Sustainable Water Resources Management Based on the DPSIR Framework in East and West African Countries

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1 Introduction

In recent years, there has been global concern about water availability. Water demands are increasing due to global population growth, human well-being and development, and the intensification of economic activities. Climate change projections predict that temperature will rise and heavy rainfall incidents will happen more often worldwide, impacting the environment and populations. Drought periods will be prolonged, and floods will occur more frequently. Water supply will be threatened along with food and health security.

Water covers 71% of the Earth's surface. Water shortage or pollution causes 80% of diseases that are pervasive worldwide (Siwailam et al., 2019). Approximately 97.5% of the world's water is saline, found in the oceans, and the remaining 2.5% is fresh. Glaciers constitute the largest part of freshwater (68.7%), groundwater is

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equal to 30.1%, and permafrost is 0.8%. Surface and atmospheric water are just 0.4% of total freshwater resources. Lakes contain 67.4% of surface water and rivers 1.6%. It is concluded that the total amount of freshwater that humanity can use to meet its demands is a very small percentage of the total amount of water on earth.

Assessment of environmental degradation and its impact on socioeconomic conditions has gained significant importance for the long-term management of water resources and ecosystem sustainability. Water management requires innovative practices to cover demands and provide good quality water in sufficient quantity for future generations.

Scientists and managers have created many indicators to assess the condition of water resources. Still, integrated water management requires an efficient tool to investigate the interaction between the environment and humans. The Driving Forces–Pressures–State–Impacts–Responses (DPSIR) framework is a valuable tool to investigate the above interaction.

DPSIR methodology has been widely used to facilitate empirical research, to develop indicators, and to organize the information contained in management plans. It has been utilized to investigate the causal chains of the environmental consequences of an off-shore wind farm (Elliot, 2002), to identify the social and economic pressures in an estuary (Caiero et al., 2004), for protection of groundwater, inland surface waters, estuaries, and coastal waters (Borja et al., 2006), for the assessment of impacts of development activities on the coastal environment and society (Lin et al., 2007), for determining sustainability indicators at coastal zones (Bell, 2012), to identify several environmental problems in a river basin, with the aim of designing an Integrated River Basin Management Plan (Kagalou et al., 2012), and for integrated groundwater resources management in Northern Greece (2014).

The EWA-BELT project, funded by the European Union's Horizon 2020 program, examines the human and ecological factors affecting water quality and quantity in case studies from West and East African countries (Ghana, Burkina Faso, Kenya, and Tanzania). This study aims to analyze the environmental and societal impacts, propose strategies to address the problems, and improve water resources management.

2 DPSIR Methodology

The DPSIR framework, promoted by the European Environmental Agency (European Environmental Agency—EEA, 1999), has proved to be a valuable tool for managing complex issues regarding water management (Kristensen, 2004; Carr et al., 2007; Crouzet et al., 2009). It has been applied in many cases to analyze environmental problems, specifically to identify the human and ecological factors affecting water quality and quantity, to propose strategies to address problems, and to improve water resources management.

According to Kristensen (2004), the components of the DPSIR framework are defined as follows:

- *Driving forces* include anthropogenic and natural factors.
- Driving forces lead to human activities that exert *Pressures* on the environment. There are three types of pressures: excessive use of environmental resources, changes in land use, and emissions to air, water, and soil. Natural phenomena may exert forces, as well.
- The *State* of the environment is the combination of the physical, chemical, and biological conditions.
- *Impacts* are caused by changes in the state that may have environmental or economic "impacts" on the functioning of ecosystems, on their life-supporting abilities, and ultimately on human health and society's economic and social performance.
- *Responses* proposed by societies or policy makers have to do with decision-making. They may seek to control the Pressures and affect any part of the chain between driving forces and impacts.

Their inter-relationship is depicted in Fig. 1.

A mixed approach was carried out in this study. Firstly, a search in databases was held to identify relevant works and further climate, agronomic, and socioeconomic information for the examined areas. This process contributed to better understand the current state and determine the main factors that have an influence on water resources' status. Based on the information obtained, a structured questionnaire was

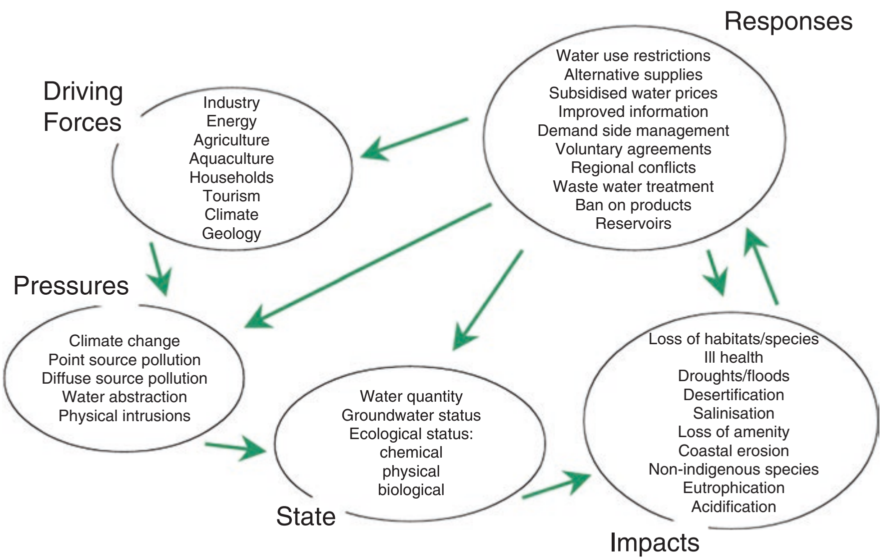


Fig. 1 A generic DPSIR framework for water (Kristensen, 2004)

designed and distributed to partners of the project in the aforementioned areas. The feedback provided by the questionnaires contributed to the establishment of the DPSIR framework, for each area.

3 Results and Discussion

3.1 Ghana Case Study

The case study area is located in the Nabdam District in the Upper East region of the country (Fig. 2). The annual precipitation in the area is equal to 950 mm. According to the Africa Groundwater Atlas (Obuobie et al., 2018), 40% of households depend on groundwater since it is considered one of the most economical and feasible sources of potable water supply despite the lack of infrastructure.

The population is primarily rural (84.3%), living in dispersed settlements. Just 15.7% of the population lives in urban areas. The Upper East region is the least urbanized area in the country. About 56% of the labor force is below 35 years. The main economic activity in the study area is smallholder agriculture (employing 80% of the population), based on rain-fed agriculture and furrows for irrigation. There is little mechanized farming. Most food crop farms are intercropped; mono-cropping is mainly associated with larger-scale commercial farms. Many people are employed in the sector of small-scale mining activities. Agricultural practices (fertilizer application) and the ineffective implementation of regulations and laws are recognized as significant drivers of water quality issues.

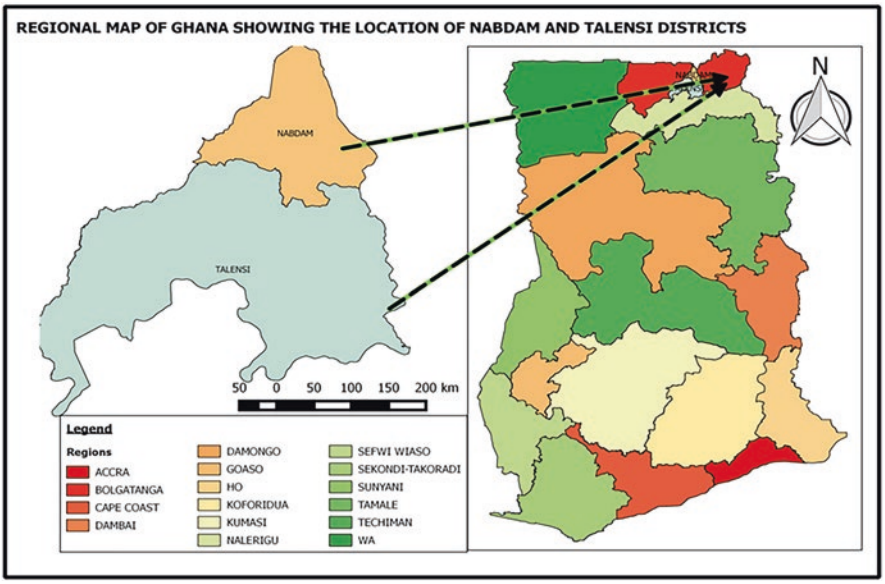


Fig. 2 Case study area in Ghana

Leveraging the gathered information, the DPSIR framework for Ghana was established. The significant factors included in the model are described below.

