construction, irrigation schemes, etc., will lead to flooding and impair the ecosystems (Hupp et al., 2010).

Also, another positive significant impact of irrigation is the reduction in wind erosion risk (Brown and Harris, 2005). However, the negative impacts of flood are devastating; it can destroy lives and properties. Flood is perceived as the most dangerous in the physical environment that destroys what people have labored for in many years (Memon and Sharjeel, 2016). Also, reduce the water quality of downstream rivers through the introduction of huge quantity of eroded materials and damage of the environment through the leakage of harmful substances which affect the ecosystem (Zeleňáková et al., 2016; Hickey and Salas, 1995). Flood is the most dangerous in the physical environment that destroys what people have labored for in many years (Memon and Sharjeel, 2016).

7.4.3 Water Table Level Change

Water gets below the earth's surface through the infiltration of surface water down the soil profile to become groundwater (Winter et al., 1998). Water is stored within cracks in the rocks and tiny pores between soil aggregates which makes up of sand, gravel, rock, etc., held together by force of cohesion and fragmentation processes (Nimmo, 2013). The amount of water held in a soil is dependent on many factors which include how well the soil particles are loosely arranged, porosity of soil, etc. There are two main zones that describe where water is found in the ground; they are: unsaturated zone and saturated zone. Unsaturated zone is the region which lies immediately below the soil surface and contains air and water in the soil pores and rock fractures. This zone, also known as the zone of aeration, is between the land surface and aquifer which contains different natural constituents; also, flow processes that occur at this zone contribute to broad variation of hydrologic processes (Nimmo, 2005).

The saturated zone is the region underlying the unsaturated zone; it has water completely filled in all its pores and rock fractures. Water table is the upper layer of the zone of saturation; this layer lies between the unsaturated and saturated zones. Depth of water table varies seasonally depending on the attributes of the land area; it can be directly below the land surface if such area is close to permanently existing water bodies such as wetlands, rivers, lakes, or hundreds of meters below the land surface in some areas (Winter et al., 1998).

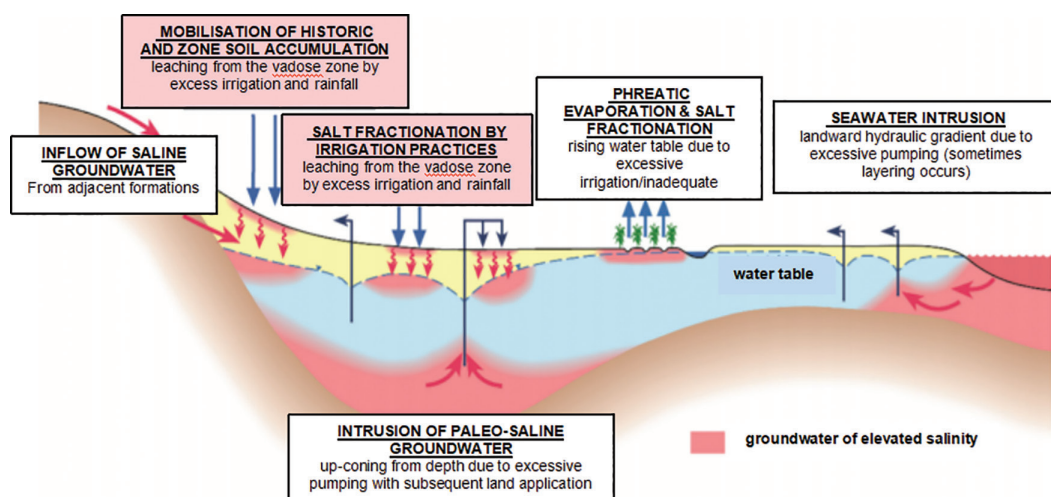


FIGURE 7.4 Processes of groundwater salinization (Foster et al., 2018).

According to Winter et al. (1998), irrigation contributes a larger percent than precipitation to groundwater recharge, especially in regions with low precipitation and low natural recharge where large irrigation systems are used, thus leading to rise in water table. Also, continuous recharge from irrigation return flow can result in permanent rise in the depth of water table, thereby causing increased outflow from irrigated area to surface water bodies from shallow groundwater (Winter et al., 1998). In areas with flat land having low hydraulic gradient, irrigation tends to raise the depth of water table as a result of losses of irrigation water through leakages from canals and percolation from irrigated fields. This results in an increase in groundwater recharge and capillary rise of water through the soil profile, thereby causing the problem of waterlogging of agricultural land and salinity of groundwater. Figure 7.4 shows a schematic representation of rising water table contributing to the processes of groundwater salinization. Groundwater-based irrigation can cause fall of water table; when irrigation water is drawn, there is a fall of water table which depletes the groundwater system, wells, springs, or river flow. Decrease in water table will cause springs that are fed by groundwater to dry up and also reduce low flow in rivers. Likewise, another problem associated with groundwater depletion is saline intrusion along the coast which leads to severe environmental and economic consequences (Dougherty et al., 1995).

7.4.4 Dam Siting and Operation Impacts

Dam is a hydraulic barrier or structure built across a stream, river to confine and check the flow of water, use for human consumption, irrigation, flood control, and electric power generation (Graham, 2002). The importance of dam to the construction of irrigation system is enormous because of the numerous benefits of impounding water for use at any seasonal period. However, there have been reports of alteration of natural flow regimes of watersheds all around the globe as a result of construction of dams (Mailhot et al., 2018; Yan et al., 2010). Dam construction is another direct means of measuring the negative impacts of irrigation on the environment. Dam siting in an area will alter the hydrological, geographical, and topographical factors in the neighboring areas, thereby causing unsuitable environmental conditions. Ajibade et al. (2020) pointed out that safety is the most significant factor over cost and capacity because a dam failure usually results in severe loss of life and property, necessitating the consideration of some crucial factors for an appropriate dam location. Penvenne (1996) reported that the impact of the construction of High Aswan Dam decreased sediment transport which led to erosion of wetlands in the Nile Delta 800 km downstream. Also, during the construction of dam, there will be

alterations in the flow of water and changes in water quality downstream. The construction of dam and servicing of irrigation systems cause disruption of natural flow regime, which can significantly cause changes in siltation and erosion pattern. Globally, different studies have shown that dam construction and operations alter frequency, duration, and magnitude of flow regime (Sakaris, 2013; Magilligan and Nislow, 2005; Magilligan et al., 2003) and reduce peak flows and alter year-to-year flow variability (Magilligan and Nislow, 2005). During dam construction, likely risk which occurs is overtopping which results in erosion; this erosion causes increased inundation and sedimentation of downstream areas.

7.5 Biotic and Ecological Effects

Intensive agriculture via irrigation has been a key factor for the loss of biodiversity and environmental deterioration globally (Benton et al., 2003; Tilman et al., 2002; Green et al., 2005). And together with the increased in farm mechanization, agrochemical application, monocropping, and change in farming landscapes (José-María et al., 2010; Benton et al., 2003), irrigation scheme agriculture reduces ecological heterogeneity, causes valley flooding and aquifer drainage, and encourages increased chemical application; increased salt content in the soil and fallow lost due to crop rotation (Dover and Sparks, 2000; Ruiz, 1990; Stoate et al., 2001; Herrero and Snyder, 1997). Since intensive agriculture via irrigation is encouraged globally to increase food production particularly in dry landscapes, agricultural production has increased in two-to-three folds over the last 50 years with 12% increase in arable land (FAO, 2011). Therefore, this enhanced agricultural production due to irrigation which is still growing 117% globally and may imply several biotic and ecological effects.

