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SMART IRRIGATION – SMART WASH

Solutions in response to the pandemic crisis in Africa

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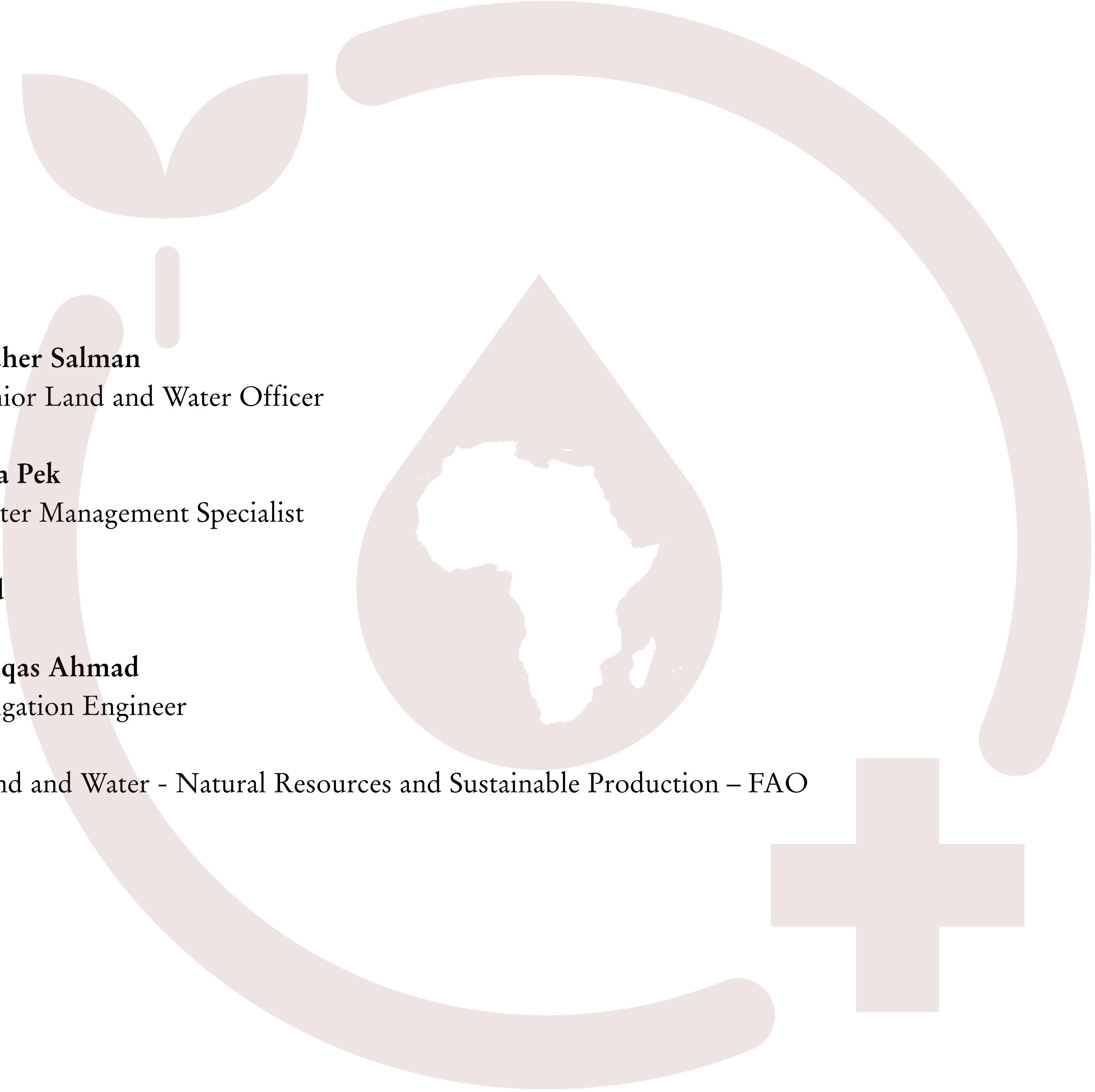

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Acknowledgements

The discussion paper “Smart irrigation – Smart WASH solutions in response to the pandemic crisis in Africa” is an effort of the Land and Water Division of FAO (NSL). The methodology of the paper is based on the internationally established and recognized vulnerability assessment indicators. Practical solutions to the pandemic crisis, for both Irrigation and WASH, in light of the assessed indicators are proposed.

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Executive summary

Uncertainties related to the impacts of COVID-19 on daily life are increasingly growing. Inherent effects have grown beyond the well-defined spear of health risks and have shocked the livelihood and food security in several countries. Particularly in the poorest countries, the impact is more devastating due to the limited availability of resources to slow down the spread of the disease. These countries require immediate actions to safeguard food security and human health. Irrigation has a great role in improving crop productivity and ensuring food security. However, expanding irrigation could impact the availability of water for sanitation and hygiene which has a central role in slowing down the spread of the disease. It is, thus, clearer that irrigation development should also comply with the requirement of extended need of water for sanitation and hygiene. Developing multiple water use would certainly allow to fight the pandemic while ensuring the basic needs of food security in rural communities. To support the concept of multiple water use, a new initiative called SMART irrigation – SMART WASH is proposed for corporate solutions to enhance irrigation and provide WASH facilities to vulnerable communities, thus, responding to the critical needs in times of pandemic crisis.

For the implementation of SMART irrigation – SMART WASH concept, geographical hotspots of the COVID-19 were identified in the African continent which is currently the most vulnerable region to face the negative impacts of this pandemic. Twelve internationally established and recognized indicators were used to identify the vulnerability of each country in the African continent. The indicators were divided into two domains: (a) improving food security and (b) increasing health facilities. The indicators are scored individually in each country and each of them is analyzed separately and visualized on a continental map. The results are then aggregated into a final score that shows the degree of vulnerability in Africa countries.

Interventions are proposed based on the degree of vulnerability for each country. The investment directions are divided into two levels of intervention: on-farm level, and system level. The on-farm level packages aim at providing engineering solutions to decrease evapotranspiration, thus, improving water productivity. The system level packages showcase possible engineering solutions customized to the groups of investment evaluation matrix. In every case, investments in multiple water use combine on-farm and system-level solutions in order to reinforce the sustainability of SMART Irrigation – SMART WASH development. The private sector partnership forms a strategic direction of FAO's work to bring the state-of-art innovations aboard, which are in line with its corporate strategic objectives. Under FAO's Strategy for Partnership with the Private Sector, FAO cooperation with innovative private companies working in the same field are recommended to achieve the objective of SMART Irrigation – SMART WASH initiative.

The engineering solutions' section is based on a systematic review of existing technologies, which are also showcased in different regions. However, the search process returned over hundreds of technologies. After reviewing them, selected technologies are presented. It is worth mentioning that this should read as a non-exhaustive "toolbox" of potential technologies. In addition, recommended local solutions require feasibility assessment based on multiple criteria. This is particularly important in Africa, where multiple water use has high unexploited potential. Although, it is not yet sufficiently advocated. Therefore, the further step of SMART Irrigation – SMART WASH approach is to scale the solutions to local level, and work out the detailed design, which should properly fit into the given conditions.

Background

This discussion paper has been prepared by the Land and Water division (NSL) of FAO with the aim to motivate a discussion on the rapidly evolving situation of COVID-19 pandemic to define the most vulnerable hotspots in the African continent, and to identify the possibilities of relief measures to slow down the spread of the disease. Uncertainties related to the impacts of COVID-19 on daily life are increasingly growing and the negative effects have already been observed beyond the well-defined health risks. Countries already facing varying dimensions of risk will need to construct their exit strategies in order to overcome the devastating outcomes. Nothing is enough when it comes to protecting the vulnerable. The leading principle of such strategy is "Only the paranoid survives", which is more than a mere poetic pretense. The spatial and temporal effects of the virus transmission are still unknown. Therefore, countries must carefully review every possible risk factor associated to the virus and create their short and long-term strategies based on well-established assessments.

The Extraordinary G20 Agriculture's Minister's meeting, involving FAO, IFAD, World Bank and WFP, issued their joint statement on COVID-19 impacts on food security and nutrition. The high-level meeting concluded that the pandemic is already affecting the entire food system from multiple directions. The situation poses critical challenges that might lead to food insecurity. Still worse, the impact on people living in the poorest countries is the most devastating. These countries require urgent support to avoid setback for the achieved progress in poverty reduction, inequality and underdevelopment. Many countries are already receiving emergency supports and funds. However, the past few months have proved that the fight against the pandemic is a marathon, not a sprint. Therefore, decent balance between emergency and development funds must be achieved to find long- term solutions not only to combat COVID-19 but to be prepared for any eventuality.

Agriculture has been the engine of overall economic growth in developing countries, whereas agriculture significantly contributes to the GDP, rural employment, household food security and trade balance. Improving the productivity and efficiency of agriculture is more relevant than ever, while tackling the long-standing issues such as climate change or environment degradation, together with the pandemic-induced conditions. Undoubtedly, exploiting irrigation potential has major role in achieving both productivity and efficiency objectives, thus, enhancing food security. Nevertheless, expanding irrigation entails considerable growth in water use, meanwhile, provision of safe water for sanitation is the prerequisite to slow down the spread of the pandemic. It is, thus, clearer that irrigation development should also comply with the requirement of extended need of water for sanitation and hygiene. Water saving in irrigation could always have a spill-over effect on sanitation making more resources available to the sector. Developing multiple water use would certainly allow to fight the pandemic while ensuring the basic needs of communities. The initiative proposes a twin- track approach, called SMART irrigation – SMART WASH, for corporate solutions to enhance irrigation and provide WASH facilities to vulnerable communities, thus, responding to the needs in times of pandemic crisis.

A critical step to introduce corporate solutions to enhance multiple use of water for irrigation and WASH sectors to vulnerable communities is tracing the impact of the Covid-19 and identifying the affected geographic hotspots in the context of agriculture, food production and hygiene. This would be followed by the assessment of appropriate technical solutions for SMART irrigation – SMART WASH, pre-evaluating their socio-economic and environmental impacts, applying them on pilot basis, and proposing and establishing a strategic partnership, actions-oriented and results-based, that would generate a critical mass of 'capacities' to deliver an 'impact-at-scale' of introduced SMART irrigation and SMART WASH solutions approach in the contexts of different countries.

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Scope of the work

MAPPING VULNERABILITY AND DEFINING GEOGRAPHIC HOTSPOTS OF COVID-19 IMPACTS IN AFRICA

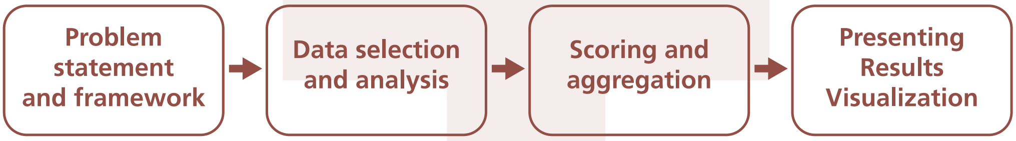
The aim of the assessment is to identify the geographical hotspots of COVID-19 impacts framed in the context of agriculture, food production and hygiene due to the date of the analysis. However, the most possible repercussions must be considered in order to build-up the best-suited strategy to sustainably maintain the food production system in the continent. Therefore, the impact mapping is carried out along largely agreed risk factors. Countries with most overlapping levels of vulnerability are defined as potential hotspots. On the other side, the spreading trend of the pandemic is analyzed in the continent, while considering the reliability of reported cases. Countries assumed to have low relative ability to testing and hospitalizing are analyzed in a qualitative manner. In addition, the intersection between countries with high vulnerability related to agricultural production and countries with high vulnerability related to the pandemic are identified as geographic hotspots. However, the aim is not to rank countries based on a single assessment, and eventually diminish the needs for investment in any of the countries. It targets to provide a solid ground to assess the potential factors of vulnerability in disaggregated and aggregated manner. Yet, the real-term impact of COVID-19 is surrounded by many uncertainties. In that sense, it is recommended to read the analysis as a dynamically evolving assessment, which needs to be adjusted over time, and not as a final ranking of countries by any means.

METHODOLOGY BACKGROUND OF MAPPING VULNERABILITY

Most of the impacts of COVID-19 can be already predicted through analysis of existing information. Based on the available reporting, food security and access to safe water are certainly in the front of the line. FAO highlights that the pandemic puts a spotlight on the need for clean water and sanitation, and for water for food production: "without clean water, hand washing is impossible, and without water food security would not be achieved" (FAO, 2020). In fact, the water use pattern is expected to change as the consequence of the crisis. Not only the increasing demand for clean water but temporal and spatial changes put more burden on existing infrastructures and utilities. Beyond the growing overall demand, the peak water use of households can be significantly increased by changing behaviors. Another scenario can be the more intensive domestic food production due to the disrupted trade. Communities relying on importing staple food can shift to subsistence farming through extended cropping areas, gardening or production intensification. Post-hoc analysis of the pandemic will certainly provide more lessons about the real-term responses. Until then, proper risk assessment methodologies are desirable to improve preparedness.