3.1.1 Driving Forces

The main driving forces, i.e., socioeconomic activities that exert pressures on water, can be summarized in the following: urbanization, intensive agriculture, agriculture expansion, animal breeding, industry, population growth, energy production, climate, and geology.

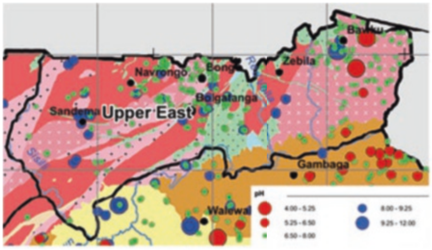
Agyemang et al. (2007) mention that the legalized small-scale mining activities attracted migrants into the area, leading to population growth, increasing and thus impacting the environment, including water resources. Environmental degradation is also attributed to the district assemblies' internal politics and indifferent attitudes, the regional coordinating council, and the government environmental agency. Bawakyillenuo (2020) highlights the role of illegal mining activities in water resources degradation, considering it the most destructive human activity. Agricultural practices (fertilizer application) and the lack of political will to implement regulations and laws are significant drivers of water quality issues.

3.1.2 Pressures

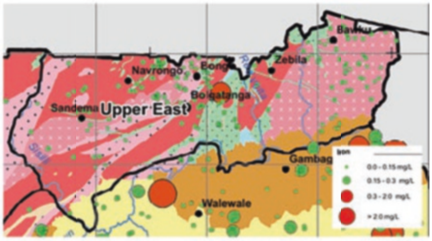
The main pressures that partners from Ghana identified on the local water resources are the over-exploitation of natural resources, including water used for mining activities which, in many cases, are illegal. Water quality degradation comes from bad practices accompanying mining activities (such as sand and stone mining) and mistaken farming practices that include bush burning affecting soil and water in the long term. Climate change also exerts pressure on water. Declining rainfall and higher evapotranspiration rates in neighboring Burkina Faso could reduce the Volta River's annual levels in the following years (McCartney et al., 2012).

3.1.3 State of the Water

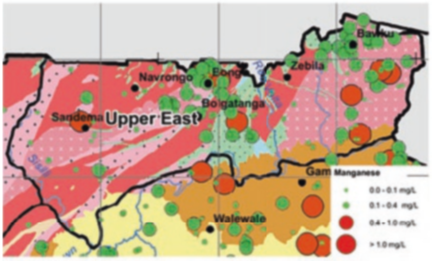
The main outcomes of the Hydrogeological Assessment Project (HAP) of the northern regions of Ghana were published in December 2011 (Carrier et al., 2011). Data concerning groundwater quality in the broader study area are provided in Fig. 3. The pH values in most of the samples range between 6.5 and 8 (Fig. 3a), displaying the typical values of freshwater. The pH values are increased only in a small number of samples, and the water is characterized as alkaline. For iron, the suggested maximum permissible limit by the World Health Organization is equal to 0.3 mg/l for potable water, and the guideline for manganese sets the value at 0.4 mg/l. Most samples are below these threshold values (Fig. 3b, c). Almost all the samples collected from the study area (Fig. 3d) display chloride values lower than 250 mg/l, representing freshwater and within the limits set by the World Health Organization for potable water.



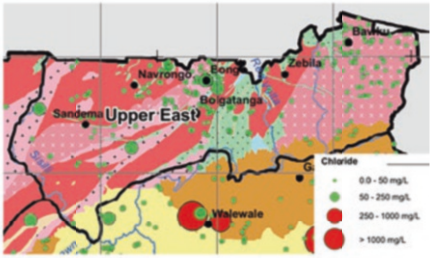
(a) Groundwater samples pH values



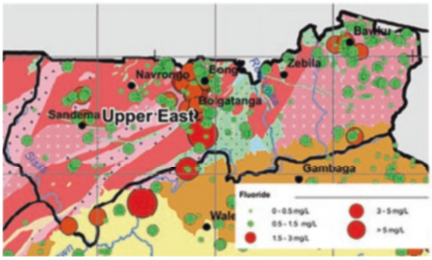
(b) Groundwater sample iron values in mg/l



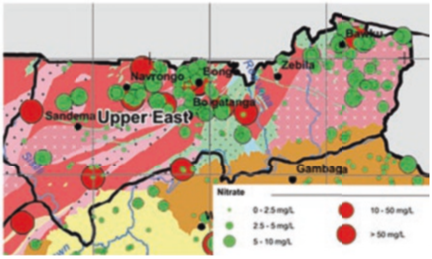
(c) Groundwater sample manganese values in mg/l.



(d) Groundwater sample chloride values in mg/l



(e) Groundwater sample fluoride values in mg/l



(f) Groundwater sample nitrate values in mg/l

Fig. 3 Groundwater samples values for pH, Fe, Mn, Cl, F, and NO_3. (**a**) Groundwater samples pH values. (**b**) Groundwater sample iron values in mg/l. (**c**) Groundwater sample manganese values in mg/l. (**d**) Groundwater sample chloride values in mg/l. (**e**) Groundwater sample fluoride values in mg/l. (**f**) Groundwater sample nitrate values in mg/l. Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA

The samples collected from the study area show fluoride values lower than 1.5 mg/l. Many samples on the axis between Bongo and Bolgatanga show extremely high values (Fig. 3e). Nitrate-nitrogen data generally display concentrations below the 50 mg/l value set by the WHO. The highest concentrations are usually observed near large urban areas, indicating anthropogenic activities as a probable source (Fig. 3f).

3.1.4 Impacts

The major impacts on human well-being and the environment can be summarized as follows:

- *Increase of flooding and drought phenomena.* The impacts of climate change on water resources and the environment are recorded all over the country (Asumadu-Sarkodie & Owusu, 2015a, b). Flooding phenomena and drought periods happen more often. Future projections based on climate models depict an increase in the severity and frequency of extreme weather events in the near future.
- *Groundwater reserves decline.* According to recent measurements, the groundwater withdrawals are lower than the renewable supply. However, groundwater level draw-down (implying reserves reduction) is recorded in many locations since many wells are clustered and unregulated. Groundwater availability and risks stem from poor regulation and enforcement, a lack of reliable data, drought, and reduced recharge from climate change.
- *Reduction of hydropower generation, inland aquaculture, and agriculture across northern Ghana.* Over the last few decades, drought has caused national hydroelectric production to fall to 33% capacity in some cases. Higher temperatures and drought will reduce agricultural production in the country's northern areas.
- *Population displacement.* Between 1988 and 2010, Ghana experienced 15 significant floods that displaced hundreds of thousands of people. Climate change has increased the flood risk of urban areas and riverine communities.
- *Health issues.* The ratio of boreholes per capita in the broader study area needs to be improved since it cannot provide good quality groundwater to the communities, and they are forced to use alternative water sources.

3.1.5 Responses

- *Incorporation of customary water management.* Before the colonial era, traditional leaders used to manage water resources successfully. This was achieved using empirical methods such as plowing, contouring, water storage in clay pots, digging wells, homestead ponds, and rainwater harvesting.
- *Strengthening of collaboration among stakeholders-authorities and assignment of specific duties.* The human activity with the most significant negative effect on the environment, specifically in Ghana's water bodies, is small-scale illegal mining. This industry type has become a major employer to many people in rural areas.
- *The strong political will to strengthen and implement existing water-related policies.* There are existing comprehensive water-related policies, laws, and regulations that are not adequately enforced and, therefore, ineffective in addressing the problem (Yeleliere et al., 2018). Actions such as banning specific plastic materials from the market, surveillance, imposition of fines, and implementing pricing policies could effectively sustain water resources for the next generations.
- *Education and sensitization of citizens*. Solid and long-term collaboration between the media, education system, and competent authorities (such as the Ministry of Information, local governments, and the National Commission for Civic Education) is required to increase awareness of citizens on water pollution threats and the risk it poses for the present and the future.