7.5.1 Biodiversity and Landscapes

Information on the understanding of the impacts of irrigation on biodiversity is still very limited. Studies, especially those focusing on the creation of irrigated land from dryland, recorded the adverse impact of such transformation on birds (de Frutos and Olea, 2008; Ursúa et al., 2005; Tella and Forero, 2000; Laiolo, 2005; Brotons et al., 2004). Records on the adverse effect of irrigation on arthropods have also been highlighted (Holzschuh et al., 2007; Ponce et al., 2011; Hyvönen and Salonen, 2002; Krauss et al., 2011; Roth et al., 2008; Prieto-Benítez and Méndez, 2011; Herzog et al., 2005; Tybirk et al., 2004; Knop et al., 2006), while positive effects such as abundance, richness, and diversity have also been published (González-Estébanez et al., 2011; Kleijn et al., 2001; Weibull and Östman, 2003; Melnychuk et al., 2003; Weibull et al., 2000). However, such dissimilarities were attributed to the landscape complexity. González-Estébanez et al. (2011) explored the complexity of landscape on butterfly diversity due to irrigation. Butterflies are known as a very important environmental indicator as the result of their sensitivity even to subtle ecological changes (Kremen, 1992; Erhardt, 1985; Stefanescu et al., 2004; Thomas, 2005). In a dry cereal farming system compared to conventional irrigation system, increased numbers of butterflies were recorded (González-Estébanez et al., 2011). This was attributed to the landscape complexity due to the irrigation scheme.

7.5.2 Impacts on Biotas and Habitats

Irrigation activities expose surface water to diverse effect ranging in different intensity, scales, duration, and strength, thus depleting biotas and causing environmental disruption (Lake, 2000; Giller and Myers, 1996). Generally, freshwaters including lakes and rivers are exposed to such disturbances especially in irrigation-fed agriculture, grazing by livestock and land clearance, which generate significant sediments into water bodies (Hornung and Reynolds, 1995; Waters, 1995; Harding et al., 1998), thus, reducing the water biodiversity, interstitial and habitat spaces (Waters, 1995; Boulton, 1999). An example is the case of the decreased diversity and abundance of benthic invertebrates such as Ephemeroptera, Plecoptera, and Trichoptera, and burrow animals such as oligochaetes and chironomids (Lake et al., 2000).

7.5.3 Water Bodies

Irrigation-fed agriculture depends on the water supply from water bodies. As a result, water characteristics and method with which the irrigation is done impact the environment (Stockle, 2001). The removal of groundwater for irrigation can cause the land to subside, aquifers to become saline, and can accelerate other adverse ecological impacts (Zektser et al., 2005; Wang et al., 2018; Greene et al., 2016). An example is the Colorado river which has been reported to hold nearly no water due to irrigation schemes (Fradkin, 1996; Nagler et al., 2008; Gertner, 2007). The same was reported for the San Joaquin which beds have been recommended by designers for construction of houses. Cotton flooding has over the past 33 years, reduced the Aral Sea to 75% of its volume causing elevated saltiness.

7.5.4 Pests, Weeds and Animal Diseases

Irrigation commonly provides favorable environments that enable the development of crop diseases, specifically, fungal and bacterial foliage diseases (Dougherty et al., 1995). Illnesses and unwanted plants often outspread easily via wastewater reuse and drainage water. Yusuf (2008) has reported some diseases such as malaria, schistosomiasis, and dysentery/diarrhea within the area of the Bakolori Irrigation Project. Irrigation brings about some favorable environmental changes to some species of pests such as rodents and insects. It may equally provide a good environmental condition for proper growth and yield of local and imported varieties of weeds. However, through the common switching of land uses and intensified application of pest-killing chemicals associated with irrigation, habitats of some natural predators like snakes, birds, and spiders may be lost or reduced (Dougherty et al., 1995). Furthermore, there is usually a problem of aquatic weeds which cause some issues such as reduction in storage and conveyance volume of reservoirs, channels and drainage systems, increased water loss via evapotranspiration, and provision of prosperous and protective environment for disease vectors (e.g., snails and mosquitoes). All these problems arise due to the presence of large water bodies that serve as breeding sites for diseases vectors and pests (Yusuf, 2008).

7.6 Ensuring Environmental Quality and Sustainability: Sustainable Ways and Techniques to Mitigate Negative Impacts of Irrigation on the Environment

The continuous growth in the world's population will lead to the construction of more dams, aqueducts, and other kinds of infrastructure for irrigation, especially in developing nations where an increase in agricultural productivity is needed. More consideration should be given to the local people and their environment by building higher standard infrastructures with minimal environmental impact and suitability than in the past. Even in regions where these infrastructures are most needed, minimal ecological disruption and cheaper resources should be considered. Based on physiography and soil conditions, the FAO has estimated the potential for an additional 400 million hectares of land, of which three-quarters of developing countries will be added to irrigation land. The belief that irrigation land is more productive than rainfed soil has created the expectation for an increase. Although, inadequate suitable lands, shortage of water supplies, and the high installation cost limit the growth of the current irrigation schemes in developing countries. Hence, improving the existing irrigation structure is more advantageous for such a region than giving room to new constructions.

Agriculture is one of the largest consumers of water. Water via irrigation is largely lost and inefficient as it moves from farmers to crops. As a result, more than half of the water diverted into agriculture never yielded to any food. Thus, a modest improvement in agricultural efficiency can save lot of waters for other purposes. Also, tremendous gains in water efficiency can be gained by shifting where people use water. For instance, supporting 100,000 innovative California occupations requires approximately 250 million gallons of water a year; a similar measure of water utilized in the horticultural area supports

less than ten positions, a shocking distinction. Comparable figures apply in numerous different nations. Eventually, these variations will prompt more strain to move water from agrarian utilizations to other financial areas.

Advanced ways to deal with addressing water needs will not be anything but difficult to execute because financial institutions are often empowering the wastage of water and damaging environmental systems. Effective water management and utilization are hampered by several factors, including inappropriately low water costs, a lack of knowledge about new, better technologies, inadequate water budgets, and government subsidies for the development of dams or water-intensive crops in desert regions. Different interventions are practicable for forestalling, alleviating, or reversing soil and water degradation at various levels with irrigation-fed farms. A summary of approaches to solving water issues are listed in different categories below:

Policy Interventions

- Introduction of better market value for water and power pricing.
- Transferable water benefits could be encouraged.
- Introduction of standards to foster groundwater recharge and penalties for defaulters.
- Incentives for land reclamation should be provided.
- Comprehensive impact assessment should be carried out for new irrigation schemes.
- Improvement and government incentives for maintaining existing irrigation schemes should be provided.

Engineering Interventions

- EIA should be incorporated in designing, construction, and operations of new irrigation schemes.
- Provision of maintenance scheme for irrigation structures.
- Construction of new and improvement of maintenance for existing drainage facilities.
- Effective alternatives to waste effluents disposal.
- Reduction and prevention of canal seepage via lining.