Understanding the probability of the risk can be largely supported by the characterization of the impacted sectors. Composite indicator analysis is broadly practiced providing aggregate information about the probability and magnitude of different crises, such as pandemic outbreak. The composite indicator analysis can be mono- or multi-sectoral, can describe different dimensions of risks, and, can be disaggregated into individual components. The number of valuable studies applying composite indicators is ample. A short introduction of the existing methodologies and available tools of risk assessment with composite indicators can definitely help understanding the selection of indicators for mapping vulnerability in specific context. OECD (2008) published a handbook on constructing composite indicators, in which the methodology is described as "simple comparisons of countries that can be used to illustrate complex and sometimes elusive issues in wide-ranging fields" (OECD, 2008).

By applying the composite indicator methodology, the vulnerability mapping developed through the following steps:



- Problem statement and framework: the analysis aims at providing a systematic assessment of countries' vulnerability to the pandemic crisis in terms of food security and health sectors, and their interaction with water management. The paper presents how underdeveloped water sectors can further hamper countries' ability to mitigate the impacts of COVID-19. The extreme diversity of the adverse effects requires a multi-sectoral approach, which sufficiently integrates the different water use activities. Therefore, the vulnerability mapping builds on a multi-dimensional approach, which measures the current status of food security and access to water and health services to assess and map countries.
- Data selection and analysis: the robustness of the results largely depends on the selected data. Selected data must have causal relationship with the measured vulnerability. For example, although a country has sufficient water resources to cover all demand, the potential is not necessarily exploited due to environmental, economic or institutional obstacles. Therefore, countries with abundant water resources are not obviously prepared to supply sufficient water for each sector. More difficult is that the analysis is carried out at country level. There is still

general data paucity at global level, which limits the opportunity to obtain homogenous data quality at the same spatial scale. Therefore, the following criteria are decided to identify the most appropriate data source: reliable data sources, regularly updated information, sufficient country coverage to ensure comparability of data, global datasets at country level. Based on these criteria, global datasets related to the dimensions of food security and health are selected from recognized sources belonging to international organizations.

- Scoring and aggregation: the selected data requires processing to be translated into meaningful information. Prior to the aggregation, normalization is necessary as most of the datasets are of different units. Amongst many normalization methods, categorical scale approach is selected, through which each indicator can be scored at the same range. Although the procedure seems relatively simple, the normalization requires some caution as each dataset has specific underlying structure. For example, spatial discrepancy results high skewness in the datasets, whereas the range of minimum and maximum values would distort the correct interpretation of irrigation development. It can be readily accepted that such dataset requires the adjustment of scores assigned to percentiles of distributions. Therefore, skewed data must be scaled with different methods than normally distributed datasets. This allows to avoid the biases of estimation. Once the scaling is performed, the sub-indicator values can be aggregated into a final score. Instead of simple ranking, the objective is to obtain country groups, which are equally vulnerable to the pandemic impacts. Therefore, the final scores are further scaled into qualitative categories.
- Presenting results - visualization: the visualization of composite indicators is of high importance. The visualization method must be able to display and communicate the most information in user-friendly manner. Albo *et al.* (2017) constructed the conceptual framework of composite indicator visualization. Visual encodings, such as tabular presentation, point-based technique, radial layout, are all readily accepted and widely applied forms of presenting results. However, choropleth maps are an extremely adequate method to represent geographic data. Indeed, many of the applied composite indicators (indices) are presented in map form. Suffice it to say that most of the index related to development (Human Development Index, Environmental Performance Index, Good Country Index, etc.) are visualized on choropleth maps. It does not mean that other methods are not appropriate to visualize data grouped on geographical bases. Maps, for example, can be complemented with tabular presentation in order to easily retrieve country-related information.

In order to better understand the advantages of composite indicators, the following list gives some relevant examples about vulnerability mapping:

- Index for Risk Management - INFORM by JRC Scientific and Policy Reports, European Commission is constructed to measure the risk of humanitarian crisis and disaster exceeding the national capacities to respond (De Groeve, Vermaccini, Poljansek, 2016; Marin- Ferre, Vernaccini, Poljansek, 2017). The framework of INFORM consists of three major dimensions of risk: Hazards & Exposure, Vulnerability, and Lack of Coping Capacity. The breakdown of the dimensions includes 17 sub-indicators related to natural, human, socio-economic, vulnerability, institutional, and infrastructural categories. Each data source of indicators is pre- processed in order to comply with consistency objectives. The Index of Risk Management tool is transferred to GIS platform. Also, INFORM index is performed on a country-by-country basis, in order to map countries by disaggregated sub-indicators and aggregated scores. The INFORM Index provides a strong methodology background of constructing composite indicator-based risk assessment relying on long-lasting trends.

- Aqueduct Water Risk Atlas constructed by World Resources Institute includes indicators related to water quantity, water variability, water quality, public awareness of water issues, and access to water and ecosystem vulnerability (Gassert, Luck, Landis, Reig, Shiao, 2015). Based on 12 indicators, the Atlas provides interactive GIS tool for water-related risks. Based on source data about micro-regions, the indicators compare spatial variations related to global water issues. Applying composite index to assess Overall Water Risk Default Weighting, the micro-regions are categorized in six major risk categories. The Water Risk Atlas is a resourceful platform to analyze water-related issues. This can be particularly advantageous for further risk assessment of crises on water resources at micro level, such as the impact of increased water demand by COVID-19.
- Global Food Security Index by The Economist - Intelligence Unit provides a comprehensive risk assessment of food security under three dimensions: affordability, availability, and quality and safety (The Economist, Intelligent Unit, 2019). Lately, fourth dimension, natural resources and resilience as risk factor was added to the methodology. The quantitative and qualitative scoring model involves 34 unique indicators, incorporating the drivers of food security. Along the four major dimensions, reports on Global Food Security Index is provided annually in country breakdown. The core advantage of the maps that they provide conclusions of the current situation related to food security, and future prediction based on trends. The website also enables the acquisition of annual datasets in order to investigate the sub- indicator performance per countries.
- Multidimensional Poverty and Risk from COVID-19 established by Multidimensional Poverty Peer Network (MPPN) provides composite indicator-based risk assessment of COVID-19 on poverty (Alkire, Dirksen, Nogales, Oldiges, 2020). It applies the Multidimensional Poverty Index (MPI) to identify hotspots of poverty. MPI is based on 10 indicators of acute poverty across three dimensions: health, education and living standards. Based on the disaggregated indicators, countries at risk are identified. Moreover, risk-prone countries are compared to the mortality rate of COVID-19, as indicated in the global map. The approach of combining actual implication of COVID-19 with existing composite indicators to prevail the relationship between risk assessment and reality has considerable advantages in order to detect real-time impacts and identify future probabilities.
- Mapping Risk Factors for the Spread of COVID-19 in Africa, published by Africa Center for Strategic Studies, provides a mapping of the pandemic spread associated to different types of risks. The Center identified nine variables, which can potentially influence the spread of the virus. Some of the identified indicators are cross-cutting with the dimensions of either food security or health, while they have also strong predictive power to analyze the future scenarios of the spread. This insightful approach is extremely useful to complement the existing information about the possible direction and intensity of spread, thus matching the vulnerability with reality (discussed later).

The diverse applicability of composite indicators allows for sufficient flexibility to provide context- tailored risk assessment. Unlike many more rigorous methodologies, this highly versatile approach should be considered as a dynamic process, which can be developed over time. It provides opportunity for further amendment, completion, and weighting of sub-indicators. Also, the approach can be scaled-out and scaled-up, depending on the center of interest. In order to facilitate the scaling of the approach based on comprehensive, reliable and updated datasets integrated in one interface, the Hand-in-Hand Geospatial Platform will certainly enhance the data retrieval

FAO's Hand-in-Hand initiative ready – A framework to deliver the SDGs

"Hand-in-Hand is an evidence-based, country-led and country-owned initiative of the Food and Agriculture Organization of the United Nations (FAO) to accelerate agricultural transformation and sustainable rural development to eradicate poverty (SDG 1) and end hunger and all forms of malnutrition (SDG2). In doing so, it contributes to the attainment of all the other Sustainable Development Goals." The Initiative was successfully rolled-out in 2019. Timelier than ever, the Initiative has started with the prioritization of left-behind countries. According to the goal of this very first step "the initiative prioritizes countries where national capacities and international support are most limited or where operational challenges, including natural- or man-made crises are greatest".

The objectives of the current paper are extremely in line with the Vision of Hand-in-Hand Initiative to set-up a rigorous framework for directing development mechanisms. Starting from prioritization based on different scales of vulnerability, through the investment guides, the analysis aims at providing complementary actions to Hand-in-Hand Initiative.

and help users to identify the necessary datasets in one place. FAO sets the target to synthetize the existing frameworks related to different aspects of food systems. Although these initiatives are often interconnected, interdependent and interlinked, the lack of a common framing is the major limitation to maximize their impact. One of the objectives to reach this synthetized operation is "to build a comprehensive, open data-sharing platform for modelling and analysis to construct scenarios" – all with a view to enabling better-targeted policies, innovations, investment and governance. Furthermore, the Hand-in-Hand GIS Platform will be extremely helpful to obtain disaggregated data at local level to prepare a thorough analysis for the implementation of the SMART Irrigation – SMART WASH approach. Nevertheless, the current paper presents a first step of performing a meaningful assessment of vulnerability at country level.

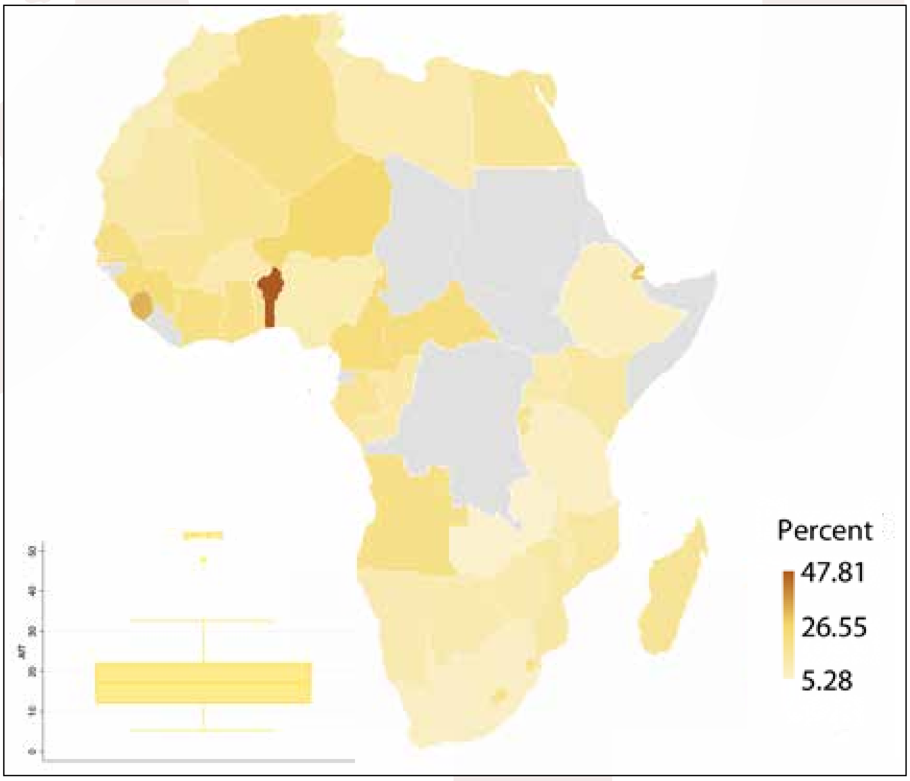
SMART Irrigation - SMART WASH approach requires a multi-sectoral analysis focusing on two dimensions: food security and health facilities. The analysis, however, is further limited to the water context, therefore, the probability of food security impact is analyzed through irrigated agriculture, and the probability of health impact considers the provision of safe water. Indicators are selected based on available sources about the pre-assessment of COVID-19 impact, which are thoroughly explained in the relevant sections.

INDICATORS OF VULNERABILITY

The vulnerability mapping involved 12 indicators associated with the risk of severe impacts of COVID-19. Indicators are selected from global datasets, which comply with the above-mentioned selection criteria. The indicators are grouped under two dimensions (a) improving food security; and (b) increasing health facilities. Each indicator is justified by the current on-going researches that they entail severe risk to increase the magnitude of potential COVID-19 impacts in the context of agriculture, food security and health. The indicators are scored individually in each country, and each indicator is analyzed separately and visualized on choropleth map, whereas dark tones indicate the increasing risk of COVID-19 impact in all cases. The indicators' results are, then, aggregated into a final score that shows the degree of vulnerability compared to other countries in Africa.

Indicator a-1 – Agri-food trade (AfT): The indicator measures the percent of food import in total merchandise imports of a country. As FAO indicated (FAO, 2020-a), the disruption and block of logistics affects severely the supply chains, as many countries rely on the import of food and production input. Although restrictions in mobility are necessary to flatten the virus transmission curve, IFPRI articulated (IFPRI, 2020), the global concern about lockdowns as "Trade restrictions are worst possible response to safeguard food security". Therefore, measuring the countries' exposure to trade disturbance as risk factor is particularly important. Figure 1 shows the internal exposure of the countries in the African continent using data from the World Development Indicators (World Bank, 2018).