- *Investment in wastewater treatment and waste re-use*. Sorting waste into components such as plastics, glass, metals, and organic at the household level is crucial for sustainable waste management in Ghana. Along with good rubbish collection, disposal and proper landfill management practices will support the effort for environmental and, therefore, water sustainability.
- *Renewable energy resources for mitigating climate change.* Climate change has become a global phenomenon. The use of alternative energy sources (such as liquefied petroleum gas, which has been promoted by the Government of Ghana under specific actions in recent years) and usage of renewable sources such as solar, wind, and hydro power could effectively reduce Ghana's footprint on emissions (Asumadu-Sarkodie & Owusu, 2016a, 2016b, 2016c).
- *Construction of facilities.* The number of boreholes constructed must be increased. Well-planned reforestation and rainwater harvesting schemes should be implemented to increase groundwater quantity. It is also of major importance that stakeholders using the existing facilities contribute to the maintenance and proper use of the equipment, which is usually a hand pump.

The DPSIR framework for the area is presented in Fig. 4.

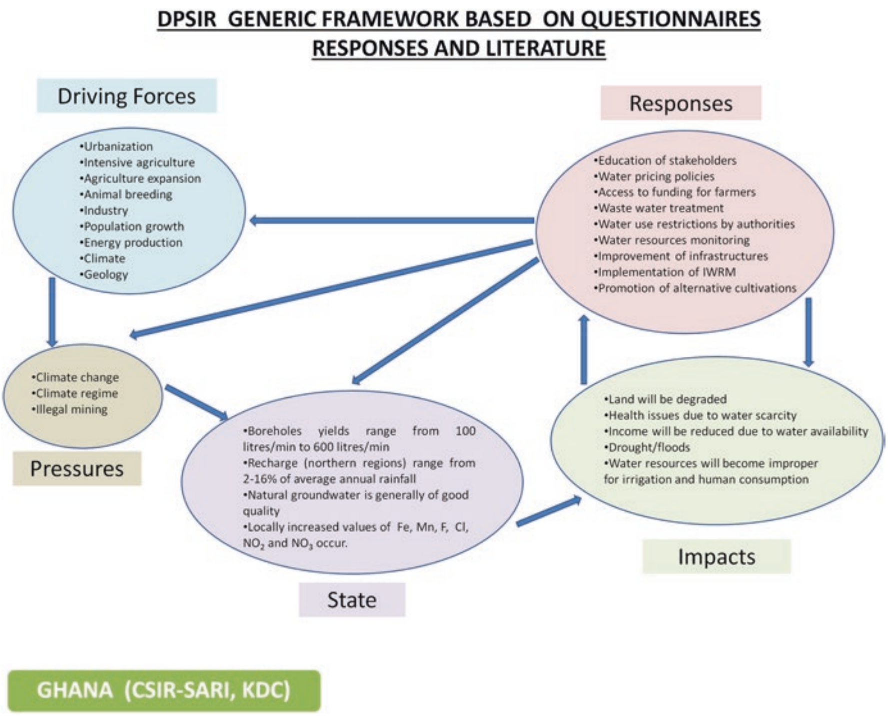


Fig. 4 DPSIR framework for water resources in the Ghana case study

3.2 Tanzania Case Study

The case study area is located in the Arusha Region in the Upper East Region of the country (Fig. 5). Tourism is one of the main economic activities in the Arusha Region, along with agriculture. The majority of the population in large urban centers depends on groundwater to meet their demands.

Many foreign horticultural agribusinesses and agro-industries operate in the area. Smallholder farmers also practice agriculture (Komakech & de Bont, 2018). The main cultivated crops are coffee, grain, vegetables, cotton, pyrethrum, papain, sisal, and sunflower seeds. Mining activities take place in the area. Tourism is one of the main economic activities in the Arusha Region, along with agriculture. Due to the favorable climatic conditions, many foreign horticultural agribusinesses and agro-industries operate there.

Fig. 5 Selected area for the implementation of the DPSIR framework in Tanzania

After a literature review and feedback from questionnaires disseminated to partners from Tanzania, the DPSIR framework was established.

3.2.1 Driving Forces

The main driving forces, i.e., socioeconomic activities that exert pressures on the water, are: population growth, geology, intensive agriculture, agriculture expansion, animal breeding, climate, and energy production.

The population of Tanzania has tripled from 1968 to 2012. The region's population doubled over the years 1988 and 2012. The annual population change is 2.8% for 2002–2012 (https://www.citypopulation.de/en/tanzania/admin/02__arusha/, accessed on 1 December 2021).

Therefore, the water demands are increasing along with the threats (pollution sources) for water resources. Groundwater quality can be affected by anthropogenic pollutants, as well. According to Ghiglieri et al. (2012), the interaction between the groundwater and fluoride-rich minerals and other natural processes could explain the observed variation in fluoride concentration in the Arusha Region.

The country has one of the largest livestock populations in East Africa (CIAT & World Bank, 2017). The most common livestock types are traditional breeds of cattle, sheep, goats, poultry, and pigs (FEWS NET, 2018). Livestock is mainly produced in extensive systems practiced by pastoralists and agro-pastoralists on natural pastures. Intensive and semi-intensive systems are standard for improved livestock breeds.

3.2.2 Pressures

The main pressure regarding Tanzania as identified in the local water resources is the uneven rainfall distribution in space and time. Due to the recorded population growth in the Arusha Region, a significant amount of land has changed use and was converted to settlements or agricultural land. This has a negative impact on groundwater quality and quantity. Water demands for domestic purposes and food production have increased, resulting in increased water abstraction. Aquifers' recharge rate is reduced since buildings, road networks, and other types of infrastructures occupy natural land. Water pollution from agriculture due to agrochemicals and fertilizers and from untreated domestic and industrial waste has increased. In combination with the operation of mining industries, the growth of tourism has increased Arusha city's water demand (Komakech & van der Zaag, 2011).

3.2.3 State of the Water

A detailed study concerning groundwater quality and quantity in the Arusha District (bordered by the three administrative districts of Monduli, Longido, and Meru) is provided by Chacha et al. (2018). The main results of this research are the following: (1) The quality of groundwater is suitable for drinking purposes and most of the

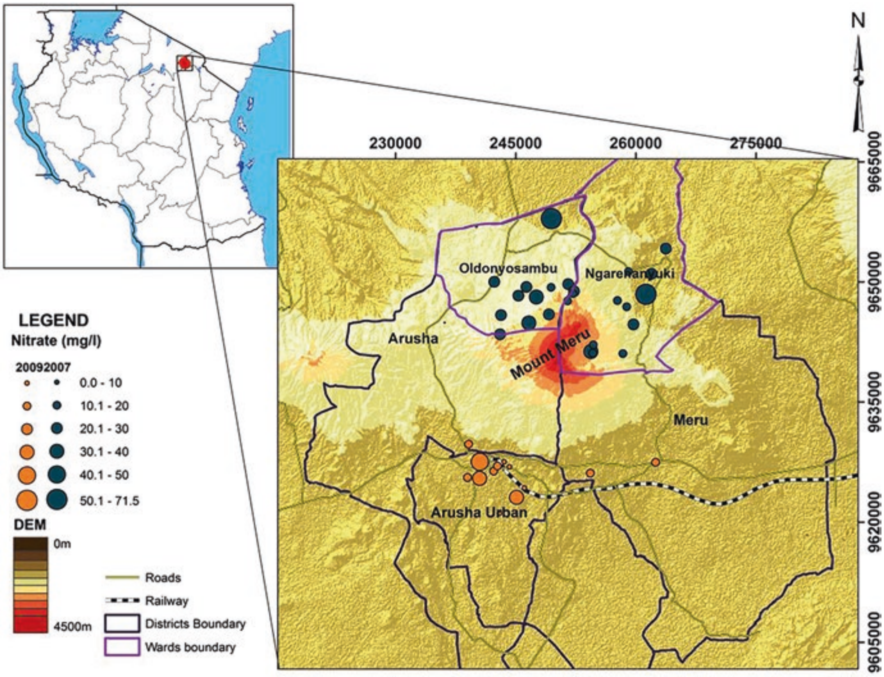


Fig. 6 Spatial distribution of nitrates concentration in groundwater samples for the Arusha Region (Elisante & Muzuka, 2017; GITEC & WEMA, 2011; Pittalis, 2010)