Irrigation/Agronomic Practices Interventions

- Water loss reduction from on-farm discharge.
- Minimizing deep percolation and surface runoff via improved irrigation systems performance.
- Improvement and precision land leveling of on-farm watercourse.
- Application of effective irrigation methods such as drip irrigation method.
- Sediment concentration in runoff water should be minimized.
- Cultivation of less water absorbing crops.
- Effective of chemical fertilizers.
- Soil amendments and reclamation practices application.

References

7.7 Conclusion

Irrigation has played significant impacts to solve agricultural water shortage for increasing food and environmental security. Due to the rapid growth of water demand from other non-agricultural sectors, the utilization of treated wastewater has been adopted as a supplement to rainfall. However, the poor wastewater treatment quality has led to adverse effects on hydrology, soil fauna communities and surrounding ecological resources. To this end, this chapter sums up the various impacts of irrigation development and practices on the environment including soil degradation, channel configuration, soil

physicochemical properties, air and water quality, general hydrology of the region of operation, biotic and general ecological community, as well as their resultant direct/indirect negative impacts to the human society. Furthermore, some promising methods and practices spanning through policy intervention, engineering technology, and improved irrigation practices/techniques were suggested to help educate farmers, irrigators, policy makers, and the general public on the better intervention developments that could be employed. This will not only increase agricultural output at less cost but also help in ensuring human health safety and the sustainability of the environment.

References

- Abunnour, M.A., Hashim, N.B. and Jaafar, M.B. (2016). Agricultural water demand, water quality and crop suitability in Souk-Alkhamis Al-Khums, Libya. *IOP Conference Series: Earth and Environmental Science*, 37(012045). <https://doi.org/10.1088/1755-1315/37/1/012045>.
- Adejumobi, M.A., Ojedian, J.O., & Olabiyi, O.O. (2014). Effects of irrigation practices on some soil chemical properties on OMI irrigation scheme. *International Journal of Engineering Research and Applications*, 4(10), 29–35.
- Aderogba, K.F. (2012). Qualitative studies of recent floods and sustainable growth and development of cities and towns in Nigeria. *International Journal of Academic Research in Economics and Management Sciences*, 1(3), 1–25, ISSN: 2226-3624
- Adewumi, J.R., & Ajibade, F.O. (2019). Periodic determination of physicochemical and bacteriological characteristics of wastewater effluents for possible reuse as irrigation water. *International Journal of Energy and Water Resources*, 3, 269–276. <https://doi.org/10.1007/s42108-019-00036-6>.
- Ajibade, F.O., Adelodun, B., Lasisi, K.H., Fadare, O.O., Ajibade, T.F., Nwogwu, N.A., Sulaymon, I. D., Ugya, A. Y., Wang, H. C., & Wang, A. (2021). Environmental pollution and their socio-economic impacts. In A. Kumar, V. K. Singh, P. K. Singh, & V. Mishra, *Microbe Mediated Remediation of Environmental Contaminants* (pp. 321–354). Cambridge: Woodhead Publishing, Elsevier. <https://doi.org/10.1016/B978-0-12-821199-1.00025-0>.
- Ajibade, F.O., Adewumi, J.R., & Oguntuase, A.M. (2014a). Sustainable approach to wastewater management in the Federal University of Technology, Akure, Nigeria. *Nigerian Journal of Technological Research*, 9(2), 27–36.
- Ajibade, F.O., Adewumi, J.R., & Oguntuase, A.M. (2014b). Design of improved stormwater management system for the Federal University of Technology Akure. *Nigerian Journal of Technology (NIJOTECH)*, 33(4), 470–481.
- Ajibade, T.F., Nwogwu, N.A., Ajibade, F.O., Adelodun, B., Temitope, E.I., Ojo, A.O., ... Akinmusere, O.K. (2020). Potential dam sites selection using integrated techniques of remote sensing and GIS in Imo State, Nigeria. *Sustainable Water Resources Management*, 6(57). <https://doi.org/10.1007/s40899-020-00416-5>.
- Alghobar, M.A., & Suresha, S. (2017). Evaluation of metal accumulation in soil and tomatoes irrigated with sewage water from Mysore city, Karnataka, India. *Journal of the Saudi Society of Agricultural Sciences*. <https://doi.org/10.1016/j.jssas.2015.02.002>.
- Ali, Y.A., Crosato, A., Mohamed, Y.A., Abdalla, S.H., & Wright, N.G. (2014). Sediment balances in the Blue Nile River Basin. *International Journal of Sediment Research*, 29, 316–328.
- Allende, A., & Monaghan, J. (2015). Irrigation water quality for leafy crops: A perspective of risks and potential solutions. *International Journal of Environmental Research and Public Health*. <https://doi.org/10.3390/ijerph120707457>.
- Al-Reyami, N.S., Shaik, F., & Lakkimsetty, N.R. (2020). Environmental impact on usage of treated effluents from ISTP for irrigation. *Journal of Water Process Engineering*, 36, 101363.
- Arienzo, M., Christen, E.W., Jayawardane, N.S., & Quayle, W.C. (2012). The relative effects of sodium and potassium on soil hydraulic conductivity and implications for winery wastewater management. *Geoderma*, 173–174, 303–310. <https://doi.org/10.1016/j.geoderma.2011.12.012>.