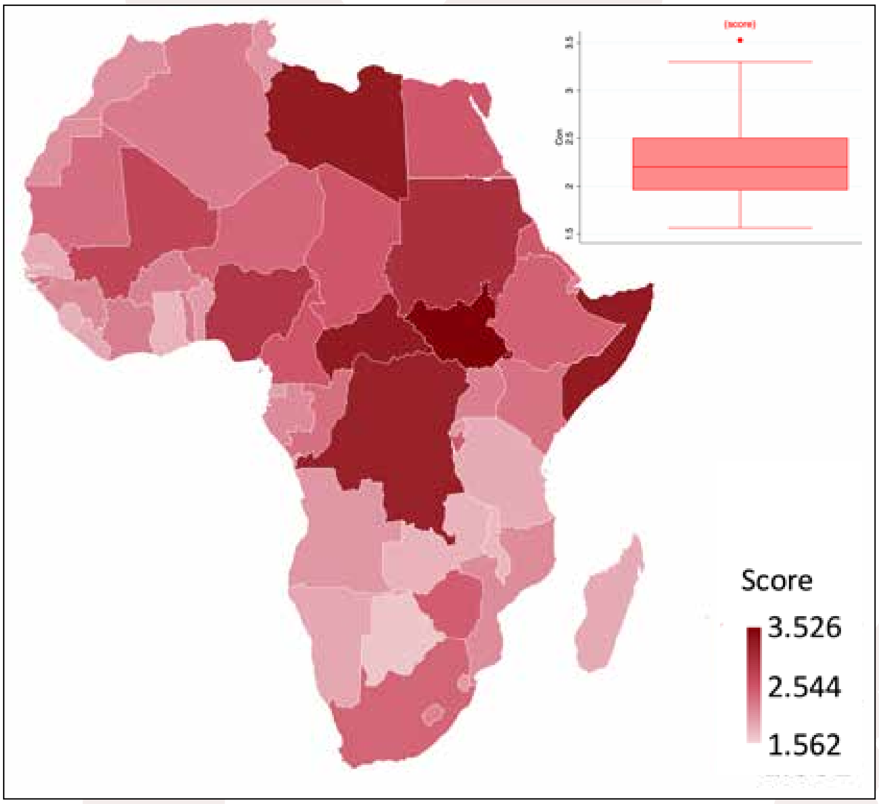
FIGURE 1
Map of agri-food trade in African countries



Source: World Bank, 2020.

Indicators a-2 - Conflict (Con): The composite indicator is based on three thematic indicators of societal safety and security, ongoing domestic and international conflict, militarization calculated by Global Peace Index (aggregating 23 indicators). Countries in fragility are particularly exposed as their capacity of resilience and mitigation is severely affected by internal conflicts (International Monetary Fund, 2020). Not only their internal resources are limited, but the ability to absorb and effectively use international funds is constrained due to instable institutional background, social disorder, lack of accessibility of communities. Figure 2 shows the Global Peace Index of the countries in the African continent (Institute of Economics & Peace, 2020).

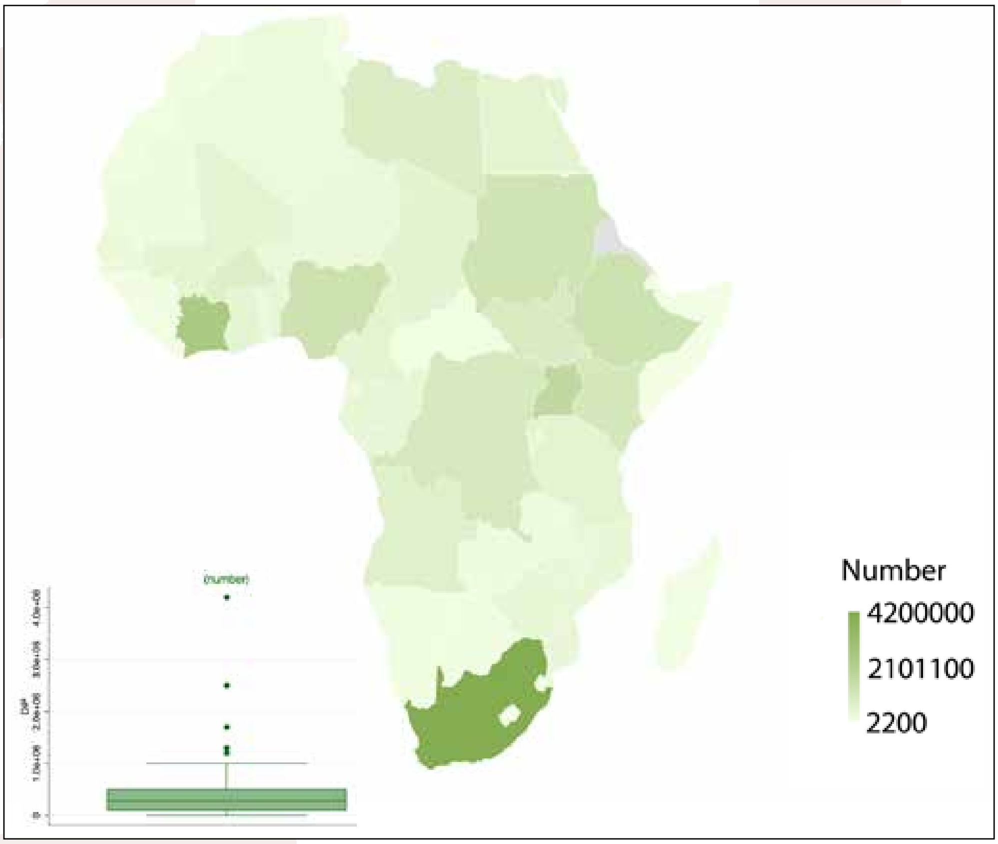
FIGURE 2
Map of the global peace index in African countries



Source: Institute of Economics and Peace, 2020.

Indicator a-3 - Displacement (DiP): The indicator is measured as the number of international migration stock in the country territory regardless of when they enter the country, including all foreign- born residents (UN DESA, 2020). According to the source of data by UN DESA, the number of international migrants may not include second-generation migrants that were born in the countries, but only parents. Also, the data does not refer to the annual migration flow data. UNHCR is heavily working on reaching out to displaced people (UNHCR, 2020). Countries with already limited financial resources are responsible to provide access to safe food, water and health system. Large degree of displacement increases the domestic food demand regardless of the capacity of the food systems. Therefore, displacement is considered a risk-driving factor of COVID-19 impact. Figure 3 shows the map of displacement in the countries of African continent (UN DESA, 2020).

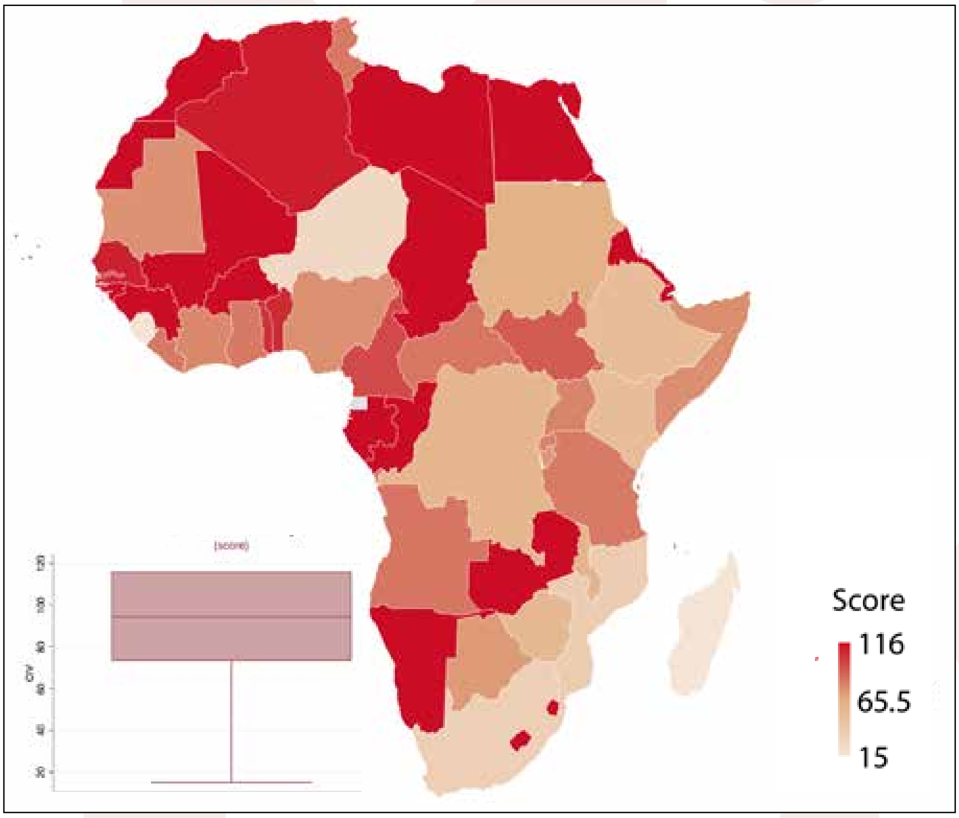
FIGURE 3
Map of displacement in African countries



Source: UN DESA, 2020.

Indicator a-4 - Climate vulnerability (ClV): The indicator expresses the level of exposure and vulnerability to extreme events aggregated by the Climate Risk Index. Food security is already associated to the adverse impact of climate change. FAO reported that “our hungriest, most vulnerable communities face a crisis within a crisis” (FAO, 2020-b). Their vulnerability is multiplicated by the effects of the COVID-19. The Figure 4 shows the Global Climate Risk Index using the dataset of GermanWatch (GermanWatch, 2018).

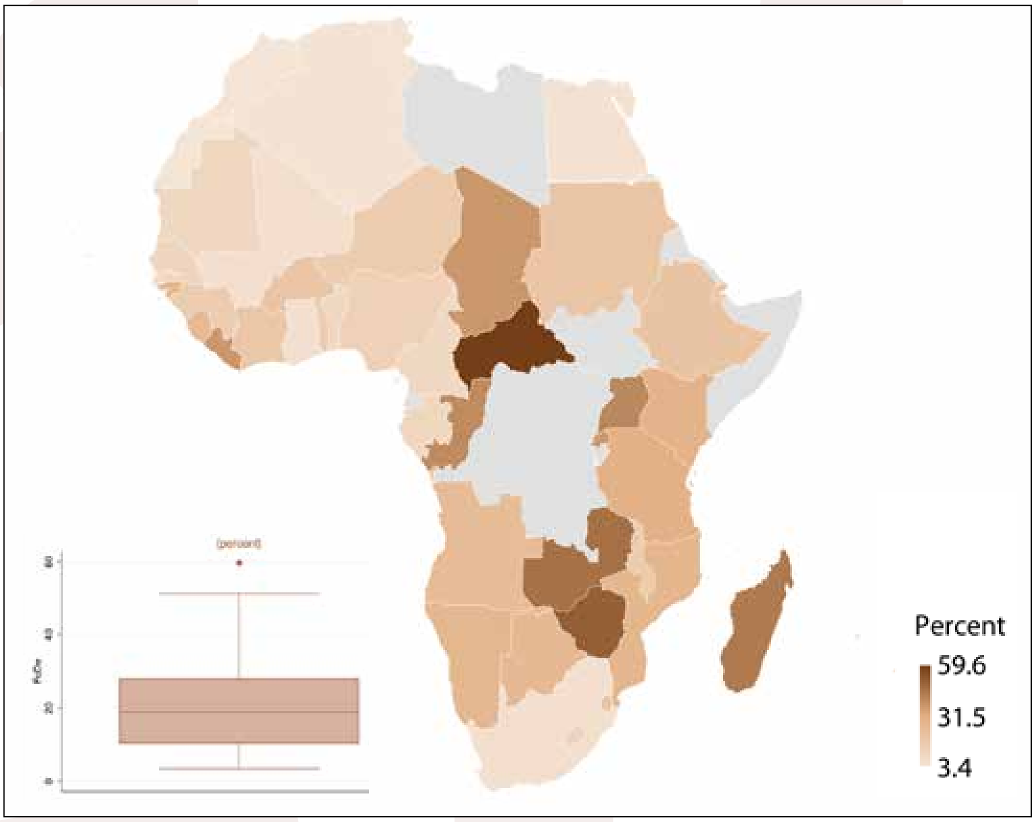
FIGURE 4
Map of climate vulnerability in African countries



Source: GermanWatch, 2020.

Indicator a-5- Food deficit (FoDe): The indicator measures the level of undernourishment along three years average in percentage. The severe undernourishment is threatened by three major facts, also discussed in the FAO Technical Note "Simulating rising undernourishment during the COVID-19 pandemic economic downturn". First, the measures to fight COVID-19 introduced a number of restrictions, which already affected the national food balances thus rising undernourishment (FAO, 2020-c). Second, undernourished people's ability to combat the virus is significantly lower. Finally, the already poor health capacities in developing countries are converted into virus protection, thus potentially crowding out people with other health issues, such as undernourishment. The Figure 5 shows the information related to food deficit in countries, sourced from FAOSTAT (FAO, 2018).