other common uses, except fluoride content. (2) Quality in the study area is dominated by sodium and bicarbonate ions, which define the general composition of the water type to be Na–K–HCO_3. (3) The groundwater chemistry is mainly determined by aquifer lithology and less by anthropogenic activities. (4) The most important source of anthropogenic pollution is the agricultural activity that takes place in the area, as it is confirmed by the presence of nitrates in the groundwater, mainly in shallow wells and springs (Fig. 6). (5) The depth from the ground surface to the groundwater level ranged from 2.7 to 93.2 m for public wells and 1.98 to 7.03 m for privately owned wells drilled in the area.

3.2.4 Impacts

The main impacts on human well-being and the environment can be summarized as follows:

- *Increase of drought and flooding phenomena.* According to the climate models' projections, precipitation in Tanzania will increase over the next few years along with the temperature. The most worrying issue is that extreme drought probability tends to increase by 4–13%, due to changes in the inter-annual and inter-seasonal precipitation patterns.

- *Water supply and food shortages.* The prolonged drought periods that have already occurred in the past (such as in 2003 and 2005) resulted in significant livestock loss and damaged farmers. Food security was threatened (FCFA, 2017; Oikos, 2011).
- *Decrease of groundwater reserves.* Olarinoye et al. (2020) ran mathematical simulation models to investigate the effect of climate change and the rapid urbanization of Arusha city on the groundwater. The results revealed that there would be a significant reduction in the aquifers' recharge rate and a major groundwater level draw-down of many tens of meters.
- *Income reduction of the farmers.* Dependence of income on rainfed farming constitutes small-scale poor farmers' income which is vulnerable to droughts since they affect crop yields (Mdemu, 2021).
- *Energy production.* The alteration of rainfall and, therefore, the flow regime of the hydrographic network will have an impact on water use for power production (Molina et al., 2020).
- *Health issues.* Flooding phenomena usually favor the spread of waterborne and insect-borne diseases (Paavola, 2004).
- *Land degradation.* In the frame of the Land Degradation Neutrality Target Setting Programme (LDN TSP), a National Working Group (NWG) was established. The main drivers identified for the entire territory of the United Republic of Tanzania were the following: overgrazing, poverty, the land tenure system, scarcity of firewood/charcoal making, population increase, poor farming practices, and climate change.

3.2.5 Responses

As has been mentioned, water availability in the future will be aggravated under climate change, and water scarcity problems will be added to the existing ones, since prolonged drought periods will occur more often. Participation of local stakeholders and end-users should be increased in the decision-making process concerning water management issues. A long-term solution in the basin that will improve irrigation efficiency and reduce water losses is the conversion of furrows to a pipeline network. Better farming practices, such as contour stone bunding, tied contour ridges, terrace farming, and others, should be promoted and applied to a larger extent (Shaghude, 2006). Artificial recharge of aquifers could also be a very efficient solution in environmental, social, and economic terms.

Partners from Tanzania, based on their knowledge, experience, and expertise, highlighted the following responses as the most effective to achieve water resources sustainability in the area: Education of stakeholders, water pricing policies, access to funding for farmers, wastewater treatment, water resources monitoring, improvement of infrastructures, implementation of IWRM, and promotion of alternative cultivations.

The produced DPSIR framework is depicted in Fig. 7.

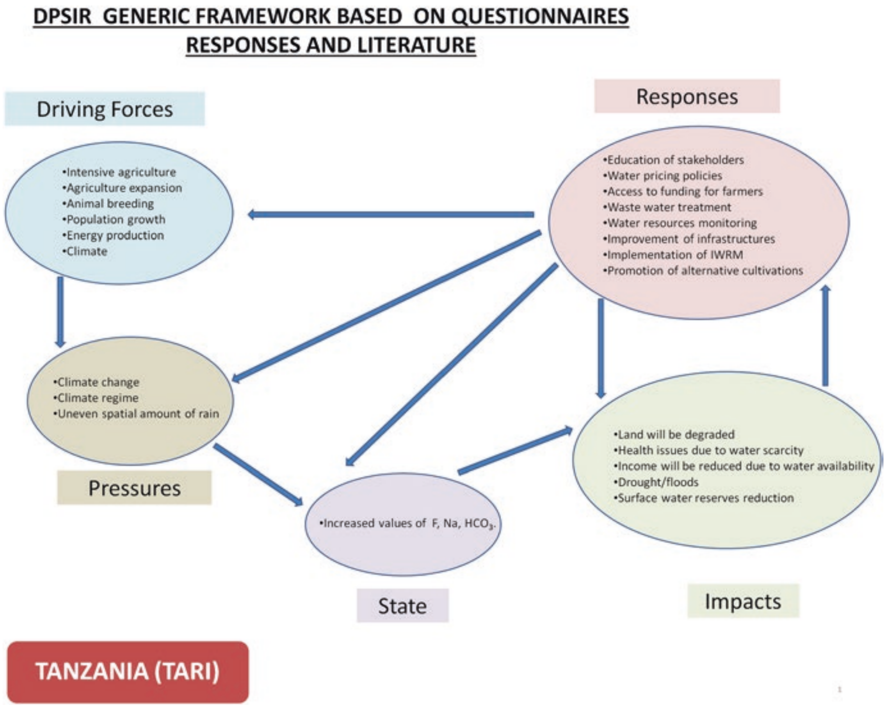


Fig. 7 DPSIR framework for water resources in the Tanzania case study

3.3 *Kenya Case Study*

The case study area is located in the Nyakach Region in the west part of the country (Fig. 8). The Nyakach Region has low water coverage, poor water management, and inadequate sanitation. As a result, health issues related to diarrheal infections, such as cholera and a high incidence of diarrhea, have been recorded in the area. Most inhabitants are occupied in agriculture, fishing, and sand harvesting (Wasonga et al., 2016). The main crops cultivated include maize, sorghum, beans, sugarcane, rice, and cotton. Small-scale production represents 90% of total agricultural production and 70% of agricultural production available in the county's market (MoALF, 2017). Floods, droughts, and heat stress have become more frequent and intense, impacting the crop's productivity and, therefore, people's income. Agriculture in the area is mainly rainfed, but large parts of agricultural land are irrigated by surface or groundwater. Industries, especially some agri-food factories, abstract water, as well.

3.3.1 Driving Forces

The main driving forces, i.e., socioeconomic activities or natural processes that exert pressures on water, are population growth, urbanization, intensive agriculture, agriculture expansion, industry, and climate.

Fig. 8 Selected area for the implementation of the DPSIR framework in Kenya

The population growth rate for Kisumu County was 1.8% for 2009–2019, and the urbanization rate was equal to 38% (1980–2020) (https://www.citypopulation.de/en/kenya/admin/, last accessed February 24, 2022). The evolution of the Nyakach sub-county population is depicted in Table 1. The Nyakach sub-county is a very densely populated area (Table 1) compared to the national level, equal to approximately 92 persons/km^2 (https://www.worldometers.info/demographics/kenya-demographics/). The majority of the population (68.8%) resides in rural areas. The mean household water consumption is 149.50 l/day with a mean per capita of 32.92 l/day for the entire Kisumu County (Wagah et al., 2010).