- Arora, M., Kiran, B., Rani, S., Rani, A., Kaur, B., & Mittal, N. (2008). Heavy metal accumulation in vegetables irrigated with water from different sources. *Food Chemistry*. <https://doi.org/10.1016/j.foodchem.2008.04.049>.
- Asawa, G.L. (2005). *Irrigation and Water Resources Engineering*. New Delhi: New Age International (P) Limited, Publishers.
- Asayehegn, K., Yirga, C., & Rajan, S. (2012). Effect of small-scale irrigation on the income of rural farm households: The case of Laelay Maichew District, Central Tigray, Ethiopia. *Journal of Agricultural Sciences*, 7(1), 43–57. <https://doi.org/10.4038/jas.v7i1.4066>.
- Ayers, R.S., & Westcot, D.W. (1985). *Water quality for agriculture. Irrigation and Drainage Paper 29 (Revised)*. Rome, Italy: FAO.
- Baldock, D., Caraveli, H., Dwyer, J., Einschütz, S., Petersen, J.K., Sumpsi-Vinas, J., & Varela-Ortega, C. (2000). *The Environmental Impacts of Irrigation in the European Union*. London: Institute for European Environmental Policy.
- Ballantine, D.J., Hughes, A.O., & Davies-Colley, R.J. (2014). Mutual relationships of suspended sediment, turbidity and visual clarity in New Zealand Rivers. *Sediment Dynamics from the Summit to the Sea Symposium: New Orleans, LA, USA*.
- Benton, T.G., Vickery, J.A., & Wilson, J.A. (2003). Farmland biodiversity: Is habitat heterogeneity the key? *Trends in Ecology & Evolution*, 18, 182–188.
- Bishaw, D., & Kedir, Y. (2015). Determining sediment load of Awash River entering into Metehara Sugarcane Irrigation Scheme in Ethiopia. *Journal of Environmental & Earth Sciences*, 5(13), 110–117.
- Blaylock, A.D. (1994). *Soil Salinity, Salt Tolerance, and Growth Potential of Horticultural and Landscape Plants*. Laramie, WY: University of Wyoming, Cooperative Extension Service, Department of Plant, Soil, and Insect Sciences, College of Agriculture.
- Boulton, A.J. (1999). The role of subsurface biological filters in gravel-bed river rehabilitation strategies. In: I. Rutherford and R. Bartley (eds) *Second Australian Stream Management Conference: The Challenge of Rehabilitating Australia's Streams* (pp. 81–86). Melbourne: CRC for Catchment Hydrology.
- Bouwer, H. (1987). Effect of irrigated agriculture on groundwater. *Journal of Irrigation and Drainage Engineering*. [https://doi.org/10.1061/\(asce\)0733-9437\(1987\)113:1\(4\)](https://doi.org/10.1061/(asce)0733-9437(1987)113:1(4))
- Braga, J.K., & Varesche, M.A. (2014). Commercial laundry water characterization. *American Journal of Analytical Chemistry*, 5(01), 8–16.
- Brotons L., Mañosa S., Estrada J. (2004) Modelling the effects of irrigation schemes on the distribution of steppe birds in Mediterranean farmland. *Biodiversity and Conservation*, 13, 1039–1058
- Brown, I. and Harris, S. (2005). *Environmental, Economic and Social Impacts of Irrigation in the Mackenzie Basin*. Wellington, New Zealand. www.waitaki.mfe.govt.nz
- Burney, J., Woltering, L., Burke, M., Naylor, R., & Pasternak, D. (2010). Solar-powered drip irrigation enhances food security in the Sudano-sahel. *Proceedings of the National Academy of Sciences*, 107(5), 1848–1853. <https://doi.org/10.1073/pnas.0909678107>.
- Chaoua, S., Boussaa, S., El Gharmali, A., & Boumezzough, A. (2019). Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *Journal of the Saudi Society of Agricultural Sciences*, 18(4), 429–436. <https://doi.org/10.1016/j.jssas.2018.02.003>.
- de Frutos A., Olea P.P. (2008) Importance of the premigratory areas for the conservation of lesser kestrel: space use and habitat selection during the post-fledging period. *Animal Conservation*, 11, 224–233.
- de Sousa, L.S., Wambua, R.M., Raude, J.M., & Mutua, B.M. (2019). Assessment of Water Flow and Sedimentation Processes in Irrigation Schemes for Decision-Support Tool Development: A Case Review for the Chókwè Irrigation Scheme, Mozambique. *AgriEngineering*, 1(8), 101–118. <https://doi.org/10.3390/agriengineering1010008>.
- Depeweg, H.T., & Paudel, K.P. (2003). Sediment transport problems in Nepal evaluated by SETRIC model. *Wiley InterScience*, 52, 260–274.
- Dougherty, T.C., Hall, A.W., & Wallingford, H.R. (1995). Environmental impact assessment of irrigation and drainage projects. *FAO Irrigation and Drainage Paper 53*.

- Dover, J., Sparks, T., 2000. A review of the ecology of butterflies in British hedgerows. *Journal of Environmental Management*, 60, 51–63.
- Dwivedi, S., & Shikha, D. (2016). Water pollution: Causes, effects and control. *Biochemical and Cellular Archives*, 16(1), 96–102.
- El Moussaoui, T., Wahbi, S., Mandi, L., Masi, S., & Ouazzani, N. (2019). Reuse study of sustainable wastewater in agroforestry domain of Marrakesh city. *Journal of the Saudi Society of Agricultural Sciences*, 18(3), 288–293.
- El-Fadel, M., Deeb, T., Alameddine, I., Zurayk, R., & Chaaban, J. (2018). Impact of groundwater salinity on agricultural productivity with climate change implications. *International Journal of Sustainable Development and Planning*. <https://doi.org/10.2495/SDP-V13-N3-445-456>.
- Erhardt, A., 1985. Diurnal Lepidoptera: Sensitive indicators of cultivated and abandoned grassland. *Journal of Applied Ecology*, 22, 849–861.
- FAO. (1992). *Les périmètres irrigués en droit comparé africain (Madagascar Maroc, Niger, Sénégal, Tunisie)*. Rome, Italy: FAO, (French only).
- FAO. (2011) *The State of the World's Land and Water Resources for Food and Agriculture (SOLAW) – Managing systems at risk*. London, UK: Food and Agriculture Organization of the United Nations, Rome and Earthscan.
- FAO. (2020). *Management of salt affected soils: 'soil management' under 'FAO SOILS PORTAL'*. In: *Food and Agriculture Organization' of the 'United Nations'*. Rome. Retrieved from <http://www.fao.org/soils-portal/soil-management/management-of-some-problemsoils/salt-affected-soils/more-information-on-salt-affected-soils/en/>.
- Fathizad, H., et al. (2020). Investigation of the spatial and temporal variation of soil salinity using random forests in the central desert of Iran. *Geoderma* 365, 114233. <https://doi.org/10.1016/j.geoderma.2020.114233>.
- Faunt, C.C., Sneed, M., Traum, J., & Brandt, J.T. (2016). Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeology Journal*. <https://doi.org/10.1007/s10040-015-1339-x>.
- Foster, S., Chilton, J., Moench, M., Cardy, F., & Schiffler, M. (2000). Groundwater in rural development: Facing the challenges of supply and resource sustainability. *World Bank Technical Paper* 463. Washington, DC: World Bank.
- Foster, S., Pulido-Bosch, A., Vallejos, Á., Llop A., & MacDonald, A.M. (2018). Impact of irrigated agriculture on groundwater-recharge salinity: A major sustainability concern in semi-arid regions. *Hydrogeology Journal*, 26, 2781–2791. <https://doi.org/10.1007/s10040-018-1830-2>.
- Fradkin, P.L. (1996). *A River No More: The Colorado River and the West*. University of California Press.
- Freeze, R.A., & Cherry, J.A. (1979). *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall.
- George, R., Clarke, J., & English, P. (2008). Modern and palaeogeographic trends in the salinisation of the Western Australian wheatbelt: A review. *Australian Journal of Soil Research*, 46(8), 751–767. <https://doi.org/10.1071/SR08066>.
- Gertner, J. (2007). The future is drying up. *New York Times Magazine*, 21.
- Giller, P.S., & Myers, A.A. (1996). *Disturbance and Recovery of Ecological Systems*. Royal Irish Academy.
- Gohil, M.B. (2000). *Land Treatment of Wastewater* (1st ed.). New Delhi, India: New Age International.
- González-Estébanez, F.J., García-Tejero, S., Mateo-Tomás, P., & Olea, P.P. (2011). Effects of irrigation and landscape heterogeneity on butterfly diversity in Mediterranean farmlands. *Agriculture, Ecosystems & Environment*, 144(1), 262–270.
- Graham, K.C. (2002). *Construction of Hydraulic Structures for Water Supply Sustenance*. pp. 56–76. ISBN: 0-916122-51-4.
- Green, R.E., Cornell, S.J., Scharlemann, J.P.W., & Balmford, A. (2005). Farming and the fate of wild nature. *Science*, 307, 550–555.
- Greene, R., Timms, W., Rengasamy, P., Arshad, M., & Cresswell, R. (2016). Soil and aquifer salinization: Toward an integrated approach for salinity management of groundwater. In *Integrated Groundwater Management* (pp. 377–412). Cham: Springer.