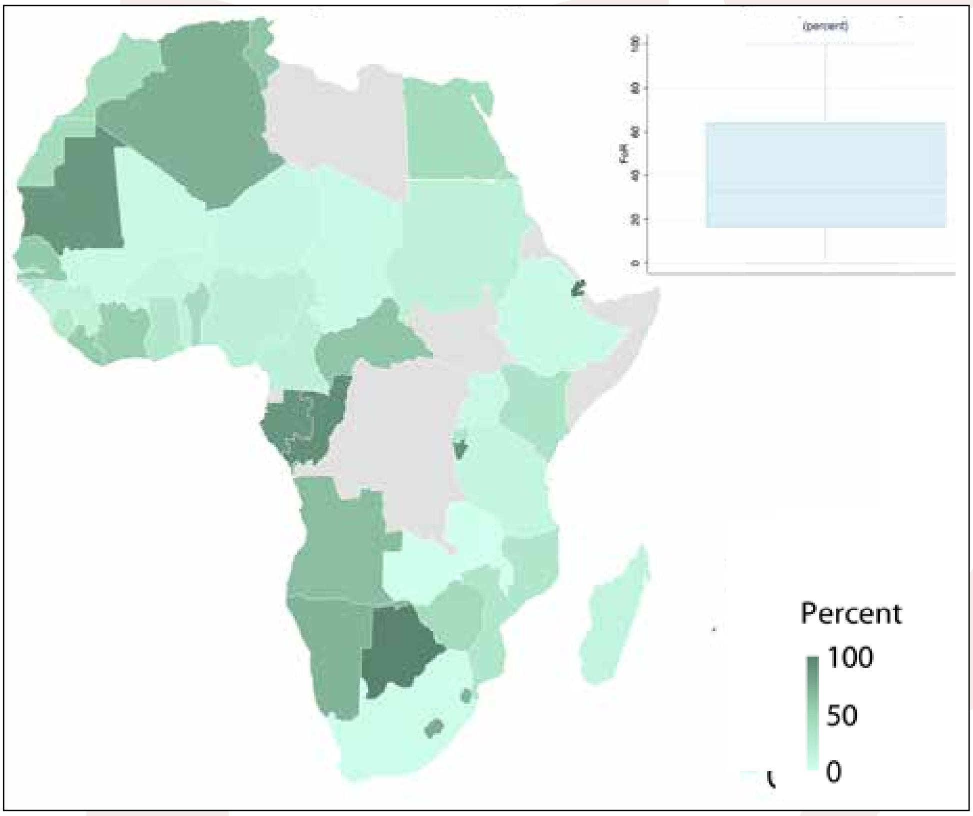
FIGURE 5
Map of food deficit in African countries



Source: FAOSTAT, 2020.

Indicator a-6 - Food import dependency ratio (FoR): The indicator expresses the ratio of domestic food supply of cereals that has been imported over the country domestic production (%). The disrupted logistics hampers the previous trade flows amongst countries. While many countries supply the domestic demand of staple crops from import, the country lockdowns and security measures are severe constraints of maintaining the previous supply levels. Figure 6 shows the food import dependency per country, sourced from FAOSTAT 2011-13 (FAO, 2013).

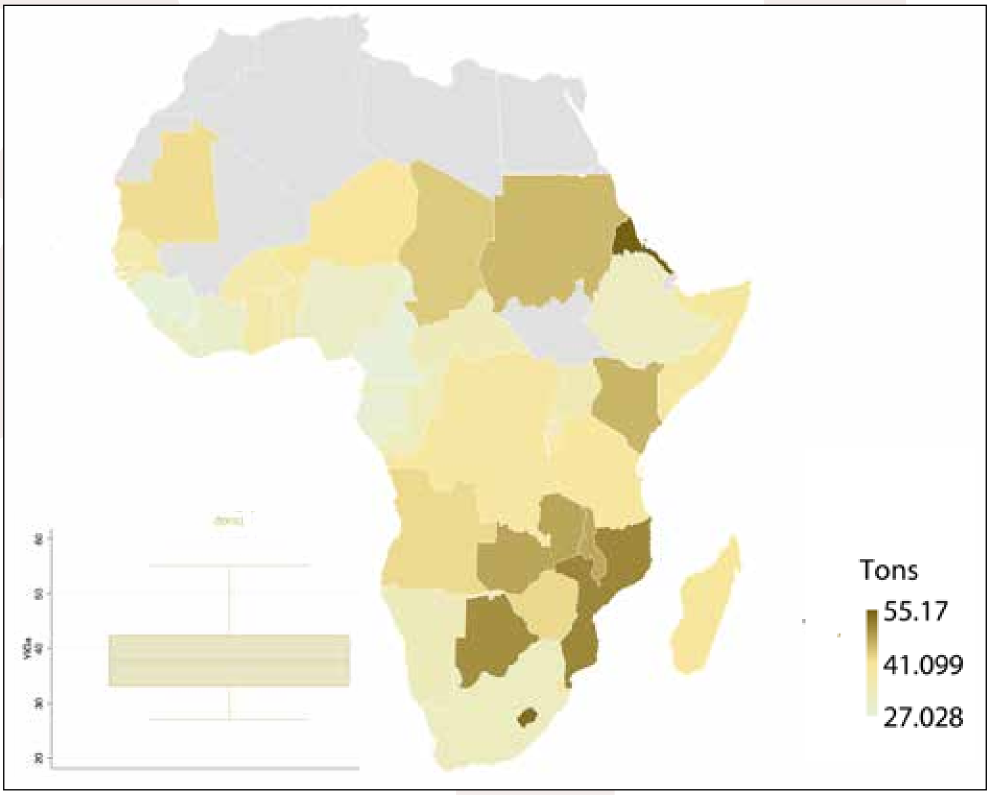
FIGURE 6
Map of food import deficiency ratio in African countries



Source: FAOSTAT, 2020.

Indicators a-7 - Yield gap (YiGa): The indicator is calculated as the difference between actual and potential yield (tons) of national cropping pattern differentiated by climatic zones per country. The indicator expresses the countries' relative capability to produce food. In countries with wide yield gap, the productivity of agriculture falls short of its potential (IFPRI, 2020-a). The gap indicates the risk coming from the production deficiencies that might lead to even higher domestic food imbalance. Figure 7 shows the aggregated yield gap per countries, sourced from IFPRI dataset (IFPRI, 2016).

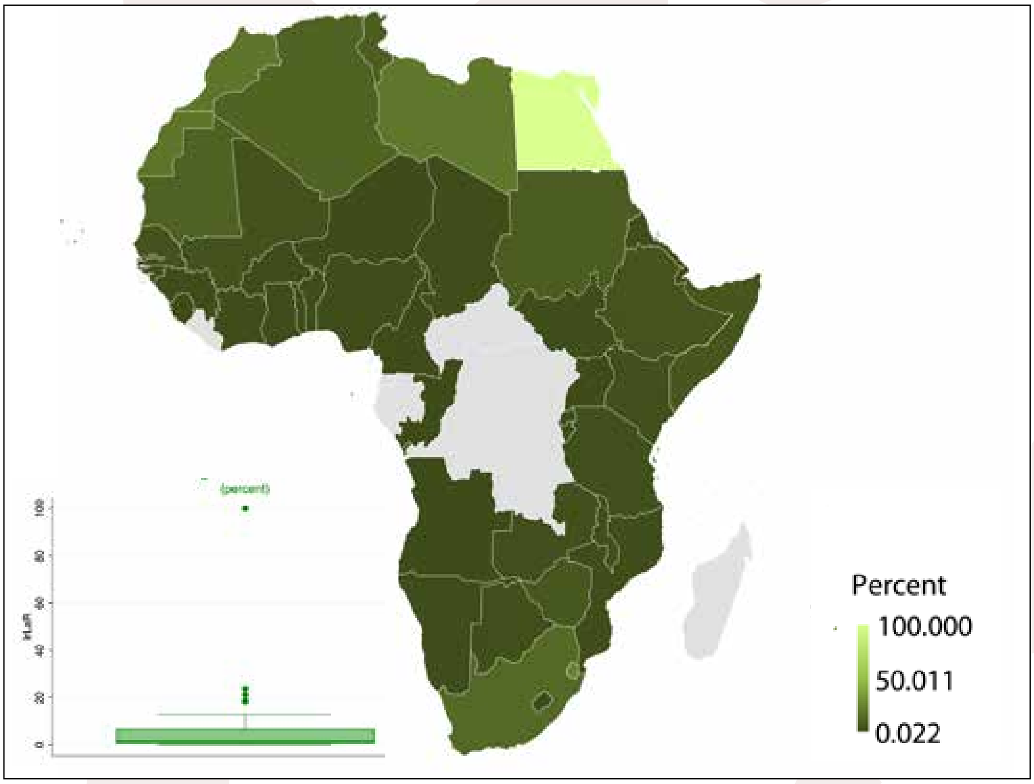
FIGURE 7
Map of yield gap in African countries



Source: IFPRI, 2020.

Indicator a-8 - Irrigated land ratio (IrLaR): The indicator is the percent ratio of total harvested irrigated crop area and cultivated harvested area. The low level of irrigation is a severe constraints of agricultural intensification. Therefore, countries have limited ability to respond to increasing domestic food demand – evolving from the disrupted trade. This is particularly important in arid countries, where further agricultural expansion depends on irrigation facilities. Figure 8 showes the dataset of irrigated land ratio, sourced from AQUASTAT (FAO, 2020-d).

FIGURE 8
Map of irrigated land ratio in African countries

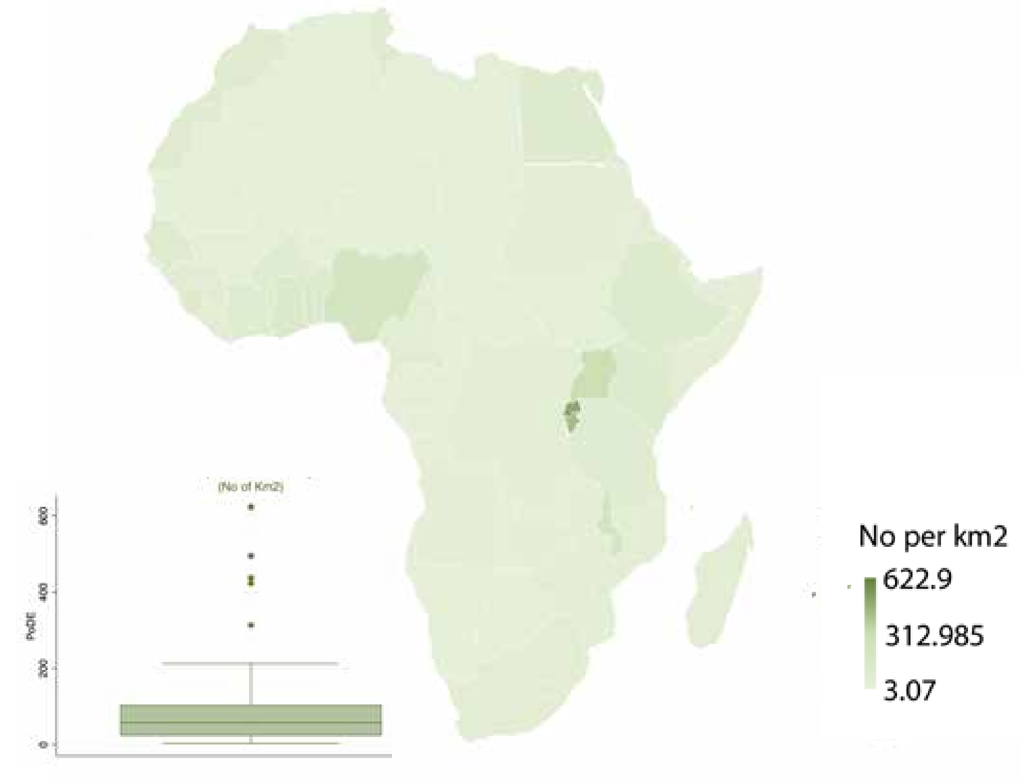


Source: AQUASTAT, 2020.

Indicator b-9 - Population density (PoDe): The population density is measured as the number of people per square km (No per km2) in a country. According to FAO (FAO, 2020), “Cities, with their high population density, are particularly vulnerable to the COVID-19 pandemic and many cities in developing countries do not have adequate capacity to address the disruptions caused by the response to the health emergency”. It further says that “policies to limit the effects of the virus such as lockdowns, or physical distancing can spell disaster for the livelihoods of those individuals and their families leading, inter alia, to food insecurity and deficient nutrition”. Figure 9 shows the population density in the African continent using data from the World Development Indicators (World Bank, 2020).