Water demands for human consumption and irrigation demands will be significantly increased, threatening food security and drinking water supply. The increased demands for food production will result in intensifying agricultural activities and probable expansion of agricultural land. Irrigation water will be of utmost importance, and its management will be essential for inhabitants. According to Owen (2020), the existing irrigation systems in Kisumu County need rehabilitation of deteriorated facilities due to insufficient maintenance. Therefore, irrigation is already considered a driver that negatively affects water resources. If future scenarios on irrigation demands are met, then agriculture will become one of the most important driving forces exerting pressure on the water.

3.3.2 Pressures

The main pressures that partners from Kenya identified on the water resources are climate change and illegal mining activities. The climate change phenomenon intensifies in Kenya as the country is already experiencing high temperatures over the last few decades (Herrero et al., 2010). Many rivers' discharge rates and water levels will decline,

Table 1 The population of the Nyakach sub-county over the years (KISUMU COUNTY INTEGRATED DEVELOPMENT PLAN II, 2018–2022)

Year	2009	2018	2020	2022
Population	133,041	168,140	177,128	186,582
Density (persons/km^2)	372	470	495	522

affecting electrical energy production (Bunyasi, 2012). Both surface and groundwater abstractions will be significantly increased to meet the increased demands under climate change and population growth. Point and diffuse pollution is estimated to be expanded, following the ongoing growth of urban areas due to the lack of sewage networks, an existing problem for many years (Kanoti et al., 2019; AFW, 2014).

3.3.3 State of the Water

Ajuang et al. (2016) conducted a questionnaire survey and interviews in the Upper Nyakach area to collect qualitative and quantitative data. Their study sought to determine household climate change awareness levels using common climate change indicators such as heavy rainfall incidents, flooding events, drought periods, and temperature. According to the findings, the majority of the households (86.7%) reported that they had observed changes in water sources. The actual changes that were observed were the following: drying up of water sources (63.3%), reduction in water quality (17.3%), conflicts over water access (12.7%), increasing distance to water sources (5.8%), and a rise in the prevalence of waterborne diseases (0.9%).

According to Oiro (2018), groundwater flow follows the direction of the hydrographic network. It flows from the high-altitude areas toward Lake Victoria. Groundwater accounts for 15% of all irrigation withdrawals (mainly in the Rift Valley Basin). There is potential for further groundwater exploitation; therefore, the National Water Master Plan projects that 8% of new irrigation abstractions by 2030 will depend on groundwater (USAID). Boreholes in the Lake Victoria Basin are deep in most locations. The average depth ranges between 50 and 150 meters (m). Shallow aquifers are developed in the coastal plains near Lake Victoria and alluvial fans along with river flow (Barry & Obuobie, 2012).

3.3.4 Impacts

The impacts of climate change in Kenya have affected some of the key sectors of the country's economy (GoK, 2007; Kuria, 2009; SEI, 2009). Kenya is naturally prone to drought due to high inter-seasonal and inter-annual variability. Severe droughts were recorded in 2010–2011, 2016–2017, and 2019 (FAO, 2020; Uhe et al., 2016). The latter prolonged drought period affected more than 3 million people. 25% experienced malnutrition since rain-fed agriculture is the prevailing cultivation pattern, and 60% of livestock are in arid and semi-arid areas (Walsh, 2019). Increased numbers of extreme rainfall events, combined with land-use changes (deforestation for agricultural expansion), cause floods that intensify soil erosion and result in siltation of watercourses, threaten infrastructure and human lives, spread water-borne diseases, and cause economic losses due to the damages caused to crops (NEMA, 2011). The entire Kisumu County is an extremely high-risk area for both drought and flooding phenomena (Fig. 9a, b).

The rapid population growth, the growing commercial activities, industrialization, and insufficient waste/water management in Kisumu and Lake Victoria Basin have increased the amount of urban waste. The lack of appropriate treatment facilities and technologies has degraded water resources quality (Juma et al., 2014). Some years ago, Scheren (2003) investigated the impacts of water pollution in the Lake Victoria catchment by applying the DPSIR framework. According to the findings of his