- Guadie, A., Yesigat, A., Gatew, S., Worku, A., Liu, W., Ajibade, F.O., & Wang, A. (2021). Evaluating the health risks of heavy metals from vegetables grown on soil irrigated with untreated and treated wastewater in Arba Minch, Ethiopia. *Science of the Total Environment*, 761, 143302. <https://doi.org/10.1016/j.scitotenv.2020.143302>.
- Hajjami, K., Ennaji, M.M., Fouad, S., Oubrim, N., & Cohen, N. (2012). Wastewater reuse for irrigation in Morocco: Helminth eggs contamination's level of irrigated crops and sanitary risk (a case study of Settat and Soualem regions). *Journal of Bacteriology & Parasitology*, 4, 1–5. <https://doi.org/10.4172/2155-9597.1000163>
- Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., & Jones, E.B.D. (1998). Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences*, 95(25), 14843–14847.
- Hass, A., Mingelgrin, U., & Fine, P. (2010). Heavy metals in soils irrigated with wastewater. In *Treated Wastewater in Agriculture: Use and Impacts on the Soil Environment and Crops*. <https://doi.org/10.1002/9781444328561.ch7>
- Hassanvand, M., Yazdi, M., & Karami, R. (2017). Environmental effects of irrigation and drainage network of Kheirabad area, SW of Iran. *Environmental Earth Sciences*, 76(15), <https://doi.org/10.1007/s12665-016-6291-0>.
- Herrero, J., & Snyder, R.L., 1997. Aridity and irrigation in Aragon, Spain. *Journal of Arid Environments*, 35, 535–547.
- Herzog, F., Dreier, S., Hofer, G., Marfurt, C., Schüpbach, B., Spiess, M., & Walter, T. (2005). Effect of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes. *Agriculture, Ecosystems & Environment*, 108, 189–204.
- Hickey, J.T, and Salas, J.D. (1995). *Environmental Effects of Extreme Floods. U.S. – Italy Research Workshop on the Hydrometeorology, Impacts, and Management of Extreme Floods Perugia (Italy), November 1995*.
- Higgins, A., Restrepo, J.C., Ortiz, J.C., Pierini, J., & Otero, L. (2015). Suspended sediment transport in the Magdalena river (Colombia, South America): Hydrologic regime, rating parameters and effective discharge variability. *International Journal of Sediment Research*, 31(1), 25–35. <https://doi.org/10.1016/j.ijsrc.2015.04.003>.
- Holy, M. (1993). Is irrigation sustainable? *Canadian Water Resources Journal*, 18(4), 443–449, <https://doi.org/10.4296/cwrj1804443>.
- Holzschuh, A., Steffan-Dewenter, I., Kleijn, D., & Tscharntke, T. (2007). Diversity of flower-visiting bees in cereal fields: Effects of farming system, landscape composition and regional context. *Journal of Applied Ecology*, 44, 42–49.
- Hornung, M., & Reynolds, B. (1995). The effects of natural and anthropogenic environmental changes on ecosystem processes at the catchment scale. *Trends in Ecology & Evolution*, 10(11), 443–449.
- Hu, A.H., Chen, C.H., Huang, L.H., Chung, M.H., Lan, Y.C., & Chen, Z. (2019). Environmental impact and carbon footprint assessment of Taiwanese agricultural products: A case study on Taiwanese Dongshan tea. *Energies*, 12(1), 138. <https://doi.org/10.3390/en12010138>.
- Hupp, C.R., Noe, G.B., & Schenk, E.R. (2010). Floodplains, equilibrium, and fluvial geomorphic impacts of human alterations. *2nd Joint Federal Interagency Conference*, Las Vegas, NV, June 27–July 1, 2010.
- Hyvönen, T., Salonen, J. (2002). Weed species diversity and community composition in cropping practices at two intensity levels – A six-year experiment. *Plant Ecology*, 154, 73–81.
- Ilori, B.A., Adewumi, J.R., Lasisi, K.H., & Ajibade, F.O. (2019). Qualitative assessment of some available water resources in Efon Alaaye, Nigeria. *Journal of Applied Science and Environmental Management*, 23(1), 29–34. <https://doi.org/10.4314/jasem.v23i1.5>.
- Imran, M., Maqsood, M.A., Rahmatullah, Kanwal, S. (2010). Increasing SAR of irrigation water aggravates boron toxicity in maize (*Zea mays* L.). *Journal of Plant Nutrition* 33 (9), 1301–1306. <https://doi.org/10.1080/01904167.2010.484091>.
- IPCC (2014). Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

- Irmak, S., & Rathje, W.R. (2008). *Plant Growth and Yield as Affected by Wet Soil Conditions Due to Flooding or Over-Irrigation*. Lincoln: Publications of University of Nebraska-Lincoln Extension.
- Islam, M.A., Romić, D., Akber, M.A., & Romić, M. (2018). Trace metals accumulation in soil irrigated with polluted water and assessment of human health risk from vegetable consumption in Bangladesh. *Environmental Geochemistry and Health*, 40(1), 59–85. <https://doi.org/10.1007/s10653-017-9907-8>.
- Islam, S.M.M., Gaihre, Y.K., Islam, M.R., Akter, M., Al Mahmud, A., Singh, U., & Sander, B.O. (2020). Effects of water management on greenhouse gas emissions from farmers' rice fields in Bangladesh. *Science of the Total Environment*, 734, 139382. <https://doi.org/10.1016/j.scitotenv.2020.139382>.
- José-María, L., Armengot, L., Blanco-Moreno, J.M., Bassa, M., & Sans, F.X. (2010). Effects of agricultural intensification on plant diversity in Mediterranean dryland cereal fields. *Journal of Applied Ecology*, 47, 832–840.
- Khan, O., Mwelwa-Mutekenya, E., Crosato, A., & Zhou, Y. (2014). Effects of dam operation on downstream river morphology: The case of the middle Zambezi River. *Water Management. Proceedings of the Institution of Civil Engineers (ICE)*, 1300122.
- Khanpae, M., Karami, E., Maleksaeidi, H., & Keshavarz, M. (2020). Farmers' attitude towards using treated wastewater for irrigation: The question of sustainability. *Journal of Cleaner Production*, 243, 118541.
- Kisi, O. (2012). Modeling discharge-suspended sediment relationship using least square support vector machine. *Journal of Hydrology*, 456, 110–120.
- Kleijn, D., Berendse, F., Smit, R., & Gilissen, N. (2001). Agrienvironment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. *Nature*, 413, 723–725.
- Knop, E., Kleijn, D., Herzog, F., & Schmid, B. (2006). Effectiveness of the Swiss agri-environment scheme in promoting biodiversity. *Journal of Applied Ecology*, 43, 120–127.
- Krauss, J., Gallenberger, I., & Steffan-Dewenter, I. (2011). Decreased functional diversity and biological pest control in conventional compared to organic crop fields. *PLoS One*, 6, e19502.
- Kremen, C. (1992). Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological Applications*, 2, 203–217.
- Kukul, M.S., & Irmak, S. (2020). Impact of irrigation on interannual variability in United States agricultural productivity. *Agricultural Water Management*, 234, 106141.
- Kumar, M., Xiong, X., He, M., Tsang, D.C., Gupta, J., Khan, E., ... Bolan, N.S. (2020). Microplastics as pollutants in agricultural soils. *Environmental Pollution*, 265, 114980.
- Kuscu, H., Bölüktepe, F.E., & Demir, A.O. (2009). Performance assessment for irrigation water management: A case study in the Karacabey irrigation scheme in Turkey. *African Journal of Agricultural Research*, 4, 124–132.
- Laiolo, P. (2005). Spatial and seasonal patterns of bird communities in Italian agroecosystems. *Conservation Biology*, 19, 1547–1556.
- Lake, P.S. (2000). Disturbance, patchiness, and diversity in streams. *Journal of the North American Benthological Society*, 19(4), 573–592.
- Lake, P.S., Palmer, M.A., Biro, P., Cole, J., Covich, A.P., Dahm, C., ... Verhoeven, J.O.S. (2000). Global change and the biodiversity of freshwater ecosystems: Impacts on linkages between above-sediment and sediment biota: All forms of anthropogenic disturbance—changes in land use, biogeochemical processes, or biotic addition or loss—not only damage the biota of freshwater sediments but also disrupt the linkages between above-sediment and sediment-dwelling biota. *BioScience*, 50(12), 1099–1107.
- Leduc, C., Favreau, G., & Schroeter, P. (2001). Long-term rise in the Sahelian water-table: The continental terminal in South-West Niger. *Journal of Hydrology*, 243, 43–54.
- Lee, D.J., & Howitt, R.E. (1996). Modeling regional agricultural production and salinity control alternatives for water quality policy analysis. *American Journal of Agricultural Economics*, 78(1), 41–53. <https://doi.org/10.2307/1243777>.
- Litskas, V.D., Aschonitis, V.G., & Antonopoulos, V.Z. (2010). Water quality in irrigation and Drainage networks of Thessaloniki plain in Greece related to land use, water management, and agroecosystem protection. *Environmental Monitoring and Assessment*, 163, 347–359.