FIGURE 9

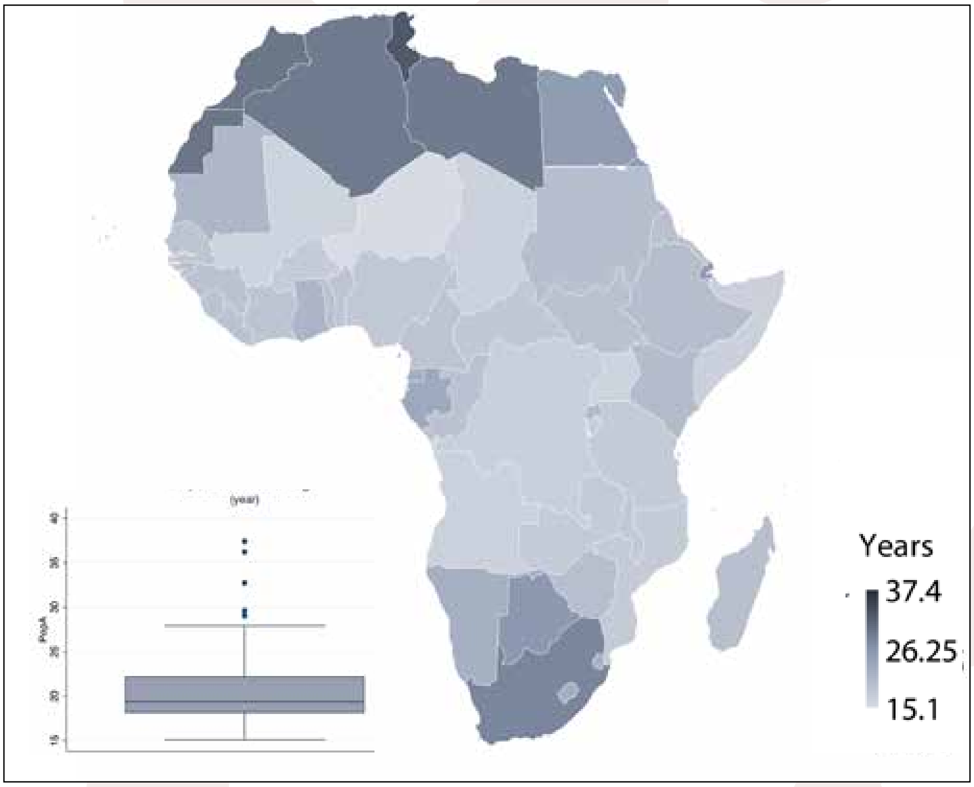
Map of population density in African countries



Source: World Bank, 2020.

Indicator b-10 - Population age (PopA): The population age indicator is derived from the median age (years) of the population. As research has already shown, aging population is more exposed to COVID-19, therefore, the limitation of movement of aged people is particularly strict. As WHO announces, "older people are facing the most threats and challenges at this time" (WHO, 2020). Figure 10 shows the classification of population age in the African continent using data from the World Development Indicators (World Bank, 2020).

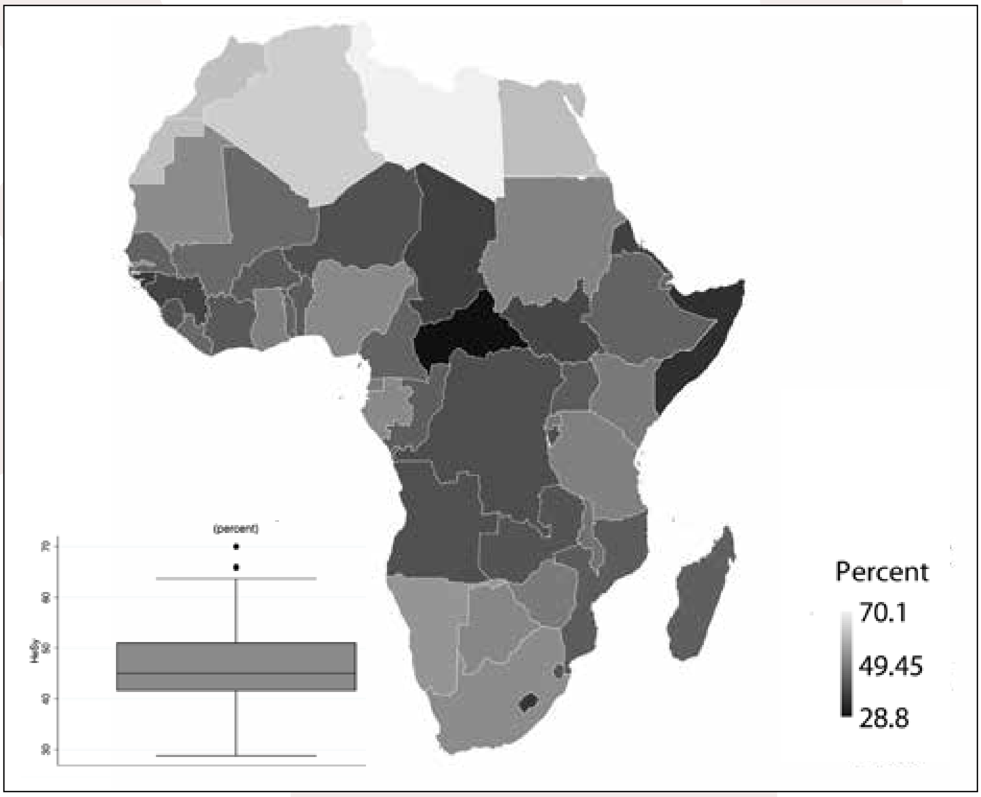
FIGURE 10
Map of population age in African countries



Source: World Bank, 2020.

Indicator b-11 - Health system (HeSy): The indicator expresses the health care access and quality based on death rates from 32 causes of death that could be avoided by timely and effective medical care aggregated by HAQ index (%). According to WHO, countries where population has poor access to health systems are the most exposed to the impacts of COVID-19. The source of the access to health system dataset shown in Figure 11 is the Global Burden of Disease study (Global Burden of Disease study, 2016).

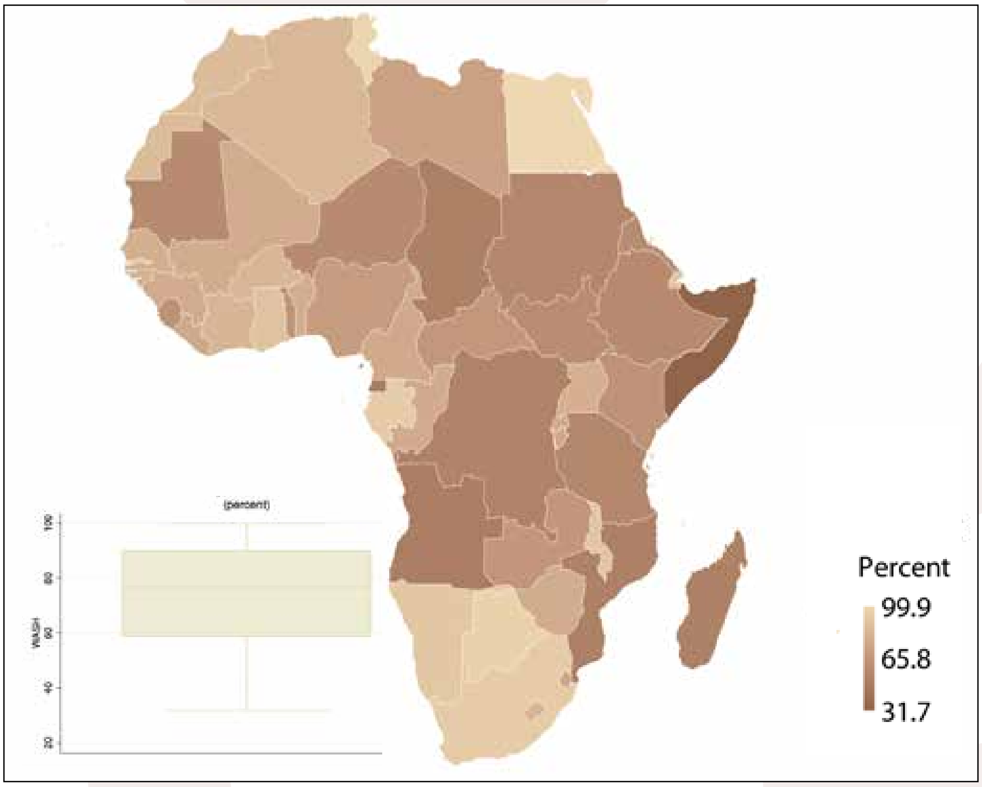
FIGURE 11
Map of access to health system



Source: Global Burden of Disease study, 2020.

Indicator b-12 - WASH: The indicator measures the population's access to improved drinking water (%). WHO raised the issue of provision of safe water, sanitation and hygienic conditions as a priority issue to fight COVID-19, which might prevent human-to-human transmission of the virus (WHO, 2020- a). Countries with poor access to safe water are the most exposed to the spreading of the virus. However, UN-Water emphasizes that "The benefits of having access to an improved drinking water source can only be fully realized when there is also access to improved sanitation and adherence to good hygiene practices. Beyond the immediate, obvious advantages of people being hydrated and healthier, access to water, sanitation and hygiene – known collectively as WASH – has profound wider socio-economic impacts, particularly for women and girls" (UN-Water, 2020). Figure 12 shows the improved water facilities per country based on the dataset of UNICEF/WHO (UNICEF & WHO, 2019).

FIGURE 12
Map of access to improved water facilities in African countries



Source: UNICEF&WHO, 2020.

Indicators are scored in 5-point Likert-scale, whereas 5 indicates the highest risk, and 1 indicates risk neutrality. As some of the global datasets have minor gaps, some countries have missing data. However, the missing values are not penalized, and the final score is achieved by taking the average of existing values. The table shows the final aggregated score of risk assessment related to SMART Irrigation – SMART WASH approach and classification in five categories:

- 5: country at serious risk of COVID-19 impact.
- 4: country at risk of COVID-19 impact.
- 3: country at moderate risk of COVID-19 impact.
- 2: country at minor risk of COVID-19 impact.
- 1: country currently not at risk of COVID-19 impact.

Indicator composition has a major role also in the selection of the technical solutions. Solutions are categorized based on their performance per indicators. This will help countries finding whichever indicator best suits their socio-economic, climatic and hydrological conditions.

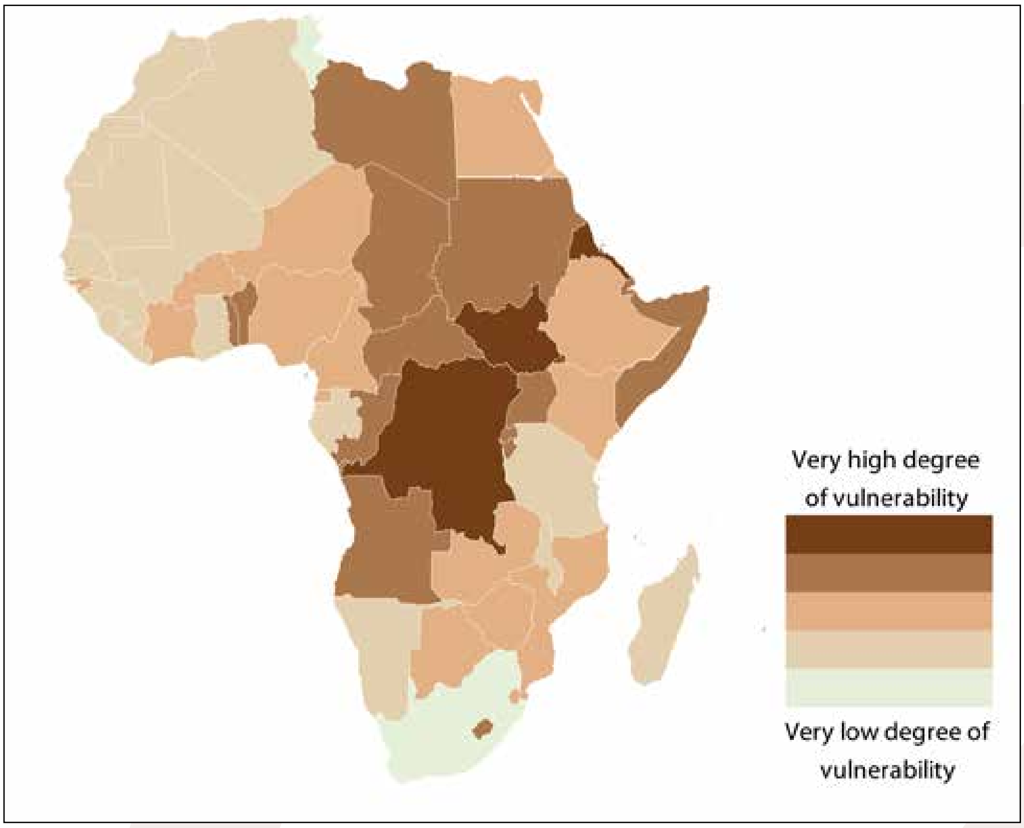
Table 1: Obtained scores per countries per indicators

	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	Final classification	FINAL score
Algeria	2	4	2	2	3	5	1	4		1	1	2	2	2.45
Angola	2	1	2	2	4	4	2	4	3	4	4	4	4	3.00
Benin	4	1	5	2	3	5	1	3	2	4	4	2	4	3.00
Botswana	1	3	1	1	2	3	3	5	5	3	3	1	3	2.58
Burkina Faso	3	1	1	2	5	5	2	1	2	4	4	2	3	2.67
Burundi	5	1	2	3	3	3		5	2	4	4	2	4	3.09
Cabo Verde	4	3	3		1	5	1	2		2	2	1	2	2.40
Cameroon	3	1	3	3	4	5	1	1	1	4	4	2	3	2.67
Central African R.	1	1	2	5	2	4	5	3	2		5	3	4	3.00
Chad	1	1		3	4	5	4	1	4	3	4	4	4	3.09
Comoros	5	2	4		1	5					3	1	4	3.00
Congo, Dem. Rep.	2	1		5	5	3			3		4	4	5	3.38
Congo, Rep.	1	1	1	2	4	5	4	5	2	5	4	2	4	3.00
Cote d'Ivoire	4	1	2	2	5	4	2	3	1	4	4	2	3	2.83
Djibouti	2	3	3	2	2	5	2	5		5	4	1	4	3.09
Egypt, Arab Rep.	4	3	2	3	4	5	1	3		1	2	1	3	2.64
Equatorial Guinea	3	2		2	3				1		3	4	3	2.57