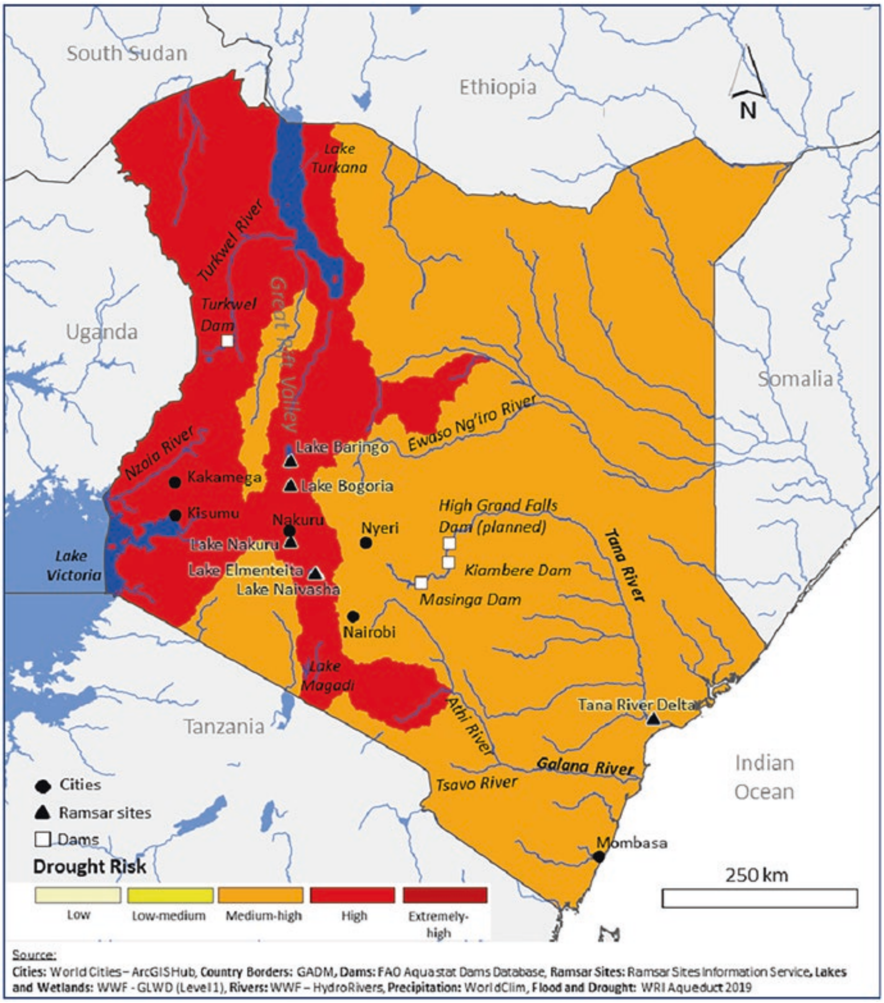


Fig. 9 (**a**) Drought risk of Kenya; (**b**) Flood risk of Kenya

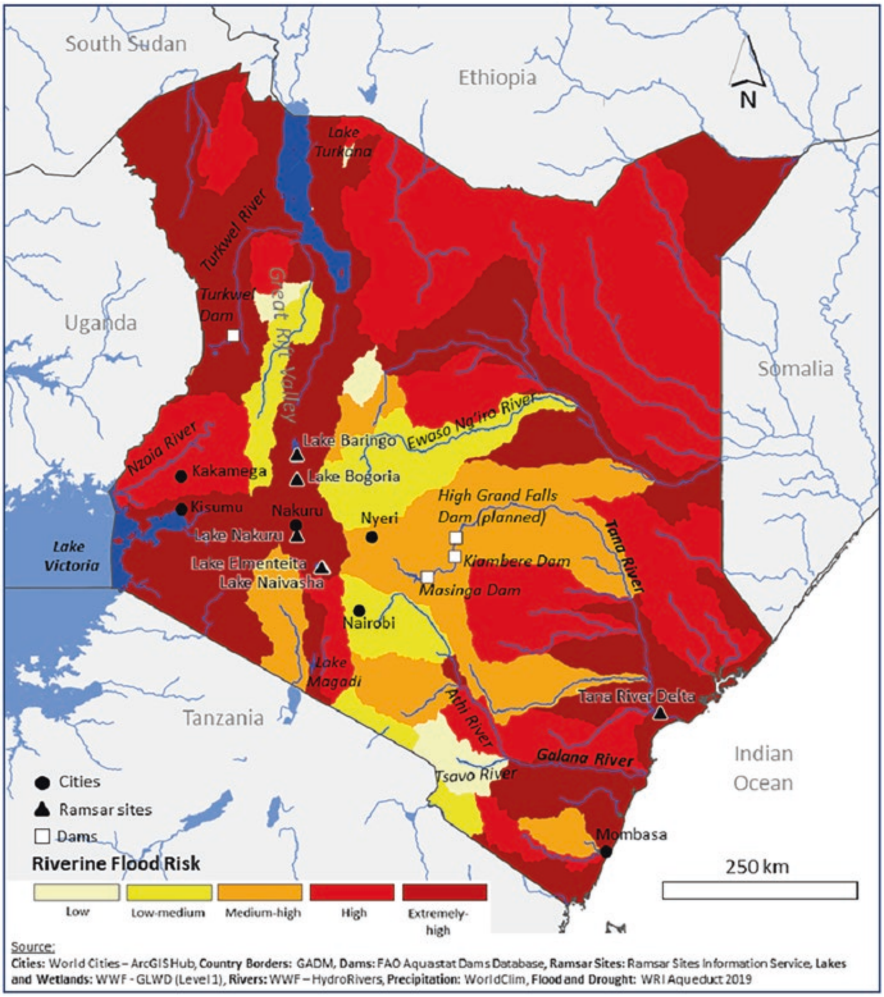


Fig. 9 (continued)

publication, it highlighted the following impacts: decrease of traditional fish resources, loss of amenity (stench and visual impacts), loss of recreational and tourism value, health issues (waterborne diseases: diarrhea, bilharzia, typhoid, dysentery, and cholera), loss of water provision value, and loss of biodiversity value.

3.3.5 Responses

The Nyando River discharges into Nyakach Bay in Lake Victoria. The basin includes parts of Nyakach County. Njogu (2000) provided a detailed list of remedial measures focusing on the conservation and protection of the area's water resources based on the findings of his research, which are presented below:

- Rehabilitation of irrigation works to reduce losses and mitigate low crop and livestock production problems
- Flood protection measures (construction of dams and dikes, installation of a flood warning system, resettlement, and construction of a reservoir)
- Protection of springs and shallow water wells
- Increased coverage of urban and rural domestic water supply and sanitation services. Maintenance of the distribution network to reduce losses
- Reforestation, improved land management practices, zoning of conservation areas for protection, improved quality sampling frequencies, established rules that govern effluent discharges by industries/households, etc.
- Recommendations about the use of fertilizers and pesticides

The appropriate institutional and management arrangements need to be adopted to achieve the above objectives. Some changes to water resources policy and legislation proposed by leading stakeholders involved in water management planning and decision-making include pricing policies that will reduce waste of water, water use charges, enforcement of polluter-pays policy, and improved surveillance and monitoring.

Seminars and training, focusing on human resources development, including stakeholders and end-users (e.g., farmers and households), should be carried out at regular time intervals. Even though institutions for water management on river basin scales exist, there is a gap in coordination and an overlap of duties with other organizations that operate on a different scale. Reorganization and integration among the functions of the different institutions are required. A top-down planning and management approach is currently in priority. It is crucial for this situation to be changed, involving local stakeholders and users in a more bottom-up approach and encouraging all interested parties to participate in the planning and decision-making process.

The produced DPSIR framework is shown in Fig. 10.

3.4 Burkina Faso Case Study

The case study area is located in the Bereba District in the Province of Tuy in the Region of Hauts-Bassins in the west part of the country (Fig. 11). The majority of the population in the area is occupied in agriculture. The main crop is cotton in rotation, with cereals irrigated by rainwater. In 2014, 49% of people living in urban areas and 81% in rural areas (in Hauts-Bassins) lived with a cost below $3.10/day. The broader area is characterized by two main seasons regarding its precipitation regime. The rainy season corresponds to cropping periods (May–October) and the dry from November to April. The average temperature in Béréba is 28.4 °C, and the average annual precipitation is 758.5 mm/year. According to the Köppen-Geiger classification, the area is classified as desert climate (BWh). August is the wettest month with an average precipitation equal to 186.17 mm, and April is the warmest month showing a mean temperature of 37.1 °C (https://tcktcktck.org/burkina-faso/hauts-bassins/bereba, last accessed 01/02/2022). Burkina Faso ranks 138th out of 169 countries in water vulnerability to climate change (ND-GAIN, 2021). Over the last few decades, extreme weather events, such as prolonged drought periods and

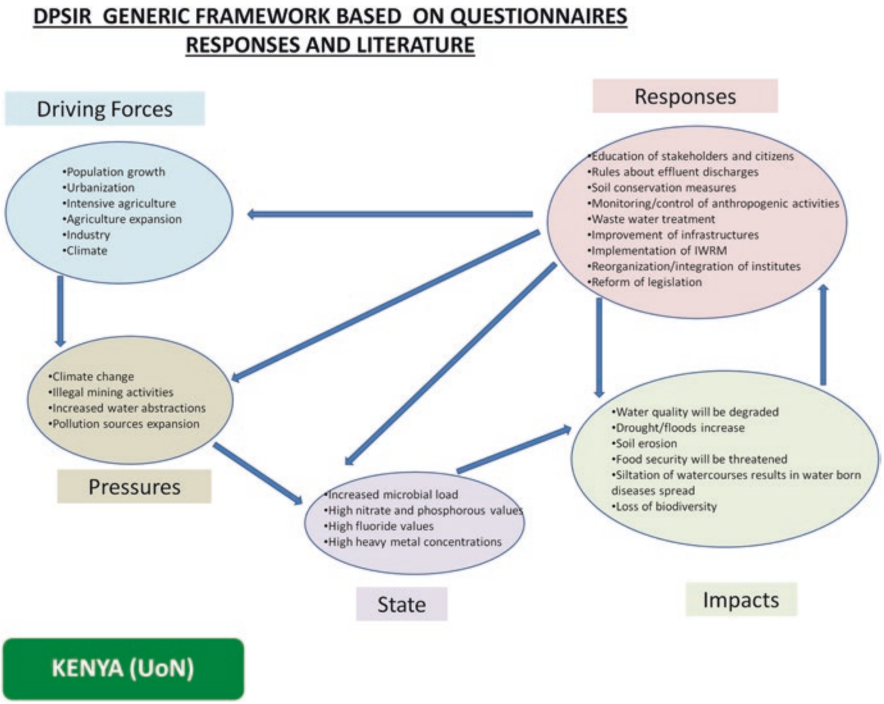


Fig. 10 DPSIR framework for water resources in the Kenya case study

Fig. 11 Selected area for the implementation of the DPSIR framework in Burkina Faso

flooding phenomena, are recorded more often (Crawford et al., 2016). Groundwater is used mainly for drinking water supply, whereas a small percentage of groundwater is used for small-scale market garden irrigation and livestock watering.

Taking into account the information gathered from the selected databases and the questionnaire survey, the DPSIR model was structured to assess the current status in Burkina Faso and propose relevant management responses.

3.4.1 Driving Forces

The main driving forces, i.e., socioeconomic activities that exert pressures on the water, are: animal breeding, population growth, and climate change.