- Lootens, M., & Lumbu, S. (1986). Suspended sediment production in a suburban tropical basin (Lubumbashi, Zaire). *Hydrological Sciences Journal*, 31(3), 39–49. <https://doi.org/10.1080/02626668609491026>.
- Magami, I.M., Yahaya, S., & Mohammed, K. (2014). Causes and consequences of flooding in Nigeria: A review. *Biological and Environmental Sciences Journal for the Tropics*, 11(2), 154–162.
- Magilligan, F.J., & Nislow, K.H. (2005). Changes in hydrologic regime by dams. *Geomorphology*, 71(1–2), 61–78. <https://doi.org/10.1016/j.geomorph.2004.08.017>.
- Magilligan, F.J., Nislow, K.H., & Graber, B.E. (2003). Scale-independent assessment of discharge reduction and riparian disconnectivity following flow regulation by dams. *Geology*, 31(7), 569–572. [https://doi.org/10.1130/0091-7613\(2003\)031<0569:saodra>2.0.co;2](https://doi.org/10.1130/0091-7613(2003)031<0569:saodra>2.0.co;2).
- Mailhot, A., Talbot, G., Ricard, S., Turcotte, R., & Guinard, K. (2018). Assessing the potential impacts of dam operation on daily flow at ungauged river reaches. *Journal of Hydrology: Regional Studies*, 18, 156–167. <https://doi.org/10.1016/j.ejrh.2018.06.006>.
- Malan, M., Müller, F., Cyster, L., Raitt, L., & Aalbers, J. (2015). Heavy metals in the irrigation water, soils and vegetables in the Philippi horticultural area in the Western Cape Province of South Africa. *Environmental Monitoring and Assessment*. <https://doi.org/10.1007/s10661-014-4085-y>.
- Manasa, M.R., Katukuri, N.R., Nair, S.S., Haojie, Y., Yang, Z., & Guo, R.B. (2020). Role of biochar and organic substrates in enhancing the functional characteristics and microbial community in a saline soil. *Journal of Environmental Management*, 110737. <https://doi.org/10.1016/j.jenvman.2020.110737>.
- Maqsood, M.A., Khan, M.K., Naeem, M.A., Hussain, S., Aziz, T., & Schoenau, J. (2015). High sodium in irrigation water caused B toxicity at low soil solution and shoot B concentration in maize (*Zea mays* L.). *Journal of Plant Nutrition*, 38(5), 728–741. <https://doi.org/10.1080/01904167.2014.939286>.
- Marchuk, A.G., & Rengasamy, P. (n.d.). Cation ratio of soil structural stability (CROSS). *2010 19th World Congress of Soil Science, Soil Solutions for a Changing World. 1–6 August 2010, Brisbane, Australia*.
- Marden, M., & Rowan, D. (2015). The effect of land use on slope failure and sediment generation in the Coromandel region of New Zealand following a major storm in 1995. *New Zealand Journal of Forestry Science*, 45, 1–18.
- Mateo-Sagasta, J., Zadeh, S.M., & Turrall, H. (2017). Water pollution from agriculture: A global review. Executive Summary.
- Mavi, M.S., Sanderman, J., Chittleborough, D.J., Cox, J.W., & Marschner, P. (2012). Sorption of dissolved organic matter in salt-affected soils: Effect of salinity, sodicity and texture. *Science of the Total Environment*, 435–436, 337–344. <https://doi.org/10.1016/j.scitotenv.2012.07.009>.
- Melnichuk, N.A., Olfert, O., Youngs, B., & Gillott, C. (2003). Abundance and diversity of Carabidae (Coleoptera) in different farming systems. *Agriculture, Ecosystems and Environment*, 95, 69–72.
- Memon, F. S., & Sharjeel, M. Y. (2016). Catastrophic effects of floods on environment and health: Evidence from Pakistan. *Pakistan Journal of Engineering, Technology & Science*, 5(2). <https://doi.org/10.22555/pjets.v5i2.903>.
- Munir, S. (2011). *Role of Sediment Transport in Operation and Maintenance of Supply and Demand Based Irrigation Canals—Application to Machai Maira Branch Canals*. Delft, The Netherlands: Wageningen University and UNESCO-IHE Institute for Water Education.
- Murphy, B. (2015). Key soil functional properties affected by soil organic matter – Evidence from published literature. *IOP Conference Series: Earth and Environmental Science*, 25, 012008.
- Nagler, P.L., Glenn, E.P., Hinojosa-Huerta, O., Zamora, F., & Howard, K. (2008). Riparian vegetation dynamics and evapotranspiration in the riparian corridor in the delta of the Colorado River, Mexico. *Journal of Environmental Management*, 88(4), 864–874.
- Niemeyer, J.C., Medici, L.O., Correa, B., Godoy, D., Ribeiro, G., Lima, S. d.-O., ... de Carvalho, D.F. (2020). Treated produced water in irrigation: Effects on soil fauna and aquatic organisms. *Chemosphere*, 240, 124791.
- Nimmo, J.R. (2013). Aggregation: Physical aspects. *Reference Module in Earth Systems and Environmental Sciences*. Elsevier. ISBN 9780124095489, <https://doi.org/10.1016/B978-0-12-409548-9.05087-9>.