	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	Final classification	FINAL score
Eritrea	3	1		3		5			5	3	4	4	5	3.50
Eswatini (Swaziland)	4	2	2	2	1	5	2	4	3	1	4	2	3	2.67
Ethiopia	4	2	1	3	5	2	2	1	1	2	4	4	3	2.58
Gabon	1	2	2	2	4	5	1	5	1		3	1	2	2.45
Gambia	5	1	3	1	3	5	1	2	3	4	3	1	3	2.67
Ghana	4	2	2	1	4	4	1	2	2	3	3	1	2	2.42
Guinea	3	1	3	2	2	5	2	1	1	4	4	2	2	2.50
Guinea-Bissau	3	1		2	1	5	3	2	2	3	5	2	3	2.64
Kenya	4	2	2	2	5	2	3	2	4	2	3	3	3	2.83
Lesotho	3	2	2	2	1	5	1	4	5	5	5	2	4	3.08
Liberia	3	1		1	2	4	4	3	1		3	2	2	2.40
Libya	1	4	1	5	5	5				1	1	3	4	2.89
Madagascar	2	2	2	1	1	1	4	1	3		4	4	2	2.27
Malawi	5	1	1	1	3	3	2	1	4	3	3	1	2	2.33
Mali	1	1	2	3	4	5	1	1		2	3	2	2	2.27
Mauritania	1	2	2	2	3	3	1	5	3	1	3	4	2	2.50
Mauritius	5	5	2	1	1	5	1	5	5	1	1	1	3	2.75
Morocco	4	4	1	2	2	5	1	3		1	2	2	2	2.45
Mozambique	2	1	2	2	3	2	3	2	5	3	4	4	3	2.75
Namibia	1	2	1	1	2	5	3	4	2	3	2	1	2	2.25

	PoDE	PopA	AfT	Con	DiP	CIV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	Final classification	FINAL score
Niger	1	1	3	3	3	1	2	1	3	5	4	4	3	2.58
Nigeria	5	1	1	4	5	3	1	1	1	4	3	3	3	2.67
Rwanda	5	2	2	2	4	4	3	2	2	5	3	2	4	3.00
Sao Tome and Principe	5	1	3		1		1		1	1	3	1	1	1.89
Senegal	4	1	2	1	3	5	1	3	2	2	4	2	2	2.50
Seychelles	5	5	3			5				2	1	1	4	3.14
Sierra Leone	4	1	4	1	2	1	2	2	1	5	4	3	2	2.50
Somalia	2	1		5	2	3			3	2	5	5	4	3.11
South Africa	3	3	1	3	5	2	1	1	2	1	3	1	1	2.17
South Sudan	2	1		5	5	4				3	4	4	5	3.50
Sudan	2	2		4	5	3	2	1	4	2	3	4	4	2.91
Tanzania	3	1	1	1	4	4	3	1	3	2	3	4	2	2.50
Togo	5	1	2	2	3	5	2	1	2	5	4	3	4	2.92
Tunisia	3	4	1	2	2	4	1	3		1	1	1	1	2.09
Uganda	5	1	1	2	5	4	4	1	2	5	4	2	4	3.00
Zambia	2	1	1	1	2	5	4	1	4	3	4	3	3	2.58
Zimbabwe	2	2	1	3	4	3	5	3	3	2	3	2	3	2.75

FIGURE 13
Map of vulnerability risk assessment on food security – health nexus based on aggregate score



The risk assessment mapping in Figure 13 shows the central axis of Africa as the potential geographic hotspot of adverse impact on food security and health. Amongst the identified countries, many are already facing severe humanitarian crises. The Democratic Republic of Congo, South-Sudan, Eritrea, Congo, Uganda, Angola, Libya, Sudan, Somalia, Rwanda, Lesotho, Djibouti, Chad, Comoros, Central African Republic, Burundi and Benin are the most exposed countries to suffer from the devastating impacts on food security and health. Amongst the countries at moderate risk are Zambia, Zimbabwe, Niger, Nigeria, Mozambique, Mauritius, Kenya, Guinea-Bissau, Gambia, Ethiopia, Eswatini, Equatorial Guinea, Egypt, Cote d'Ivoire, Cameroon, Burkina Faso and Botswana.

Indicator-wise, countries have a generally low performance in population density, climate vulnerability, displacement, irrigated land ratio and access to health system. Through preventive measures, three indicators out of five can be tackled to mitigate impacts: climate vulnerability, irrigated land ratio and access to health system. By guiding actions towards these three thematic areas, impacts can be significantly lowered.

However, not all countries experience the same level of pandemic spread. In order to translate the potential risk into actual risk, the current trends in COVID-19 spread is analyzed. The overlap between the risk assessment and occurrence of COVID-19 is then investigated.

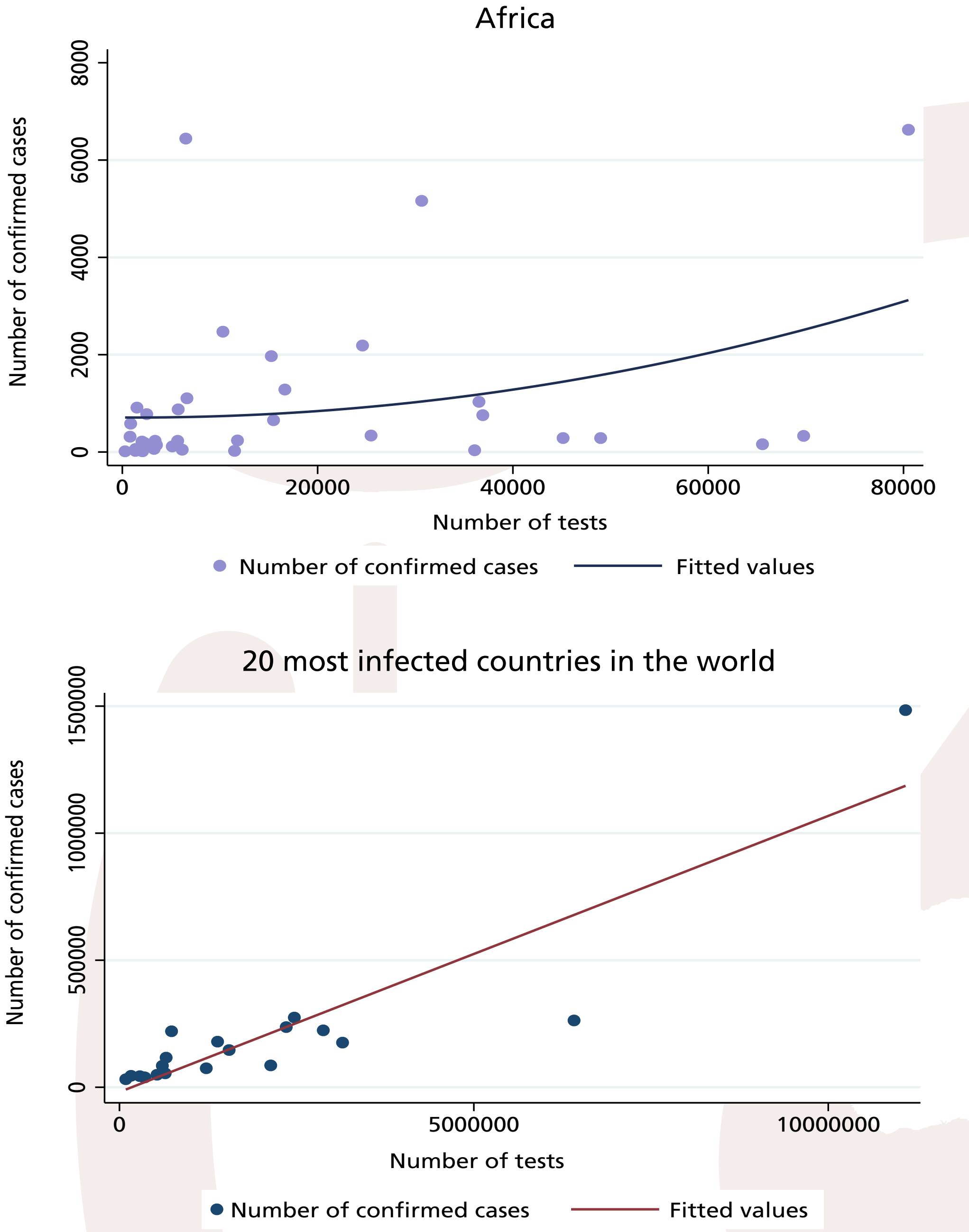
MAPPING THE CRITICAL TRENDS OF COVID-19 SPREAD

The trends of COVID-19 spread across Africa is examined based on the number of confirmed cases and fatality of the virus. As these data refer to the current situation, the future trends are also considered in order to forecast the risk zones. Although up-to-date, global dataset is available through John Hopkins COVID-19 counter application (Johns Hopkins University, 2020), there is a general paucity of reliable data related to Africa. Except North-Africa, only the identified cases are reported. Furthermore, there is no standardized protocol on COVID-19 statistics, therefore, the data needs careful interpretation.

Two available indicators are examined: confirmed cases and mortality rate. In order to validate the data, the confirmed cases are compared to the number of tests conducted. However, the validation cannot be completed due to the large proportion of the countries with no reports on testing.

The visual interpretation of the relation between confirmed cases and number of tests conducted raises further questions as shown in Figure 14. In general, the two variables are correlated to a certain level, because testing is the pre-requisite to confirm the revealed cases. The degree of correlation, however, greatly varies amongst countries. The most infected countries show strong, almost linear correlation between the number of conducted tests and the number of identified cases. Consequently, it can be assumed that any increase in the number of tests in Europe will result in an increase in the number of confirmed cases. This is not the case in Africa. Many countries with triple or quadruple number of tests have still the same low level of confirmed cases. However, it must be noted that a large number of countries have no statistics on the number of testing. This is not to argue the necessity of testing, as it is included in the commonly agreed international protocol of managing the situation, but to show that based on the currently available data, the predictive power of the testing number is little in Africa. From a statistical point of view, it cannot be assumed that an increase in testing results in an increase of confirmed cases at the current stage in the continent. The Africa Centre for Disease Control and Prevention together with the African Union Commission endorsed the new initiative Partnership to Accelerate COVID-19 Testing (PACT): Trace, Test and Track. However, the initiative was approved only on 26 March, when the rest of the world was already practicing the mass testing. The market shortage of testing kit is raised in several forums assuming that African countries are crowded-out from international markets. Therefore, PACT highlighted the importance of pooled procurement in order to accelerate the market power of African countries. However, PACT emphasized that it requires strong coordination in order to well distribute the medical supplies amongst countries. These facts together confirm that statistics are somewhat biased in this early stage of the pandemic.

FIGURE 14
Correlation between confirmed cases and number of tests in Africa versus in the 20 most infected countries



The current status of infection together with its mortality rate is dynamic information, which might change from one day to another. Since the virus is found to be highly contagious (i.e. compared to the seasonal flu), some prediction must be forecasted related to the trends of spread. The major activities that can carry the virus transboundary are the tourism, trade and business. As Africa CDC defines in its study, “Using data to find balance” (Partnership for Evidence-based Response to COVID-19 - PERC, 2020), the members of African Union have taken precaution measures in timely manner, thus, reacting on the crisis and suppressing the potential transmission before the major outbreak. This harmonized and quick action seemed to be effective to protect countries. However, the established consortium PERC emphasizes in the same report that “measures can have adverse consequences for social and economic activity that could outweigh health benefits, especially in resource-constrained settings”. Three major domains with possible adverse impact beyond the health concerns are the economic hardship, food insecurity and malnutrition, and violence. Therefore, the AFRICA CDC study suggests introducing relief measures to reduce the negative impact of public health and social measures. Based on this demand, it can be envisaged that countries will urge the precautious restoration of trade. It is difficult to predict any further relief measure at the current stage. Africa Center for Strategic Studies adapts measures in a similar way to map the risk factors of pandemic spread (Mapping Risk factors for the Spread of COVID-19 in Africa, Africa Center for Strategic Studies). Using composite indicator methodologies, the Center for Strategic Studies compiled risk assessment based on nine sub-indicators, which can directly or indirectly boost the spread during the first and a projected second phase. Similar to Africa CDC, the Center highlights international exposure, size of urban population and capacity for testing as major drivers of spread, from which international exposure includes the vulnerability by international contacts (travel, trade, tourism and business).

Taking into account these considerations, trade is also evaluated as a primary risk factor of spread. Therefore, the effect of trade reset is evaluated to complete the COVID-19 spread map. The major trading partners of each country is identified, in order to see whether there is any threat of transboundary virus spread. If the given country has active trading with highly infected countries, the threat is higher. Table 2 shows the countries with the five major international trading partner (IP) and five major the continental trading partner (RP), extracted from the databased of International Trade Centre (ITC, Trade Map). The trade is measured as the annual import value, and the numbering of partners express their ranking based on import value.