Over the years, the population of Burkina Faso shows a continuing increase and the current population is 21.85 million (https://worldpopulationreview.com/countries/burkina-faso-population, accessed 02/02/2022). Population growth leads to increased food demands and the need for employment. Therefore, many savannas (the dominant landscape in those years) were converted into croplands to meet the ongoing needs. The agricultural expansion rate is estimated to be 4% per year for the period 1975–2013 (https://eros.usgs.gov/westafrica/land-cover/land-use-land-cover-and-trends-burkina-faso). The population of Tuy Province showed an average annual growth rate equal to 2.9% (2006–2019). At the same time, the population of Bereba is enhanced as well, showing an increased rate of 1.7% for the corresponding years. The population density in Tuy Province is equal to 58.43 people/km^2.

3.4.2 Pressures

The variation of the climate conditions due to climate change is highlighted by the stakeholders as the main pressure on the water resources in Burkina Faso. Furthermore, the groundwater level is decreased, meaning that available water reserves are shrinking. Increased local water abstraction constitutes another significant pressure resulting from population growth, urbanization, intensive uncontrolled mining activities, agriculture expansion, and population displacement due to armed conflicts in the country after 2016 (https://www.icrc.org/en/document/burkina-faso-water-scarcity-conflict, accessed 02/02/2022; Sanon et al., 2020). Pollution of water resources from gold mining and agriculture has been an additional pressure over the last few years.

3.4.3 State of the Water

A detailed study concerning groundwater quality and quantity in Burkina Faso is provided by Martin and van de Giesen (2005). The main results of this research work are the following:

1. Groundwater production through boreholes, modern hand-dug wells, and piped systems has increased substantially over the past few decades in the

Volta River Basin. It has made groundwater an essential water source for rural and urban water supply. The groundwater consumption per person in the broader study area is depicted in Fig. 12 and is classified as one of the highest in the country.

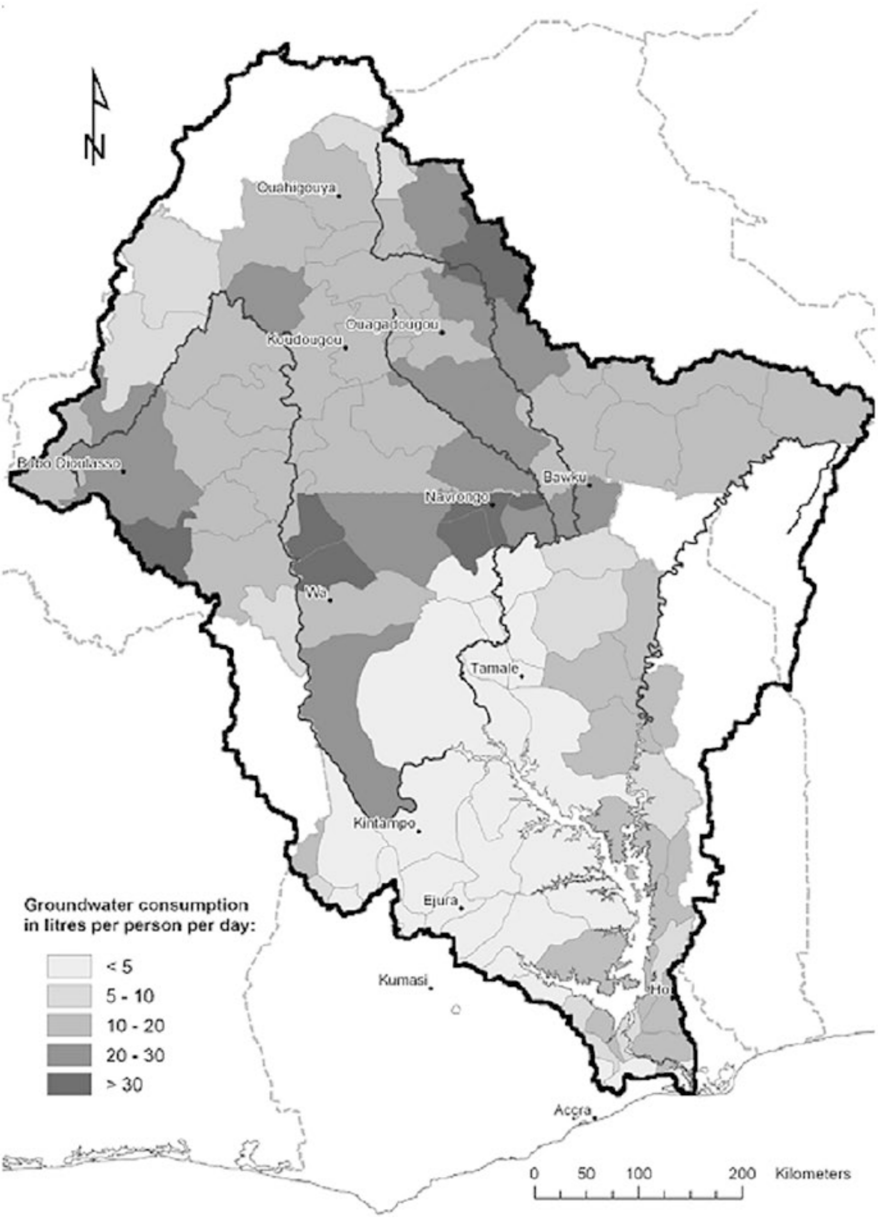


Fig. 12 Average daily per person groundwater consumption (Martin & van de Giesen, 2005)

2. The ratio of groundwater production to aquifer recharge in parts of the study area exceeds the average national ratio (Fig. 13); it is indicative, though, that there is potential for further exploitation of groundwater without posing any threats to the aquifers or having a significant effect on the hydrological balance of the area.

Although the groundwater quality in Burkina Faso is considered good to meet people's demands (Groen et al., 1988), pollution problems occur locally, especially in shallow aquifers (Yameogo & Savadogo, 2002). The use of fertilizers and chemicals in agricultural activities and the uncontrolled disposal of untreated waste from industries constitute the most significant sources of pollutants in groundwater. Due to poor sanitation facilities and services, high nitrate values in groundwater samples are recorded in densely populated areas (Groen et al., 1988).

3.4.4 Impacts

The main impacts on human well-being and the environment can be summarized in the following:

- *Land degradation.* The increase in the frequency of extreme rainfall events and prolonged drought periods potentially leads to soil degradation and erosion. Therefore, fertile land is at risk of being lost. The high deforestation rates (Crawford et al., 2016) will contribute significantly to this loss. Desertification is expanding from north areas to the south (GFDRR, 2011). It is estimated that an area of 360,000 hectares of productive land will be lost every year (FAO, 2021).
- *Decrease of per capita water availability.* The Potsdam Institute (2020) estimates that climate change and population growth will reduce per capita available water in the next 60 years.
- *Increase of health vulnerability.* The upcoming changes in the climate, temperature, and rainfall regime affect infectious disease rates. Climate change shifts timing, seasonality, and geographical spread of disease epidemics (USAID, 2012) such as meningitis and malaria (Feldscher, 2018; USAID, 2012).
- *Undernutrition.* Water scarcity, which is aggravated by climate change, may reduce food production. Desertification decrease of crop yields will increase food insecurity (Potsdam Institute, 2020), as well.
- *Conflicts and people displacement.* Desertification and decreased access to water sources have amplified tensions and conflicts between different groups of people (e.g., pastoralists and farmers) in recent years. People compete to achieve access to critical water sources and fertile land (Relief Web, 2020).