- Nimmo, J.R., (2005). Unsaturated zone flow processes, In Anderson, M.G., & Bear, J., (eds.), *Encyclopedia of Hydrological Sciences: Part 13 – Groundwater* (Vol. 4, pp. 2299–2322). Chichester, UK: Wiley, <https://doi.org/10.1002/0470848944.hsal61>, <http://www.mrw.interscience.wiley.com/ehs/articles/hsal61/frame.html>.
- Nolan, J., & Weber, K.A. (2015). Natural uranium contamination in major U.S. aquifers linked to nitrate. *Environmental Science and Technology Letters*. <https://doi.org/10.1021/acs.estlett.5b00174>.
- Ochiere, H.O., Onyando, J.O., & Kamau, D.N. (2015). Simulation of sediment transport in the canal using the HEC-RAS (Hydrologic Engineering Centre—River Analysis System) in an underground canal in southwest Kano irrigation scheme—Kenya. *International Journal of Science and Engineering Invention*, 4, 15–31.
- OECD (2010), “Water and agriculture: Managing water sustainably is key to the future of food and agriculture” [Online]. <https://www.oecd.org/agriculture/topics/water-and-agriculture/>
- Ofori, S., Puskacova, A., Ruzickova, I., & Wanner, J. (2021). Treated wastewater reuse for irrigation: Pros and cons. *Science of the Total Environment*, 760, 144026.
- Omotade, I.F., Alatishe, M.O., & Olanrewaju, O.O. (2019). Recycling of aquaculture wastewater using charcoal based constructed wetlands, *International Journal of Phytoremediation*, 21(5), 399–404, <https://doi.org/10.1080/15226514.2018.1537247>.
- Osman, I.E. (2015). *Impact of improved operation and maintenance on cohesive sediment transport in Gezira scheme, Sudan*. Delft, The Netherlands: Wageningen University. UNESCO-IHE Institute for Water Education.
- Oster, J.D., Sposito, G., & Smith, C.J. (2016). Accounting for potassium and magnesium in irrigation water quality assessment. *California Agriculture*, 70(2), 71–76. <https://doi.org/10.3733/ca.v070n02p71>.
- Ouellet-Proulx, S., St-Hilaire, A., Courtenay, S.C., & Haralampides, K.A. (2016). Estimation of suspended sediment concentration in the Saint John River using rating curves and machine learning approach. *Hydrological Sciences Journal*, 61(10), 1847–1860. <https://doi.org/10.1080/02626667.2015.1051982>.
- Paudel, K.P. (2010). *Role of Sediment in the Design and Management of Irrigation Canals Sunsari Morang Irrigation Scheme, Nepal*. Delft, The Netherlands: Wageningen University and UNESCO-IHE Institute for Water Education.
- Penvenne, L.J. (1996). Disappearing delta. *American Scientist*, 84(5), 438.
- Perret, S.R., & Payen, S. (2020). Irrigation and the environmental tragedy: Pathways towards sustainability in agricultural water use. *Irrigation and Drainage*, 69, 263–271.
- Petts, E., & Gurnell, A.M. (2005). Dams and geomorphology: Research progress and future directions. *Geomorphology*, 71(1–2), 27–47.
- Pezechki, S.R., & DeLaune, R.D. (2012). Soil oxidation-reduction in wetlands and its impact on plant functioning. *Biology*. <https://doi.org/10.3390/biology1020196>.
- Pierret, A., Doussan, C., Capowiez, Y., Bastardie, F., & Pagès, L. (2007). Root functional architecture: A framework for modeling the interplay between roots and soil. *Vadose Zone Journal*. <https://doi.org/10.2136/vzj2006.0067>.
- Pimentel, D., & Pimentel, M. (2003). World population, food, natural resources, and survival. *World Futures*. <https://doi.org/10.1080/02604020310124>.
- Ponce, C., Bravo, C., García de León, D., Magaña, M., & Alonso, J.C. (2011). Effects of organic farming on plant and arthropod communities: A case study in Mediterranean dryland cereal. *Agriculture, Ecosystems & Environment*, 141, 193–201.
- Prieto-Benítez, S., & Méndez, M. (2011). Effects of land management on the abundance and richness of spiders (Araneae): A meta-analysis. *Biological Conservation*, 144, 683–691.
- Pulido-Bosch, A., Rigol-Sanchez, J.P., Vallejos, A., Andreu, J.M., Ceron, J.C., Molina-Sanchez, L., & Sola, F. (2018). Impacts of agricultural irrigation on groundwater salinity. *Environmental Earth Sciences*, 77, 197. <https://doi.org/10.1007/s12665-018-7386-6>.
- Rageh, A.Y., Al-Garadi, M.A., & Al-Mashreki, M.H. (2017). Environmental effects of wastewater use in agricultural irrigation at Dhamar city, Republic of Yemen. *SCIREA Journal of Environment*, 2(2), 38–52.

- Rehman, K., Bukhari, S.M., Andleeb, S., Mahmood, A., Erinle, K.O., Naeem, M.M., & Imran, Q. (2019). Ecological risk assessment of heavy metals in vegetables irrigated with groundwater and wastewater: The particular case of Sahiwal district in Pakistan. *Agricultural Water Management*, 226 (September).
- Roth, T., Amrhein, V., Peter, B., & Weber, D. (2008). A Swiss agri-environment scheme effectively enhances species richness for some taxa over time. *Agriculture, Ecosystems & Environment*, 125, 167–172.
- Ruiz, M., (1990). Development of Mediterranean agriculture: An ecological approach. *Landscape Urban Plan*, 18, 211–220.
- Sainju, U.M., Stevens, W.B., Caesar-TonThat, T., & Liebig, M.A. (2012). Soil greenhouse gas emissions affected by irrigation, tillage, crop rotation, and nitrogen fertilization. *Journal of Environmental Quality*. <https://doi.org/10.2134/jeq2012.0176>
- Sakaris, P.C. (2013). A review of the effects of hydrologic alteration on fisheries and biodiversity and the management and conservation of natural resources in regulated river systems. In: P. M. Bradley (ed). *Current Perspectives in Contaminant Hydrology and Water Resources Sustainability*. IntechOpen, <https://doi.org/10.5772/55963>.
- Salas, J.D., Govindaraju, R.S., Anderson, M., Arabi, M., Frances, F., Suarez, W., Lavado-Casimiro, W.S., & Green, T.R. (2014). Volume 15: Modern Water Resources Engineering. L.K. Wang and C.T. Yang (eds.). *Handbook of Environmental Engineering*. https://doi.org/10.1007/978-1-62703-595-8_1.
- Santos, J.N., Andrade, E.M., Medeiros, P.A., Palácio, H.d, & Neto, J.R.d.A. (2017). Sediment delivery ratio in a small semi-arid watershed under conditions of low connectivity. *Revista Ciência Agronômica*, 48, 49–58.
- Sapkota, A., Haghverdi, A., Avila, C.C.E., & Ying, S.C. (2020). Irrigation and greenhouse gas emissions: A review of field-based studies. *Soil Systems*, 4(2), 1–21. <https://doi.org/10.3390/soilsystems4020020>
- Scanlon, B.R., Jolly, I., Sophocleous, M., & Zhang, L. (2007). Global impacts of conversions from natural to agricultural ecosystems on water resources: Quantity versus quality. *Water Resources Research*. <https://doi.org/10.1029/2006WR005486>.
- Singh, A. (2018). Managing the environmental problems of irrigated agriculture through the appraisal of groundwater recharge. *Ecological Indicators*, 92, 388–393.
- Singh, A. (2021). Soil salinization management for sustainable development: A review. *Journal of Environmental Management*, 277, 111383.
- Singh, A., Sharma, R.K., Agrawal, M., & Marshall, F.M. (2010). Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. *Tropical Ecology*.
- Singh, S., Ghosh, N.C., Gurjar, S., Krishan, G., Kumar, S., & Berwal, P. (2018). Index-based assessment of suitability of water quality for irrigation purpose under Indian conditions. *Environmental Monitoring and Assessment*. <https://doi.org/10.1007/s10661-017-6407-3>
- Spear, B., Smith, D., Largay, B., & Haskins, J. (2008). *Turbidity as a Surrogate Measure for Suspended Sediment Concentration in Elkhorn Slough*, CA. Monterey Bay, CA: The Watershed Institute, Division of Science and Environmental Policy—California State University.
- Stefanescu, C., Herrando, S., & Páramo, F. (2004). Butterfly species richness in the northwest Mediterranean Basin: The role of natural and human-induced factors. *Journal of Biogeography*, 31, 905–915.
- Stoate, C., Boatman, N.D., Borralho, R.J., Rio Carvalho, C., de Snoo, G.R., & Eden, P., 2001. Ecological impacts of arable intensification in Europe. *Journal of Environmental Management*, 63, 337–365.
- Stockle, C.O. (2001). *Environmental Impact of Irrigation: A Review*. Washington State University.
- Suarez, D.L. (1989). Impact of agricultural practices on groundwater salinity. *Agriculture, Ecosystems and Environment*. [https://doi.org/10.1016/0167-8809\(89\)90014-5](https://doi.org/10.1016/0167-8809(89)90014-5)
- Sutama, N.H. (2010). *Mathematical Modelling of Sediment Transport and Its Improvement in Bekasi Irrigation System, West Java, Indonesia*. Delft, The Netherlands: UNESCO-IHE, Institute for Water Education.
- Tella J.L., & Forero M.G. (2000) Farmland habitat selection of wintering lesser kestrels in a Spanish pseudosteppe: Implications for conservation strategies. *Biodiversity and Conservation*, 9, 433–441.