Table 2: Countries with main international and regional trading partners in order of the value of import

Countries	IP1	IP2	IP3	IP4	IP5	RP1	RP2	RP3	RP4	RP5
Algeria	China	France	Spain	Italy	Russia	Morocco	South Africa	Benin	Nigeria	Burkina Faso
Angola	China	USA	Belgium	Portugal	Nigeria	Nigeria	South Africa	Namibia	Morocco	Eswatini
Benin	China	India	France	Thailand	Togo	Togo	Morocco	Mauritania	Nigeria	Cote d'Ivoire
Botswana	S.-Africa	Namibia	Canada	China	India	South Africa	Namibia	Zimbabwe	Eswatini	Zambia
Burkina Faso	China	Cote d'Ivoire	Russia	France	Ghana	Cote d'Ivoire	Ghana	Morocco	Togo	South Africa
Burundi	China	India	Belgium	Zambia	Germany	Zambia	South Africa	Morocco	Mozambique	Nigeria
Cabo Verde	Portugal	Netherlands	Spain	China	Belgium	South Africa	Senegal	Nigeria	Morocco	Namibia
Cameroon	China	Nigeria	France	Belgium	Thailand	Nigeria	Morocco	South Africa	Senegal	Benin
Central-A R.	France	USA	China	Netherlands	Belgium	Senegal	Morocco	South Africa	Benin	Madagascar
Chad	China	France	USA	India	Turkey	Senegal	Benin	Morocco	Nigeria	South Africa
Comoros	China	France	India	Turkey	Madagascar	Madagascar	Mauritius	South Africa	Morocco	Eswatini
Congo, D.R.	China	South Africa	Zambia	Belgium	India	South Africa	Zambia	Namibia	Morocco	Eswatini
Congo, Rep.	China	France	India	USA	Belgium	South Africa	Senegal	Morocco	Nigeria	Zambia
Cote d'Ivoire	China	France	Nigeria	India	Netherlands	Nigeria	Morocco	Burkina Faso	Senegal	South Africa
Djibouti	China	India	Turkey	Morocco	USA	Morocco	South Africa	Benin	Burkina Faso	Mauritius
Egypt	China	Russia	USA	Germany	Turkey	Morocco	South Africa	Benin	Namibia	Nigeria
Equatorial Guinea	USA	Spain	China	Italy	UK	Nigeria	Morocco	Senegal	South Africa	Benin
Eritrea	China	Italy	Germany	USA	Turkey	South Africa	Mozambique	Mauritius	Zambia	Madagascar
Eswatini	China	Mozambique	India	USA	UAE	South Africa	Mozambique	Mauritius	Lesotho	Egypt

Countries	IP1	IP2	IP3	IP4	IP5	RP1	RP2	RP3	RP4	RP5
Ethiopia	China	USA	India	France	UK	South Africa	Morocco	Burkina Faso	Madagascar	Senegal
Gabon	France	China	Belgium	USA	Netherlands	Morocco	South Africa	Senegal	Benin	Nigeria
Gambia	China	India	Brazil	Senegal	Netherlands	Morocco	South Africa	Senegal	Benin	Nigeria
Ghana	China	Nigeria	USA	India	Netherlands	Nigeria	South Africa	Burkina Faso	Morocco	Senegal
Guinea	China	India	Netherlands	Belgium	Germany	Senegal	Morocco	South Africa	Nigeria	Burkina Faso
Guinea-Bissau	Portugal	Senegal	China	Netherlands	India	Senegal	Nigeria	Morocco	South Africa	Benin
Kenya	China	India	Japan	South Africa	UK	South Africa	Eswatini	Zambia	Mauritius	Zimbabwe
Lesotho	S.-Africa	China	Taipei	India	Hong Kong	South Africa	Mozambique	Eswatini	Namibia	Zambia
Liberia	China	Singapore	Japan	Korea, R.	Brazil	South Africa	Morocco	Senegal	Nigeria	Mozambique
Libya	China	Turkey	Italy	Korea, R.	Netherlands	Morocco	South Africa	Namibia	Madagascar	Burkina Faso
Madagascar	UAE	India	France	South Africa	EU	South Africa	Egypt	Mauritius	Seychelles	Eswatini
Malawi	S.--Africa	China	India	Zambia	Germany	South Africa	Zambia	Mozambique	Zimbabwe	Eswatini
Mali	Senegal	China	France	Austria	Belgium	Senegal	South Africa	Morocco	Burkina Faso	Benin
Mauritania	China	Spain	France	Morocco	Turkey	Morocco	Senegal	South Africa	Burkina Faso	Mozambique
Mauritius	India	South Africa	UAE	France	Spain	Seychelles	Madagascar	Kenya	Egypt	Zambia
Morocco	Spain	France	China	USA	Italy	Egypt	Algeria	Tunisia	Togo	South Africa
Mozambique	S.-Africa	China	UAE	Singapore	India	South Africa	Namibia	Eswatini	Mauritius	Liberia
Namibia	S.-Africa	Zambia	China	Bulgaria	India	South Africa	Zambia	Botswana	Congo, D.R.	Togo
Niger	China	France	India	Nigeria	USA	Nigeria	Burkina Faso	Morocco	Benin	Senegal
Nigeria	China	India	USA	Netherlands	Belgium	South Africa	Benin	Egypt	Cote d'Ivoire	Mauritania
Rwanda	China	India	Hong Kong	Belgium	Germany	South Africa	Zambia	Morocco	Mozambique	Eswatini

Countries	IP1	IP2	IP3	IP4	IP5	RP1	RP2	RP3	RP4	RP5
Sao Tome a. P.	Portugal	China	Netherlands	Brazil	USA	South Africa	Morocco	Zambia	Mauritius	Nigeria
Senegal	France	China	Belgium	Netherlands	Nigeria	Nigeria	Morocco	South Africa	Cote d'Ivoire	Ghana
Seychelles	Germany	China	France	South Africa	Spain	South Africa	Mauritius	Madagascar	Namibia	Eswatini
Sierra Leone	China	India	USA	Turkey	South Africa	South Africa	Senegal	Morocco	Nigeria	Burkina Faso
Somalia	China	India	Turkey	USA	Malaysia	South Africa	Eswatini	Mozambique	Morocco	Mauritius
South Africa	China	Germany	USA	India	Saudi A.	Nigeria	Eswatini	Mozambique	Namibia	Ghana
South Sudan	China	Netherlands	India	Germany	UK	Mozambique	Zambia	South Africa	Nigeria	Angola
Sudan	China	India	Saudi A.	Turkey	Russia	South Africa	Morocco	Madagascar	Senegal	Zimbabwe
Tanzania	China	India	South Africa	USA	Japan	South Africa	Zambia	Eswatini	Morocco	Mozambique
Togo	China	Korea, R.	India	Belgium	Netherlands	Nigeria	Morocco	South Africa	Senegal	Burkina Faso
Tunisia	France	Italy	Germany	China	Spain	Morocco	South Africa	Senegal	Nigeria	Mozambique
Uganda	China	India	Japan	South Africa	Canada	South Africa	Eswatini	Zambia	Morocco	Mozambique
Zambia	China	UAE	India	Congo, D.R.	Japan	South Africa	Congo, D.R.	Tanzania	Mauritius	Namibia
Zimbabwe	Singapore	China	India	Mauritius	UK	Mauritius	Zambia	Mozambique	Botswana	Malawi

Source: International Trade Centre, Trade Map, 2019

In general, the share of international trading partners is way larger than the share of continental partners. However, the imposed international trade restrictions are longer standing and more difficult to recover than the trade reconsideration within Africa continent. Therefore, the trade remedies are more likely to be focused on regional level at first step. After successful recuperation without accelerating the spread of the virus, global trade remedies are forecasted. The stress is here, the current forecasting is just theoretical, as the uncertainties around the pandemic mitigation steps are still increasingly growing world-wide.

Therefore, it is proposed to focus on the internal trading in Africa. As Table 3 indicates, the trade is heavily concentrated, as 13 countries cover 90 percent of the internal trade from geographical point of view, and 4 countries share 50 percent. South Africa has trading partnership with 49 countries in the continent, of which 24 are major importers form the country. Countries with such intensive trading are more exposed to the virus spread. However, the 13 trading countries show regional disparity. The balance of geographic focus is concentrated in the southern part of the continent (South Africa, Namibia, Eswatini, Madagascar, Mozambique, Namibia and Zambia), in the southern part of West Africa (Benin, Burkina Faso, Nigeria) and in West-North Africa (Morocco, Senegal).

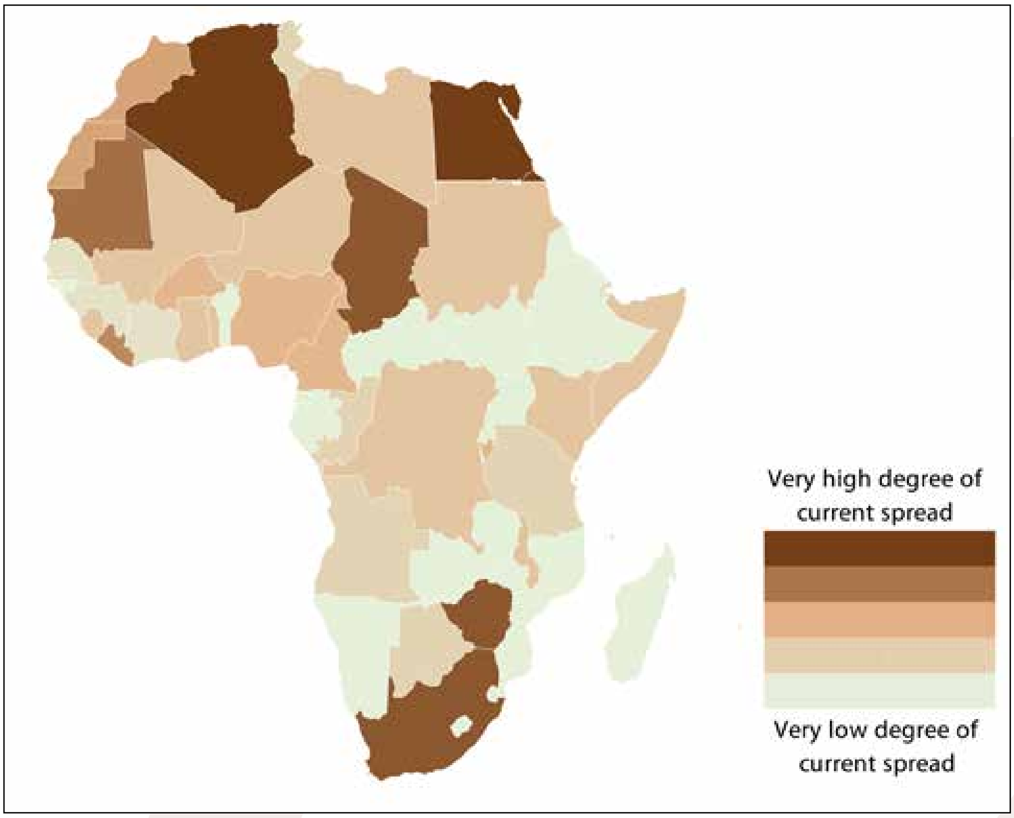
Table 3: Main trading countries with number of partners (International Trade Centre, Trade Map, 2019)

	RP1	RP2	RP3	RP4	RP5	Total
South Africa	24	11	8	2	4	49
Morocco	8	12	9	8	0	37
Nigeria	9	1	1	9	5	25
Senegal	5	4	5	4	3	21
Eswatini	0	4	3	1	7	15
Mozambique	1	3	4	2	5	15
Zambia	1	7	2	1	4	15
Benin	0	2	3	4	4	13
Burkina Faso	0	1	3	3	5	12
Mauritius	1	2	3	4	2	12
Namibia	0	2	3	4	2	11
Madagascar	1	1	2	2	2	8
Egypt	1	1	1	1	1	5

In order to take the underlying risk of trade into consideration, two maps are produced. At first step, COVID-19 spread map is produced as shown in Figure 15 to identify the current status of infection, which aggregates the number of current cases combined with the mortality rate. Due to the large homogeneity of obtained values, the scoring is made on 10-point Likert-scale, whereas final classifications are categorized into 0.5 step. The status of pandemic spread is presented as of May 2020 from John Hopkins COVID-19-19 Dashboard by the Center for Systems Science and Engineering (CSSE) (John Hopkins, 2020). As a second step, COVID-19 spread map is overlapped with the trade risk map as shown in Figure 16, whereby the achieved scoring by spread and mortality is increased by the risk of trading. As a result, the map in Figure 15 represents the current actual situation about the spread of COVID-19 while the map in Figure 16 presents the actual spread of COVID-19 combined with the trade risk.