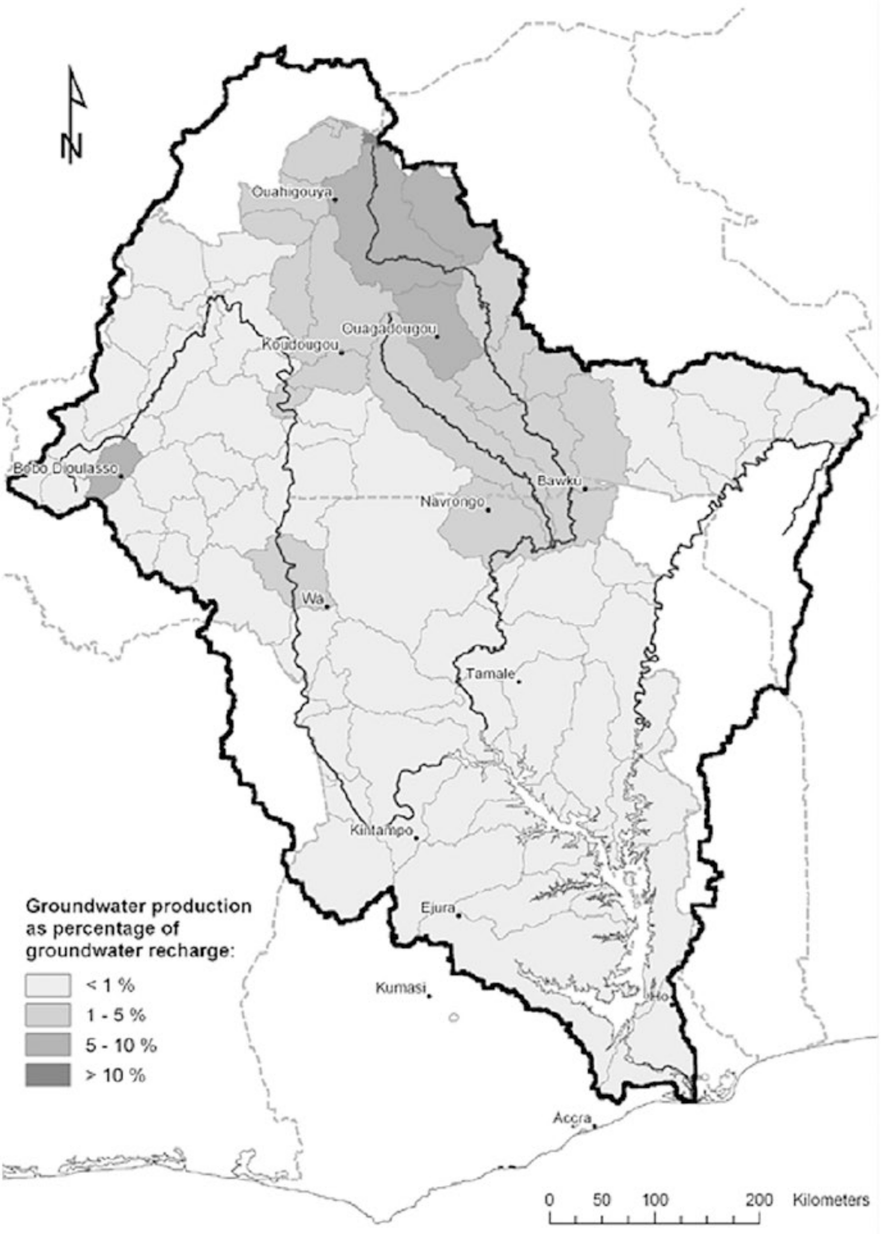


Fig. 13 The ratio of groundwater production to groundwater recharge (Martin & van de Giesen, 2005)

3.4.5 Responses

Burkina Faso has two main export products, which are cotton and gold mining (CIA, 2021). The first one is a water-intensive and heat-sensitive cultivation. It is significant for farmers to adopt alternative crops that are resilient to climate change with less water demand. In the National Climate Change Adaptation Plan (Ministry of Environment and Fishery Resources-Burkina Faso, 2015), specific long- and short-term measures for preserving and protecting the country's water and natural resources are described. The following are included among the actions that are proposed to be adopted:

- A national teaching strategy on climate change
- Greater synergies between parties involved in climate change (researchers, government technical services, producers, the private sector, NGOs and associations, etc.)
- An increased number of training and awareness-raising measures informing the public about the consequences of climate change for their livelihoods and means of subsistence
- Regular meetings between the government and its various partners with a view to the implementation of the current National Adaptation Plan
- The establishment of a committee to monitor the implementation of the National Adaptation Plan

Finally, the partners from Burkina Faso, based on their knowledge, experience, and expertise, highlighted the following responses as the most effective to achieve water resources sustainability in the area: access to funding for farmers, wastewater treatment, water use restrictions by authorities, water resources monitoring, improvement of infrastructures, implementation of integrated water resources management, and promotion of alternative cultivations.

The produced DPSIR framework is shown in Fig. 14.

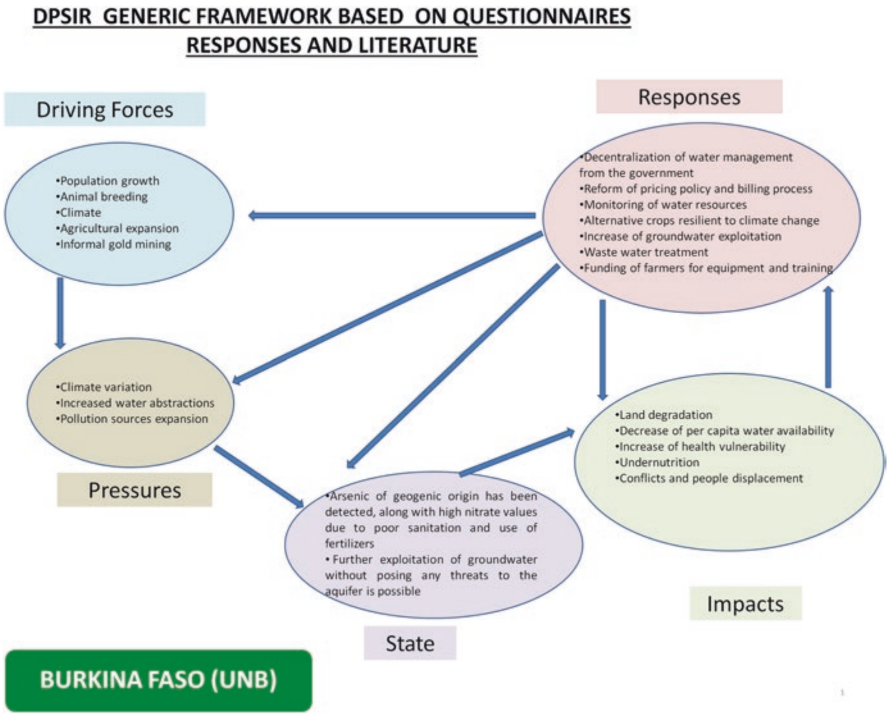


Fig. 14 DPSIR framework for water resources in the Burkina Faso case study

4 Conclusions

One of the main challenges of water management in the foreseeable future is to integrate socioeconomic parameters with natural processes. The development of societies and economies and their relationship with water resources systems require holistic management unlike the fragmented approaches implemented in the past. The DPSIR model is regarded as an appropriate tool for such integration. In this chapter, it is used to organize information about the factors affecting water quality and quantity in West and East African countries (Ghana, Burkina Faso, Kenya, and Tanzania), focusing on those that exacerbate the water budget deficit under the EWA-BELT project. DPSIR will allow decision-makers and stakeholders to view the water sustainability issues more comprehensively. Therefore, the project impact will have a long lifespan, since the implementation of the suggested measures will accelerate the achievement of water sustainability through appropriate water management. Preliminary results indicate that there is an overall increase in the driver of water consumption, in the selected case studies. Changes of climate, together with the population growth, can generate conditions of water scarcity and stress. The intensive agriculture production has put high pressure on local water resources, as well. In addition, lack of infrastructure and irrational management practices aggravate the unsustainable utilization of water resources. Further findings indicate that farmers' income is decreasing and health issues arise over the years, generating negative impacts on human well-being and on sustainable development.

The response options are measures to improve regional water resources sustainability, based on science and on serving society. It can be achieved by changing behaviors and enhancing the education and funding of stakeholders. Additional measures may include changes during the agricultural production processes, for reducing high water consumption and high nitrogen pollution. Water-conserving technology adoption and improvement of infrastructures can also contribute to sustainable water resource utilization, through the establishment of monitoring networks and the increase of wastewater treatment usage. Overall, the implementation of integrated water resources management is identified as the most appropriate response.

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