- Thiruchelva, S.R., Chandran, S., Kumar, P.L., & Veluswamy, K. (2020). Assessment of environmental impacts in the untreated urban wastewater irrigated sites – A case study. *ASABE 2020 Annual International Meeting*, 2001193. <https://doi.org/10.13031/aim.202001193>.
- Thomas, J.A. (2005). Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society B*, 360, 339–357.
- Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418, 671–677.
- Tybirk, K., Alroe, H.F., Frederiksen, P. (2004). Nature quality in organic farming: A conceptual analysis of considerations and criteria in European context. *Journal of Agricultural and Environmental Ethics*, 17, 249–274.
- Uhrich, M.A., & Bragg, H. m. (2003). *Monitoring Instream Turbidity to Estimate Continuous Suspended-Sediment Loads and Yields and Clay-Water Volumes in the Upper North Santiam River Basin, Oregon, 1998–2000*. Portland, ON: U.S. Department of the Interior and U.S. Geological Survey.
- Ursúa, E., Serrano, D., & Tella, J.L. (2005). Does land irrigation actually reduce foraging habitat for breeding lesser kestrels? The role of crop types. *Biological Conservation*, 122, 643–648.
- US EPA (US Environment Protection Agency), 1992. *Managing Nonpoint Source Pollution*. Washington, DC: US EPA, Office of Water.
- Usman, M.A., & Gerber, N. (2019). Assessing the effect of irrigation on household water quality and health: A case study in rural Ethiopia. *International Journal of Environmental Health Research*, <https://doi.org/10.1080/09603123.2019.1668544>.
- Van Weert, F., Van der Gun, J., & Reckman, J.W.T.M. (2009). Global overview of saline groundwater occurrence and genesis. *IGRAC Report GP 2009-1*.
- Vartapetian, B.B., & Jackson, M.B. (1997). Plant adaptations to anaerobic stress. *Annals of Botany*. <https://doi.org/10.1006/anbo.1996.0295>
- Villamar, C.A., Vera-Puerto, I., Rivera, D., & De la Hoz, F. (2018). Reuse and recycling of livestock and municipal wastewater in Chilean agriculture: A preliminary assessment. *Water*, 10(6), 817. <https://doi.org/10.3390/w10060817>.
- Wada, Y., Van Beek, L.P.H., Van Kempen, C.M., Reckman, J.W.T.M., Vasak, S., & Bierkens, M.F.P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters*. <https://doi.org/10.1029/2010GL044571>.
- Wallace, J.S. (2000). Increasing agricultural water use efficiency to meet future food production. *Agriculture, Ecosystems & Environment*, 82, 105–119.
- Wang, Y., Zheng, C., & Ma, R. (2018). Safe and sustainable groundwater supply in China. *Hydrogeology Journal*, 26(5), 1301–1324.
- Water Cycle. (2020, June 8). *New World Encyclopedia*. Retrieved 09:32, June 25, 2022 from https://www.newworldencyclopedia.org/p/index.php?title=Water_cycle&oldid=1037916.
- Waters, T.F. (1995). *Sediment in Streams: Sources, Biological Effects, and Control*. American Fisheries Society.
- Weibull A-C., Bengtsson J., Nohlgren E., (2000) Diversity of butterflies in the agricultural landscape: The role of farming system and landscape heterogeneity. *Ecography* 23: 743–750.
- Weibull, A.C., & Östman, Ö. (2003) Species composition in agroecosystems: The effect of landscape, habitat and farm management. *Basic and Applied Ecology*, 4, 349–361.
- Werner, A.D., Bakker, M., Post, V.E.A., Vandenbohede, A., Lu, C., Ataie-Ashtiani, B., Simmons, C.T., & Barry, D.A. (2013). Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Advances in Water Resources*. <https://doi.org/10.1016/j.advwatres.2012.03.004>
- Winter, T.C., Harvey, J.W., Franke, O.L., & Alley, W.M. (1998). *Ground Water and Surface Water a Single Resource*. U.S. Geological Survey Circular 1139. U.S. Government Printing Office. ISBN 0-607-89339-7.
- WWAP (United Nations World Water Assessment Programme). (2017). *The United Nations World Water Development Report 2017*. Paris: UNESCO.

- Yan, Y., Yang, Z., Liu, Q., Sun, T. (2010). Assessing effects of dam operation on flow regimes in the lower Yellow River. *Procedia Environmental Sciences*, 2(6), 507–516, <https://doi.org/10.1016/j.proenv.2010.10.055>.
- Yusuf, R.O. (2008). Environmental impacts of an irrigation scheme: The Bakolori irrigation project. *Journal of Environmental Research and Policies*, 3(4), 75–80.
- Zektser, S., Loáiciga, H.A., & Wolf, J.T. (2005). Environmental impacts of groundwater overdraft: Selected case studies in the southwestern United States. *Environmental Geology*, 47(3), 396–404.
- Zeľeňáková, M., Blišťan, P., Alkhalaf, I., Gaňová, L., & Zvijáková, L. (2016). Assessment of environmental damages in case of flood in Bodva River Basin, Slovakia. *International Journal of Safety and Security Engineering*, 6(3), 498–507. <https://www.usgs.gov/water-science-school>.