FIGURE 15

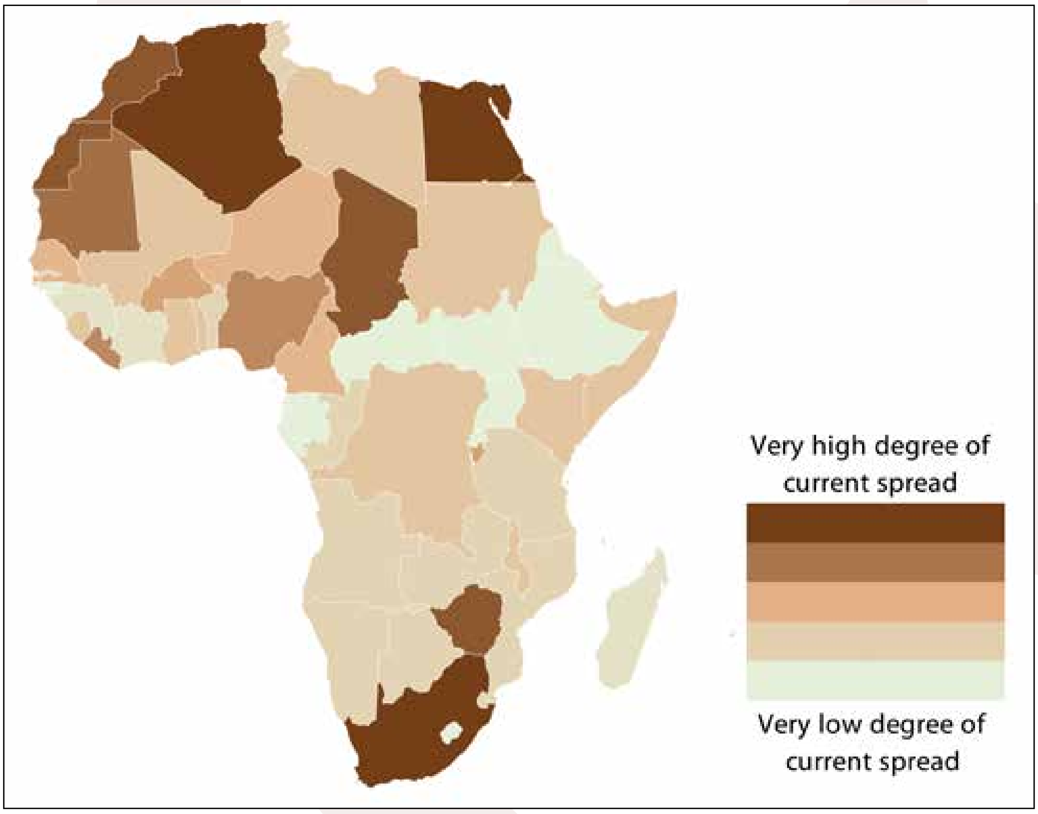
Current situation of the pandemic spread with fatal outcome (As of May 2020);



Source: John Hopkins, Center for systems Science and Engineering, 2020.

FIGURE 16

Current situation of the pandemic spread with fatal outcome combined with trade risk

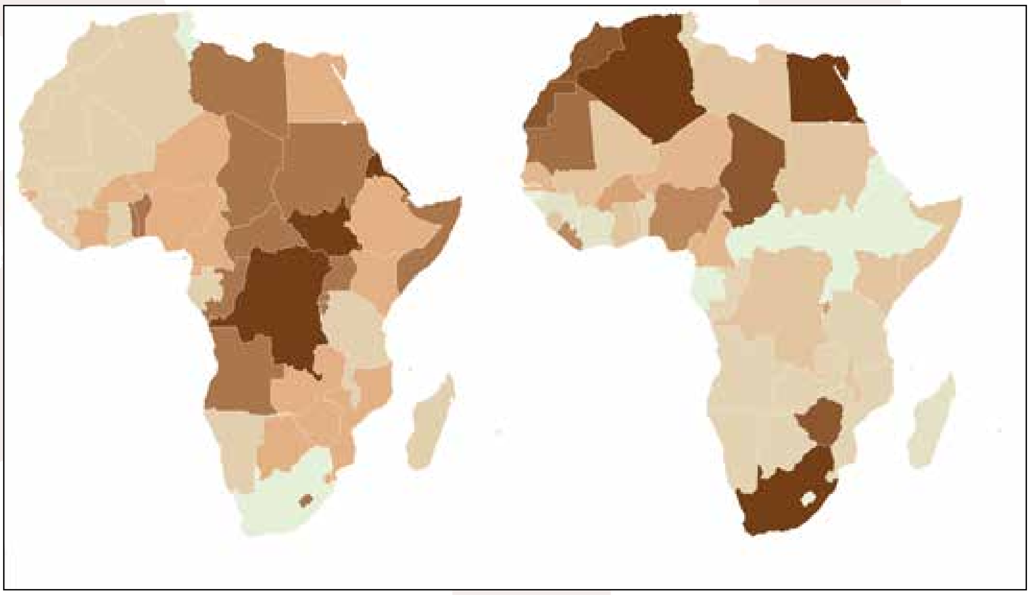


MATCHING VULNERABILITY WITH EXISTING RISK

As illustrated in Figure 17, the vulnerability map (on the left) and COVID-19 spread map (on the right) show differences in geographical focus in terms of vulnerability and pandemic spread. While the identified most vulnerable countries are in East-Africa, the occurrence of the virus is scattered across three major spots: North-West Africa, Central-Africa, and South Africa.

FIGURE 17

Vulnerability on food security – health nexus (on the left) vs COVID-19 spread map (on the right)



However, it is important to note that the COVID-19 spread map reflects the current situation (stress is here). Due to the experienced fast spread of the virus, outbreak can occur from one day to another in any country. Therefore, strategic intervention must be planned based on the vulnerability, but scheduled according to the occurrence of the virus. For example, based on the very recent spread rate of the virus and the set of applied indicators of vulnerability, northern Central-Africa and their neighboring countries would be the starting point of such gradual planning of developing resilience through parallel and harmonized improvement of proposed irrigation and WASH corporate solutions. In order to maximize the efficiency of development, triangular or regional cooperation is recommended, whereas horizontal collaboration pulls together countries with different strengths and development level.

Although it is difficult to find general conclusions amongst the many on-going researches about the COVID-19 impact around the world, field data seems to be the most reliable. The mentioned "Using data to find balance" study by Africa CDC included field survey conducted by PERC. Twenty member countries[1] of the African Union were involved in the household survey, where people were asked what they find the most difficult about 14-days stay-at-home order as shown in Figure 18. The introduced chart in the study is reproduced in order to find similarity with the theoretic geographical focus. The survey

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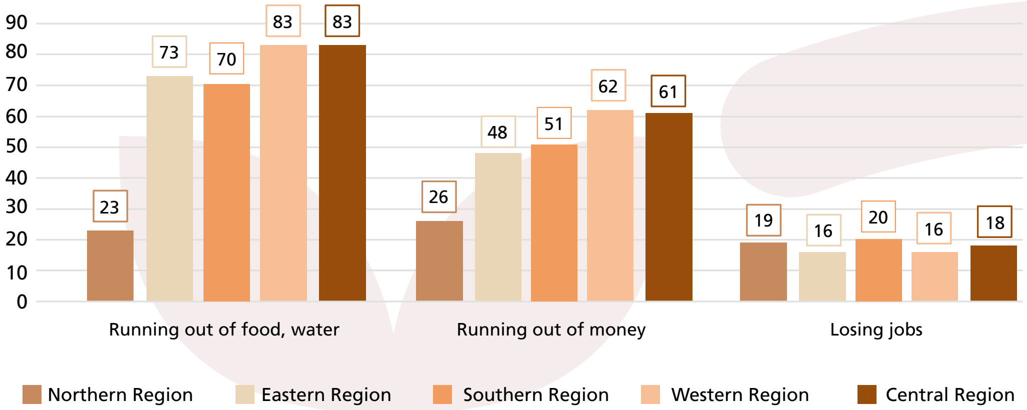
[1] The Ipsos survey methodology included 20 countries: Liberia, Ghana, Nigeria, Guinea, Senegal, Cote d'Ivoire, Kenya, Uganda, Ethiopia, Tanzania, Sudan, Egypt, Morocco, Tunisa, Cameroon, Democratic Republic of Congo, South Africa, Zimbabwe, Mozambique, Zambia

results show that running out of food and water is a major issue for Central, Western, Southern and Eastern region, of which Central region is the most sensitive respectively.

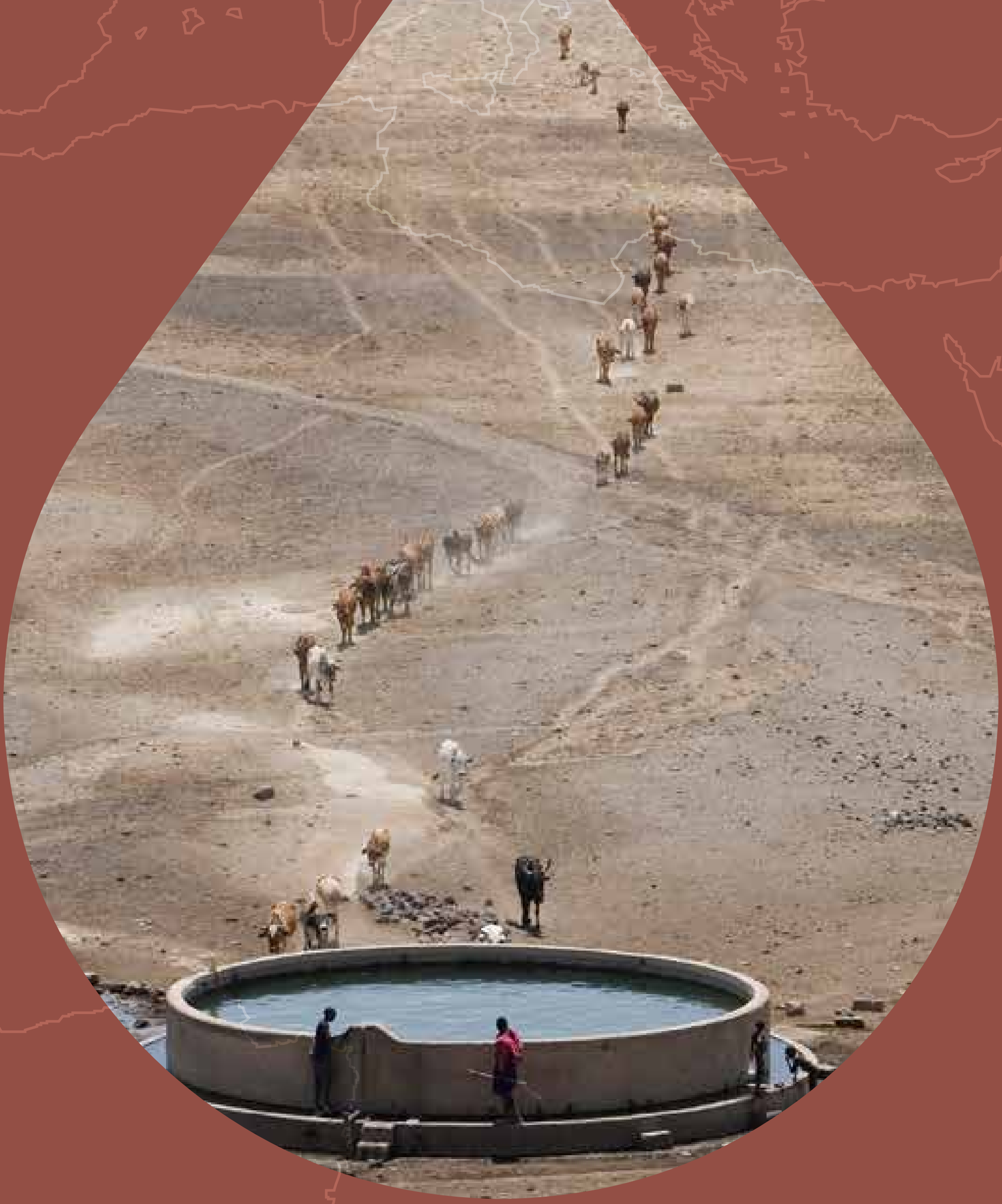
FIGURE 18
Barriers to stay-at-home order



Source: "Using data to find balance"; Africa CDC, UK Public Health Rapid Support Team, 2020

According to OECD, triangular cooperation is positioned at the heart of development initiatives in order to create strong basis for flexible, cost-effective and innovative strategies to achieve SDGs. Triangular cooperation has numerous merits in providing fast responses to the pandemic situation. It has its advantages to address the challenges in similar socioeconomic context while harmonizing the within-continent actions to minimize the risk of COVID-19. This can facilitate both endogenous and exogenous development processes: increased resilience at country level due to knowledge transfer, and harmonized plans of COVID-19 mitigation at continent level.

One of the important conclusions of the above analysis is that merely mapping the virus occurrence is not enough to find geographical focus of intervention. Relying on the currently available maps of virus spread might be misleading, as the most infected countries are not necessarily the most vulnerable ones. Perhaps, they have appropriate infrastructure to contain the virus and provide enough health care, while food security is neither affected. On the other side, there are countries with low resilience capacity, where a few confirmed cases and the imposed virus mitigation measures together are posing way higher risk to national health and food sectors.



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SMART Irrigation – SMART WASH: Defining target countries

The mapping shows that countries have different types of investment need in multiple water use, with regards to irrigation and WASH infrastructure. In order to avoid the daunting workload of analyzing the context country by country, a holistic framework is set to sufficiently reduce the numbers of investment packages by pooling countries into characteristics-based clusters. The introduced hierarchical clustering allows the classification of indicators into different groups; thus, each group will contain countries with similar investment package need. The two major outcomes of using cluster analysis are 1) the described typology of groups, and 2) the defined number of groups with similar countries. The typology of groups can be described by the analysis of outperforming indicators, and the number of groups can be defined through statistical and visual testing of classifications produced by the cluster analysis. **It is important to note that each country requires the development of multiple water use through combined solutions for irrigation and WASH.** The clustering only helps assigning enough weight to the two sectors while formulating the investment package. Ideally, the maximum development of both irrigation and WASH sectors would be the most desirable. However, investment strategies must target optimal combinations which respond to the country needs.

The cluster analysis is performed in two steps. At the first step, the clustering is carried out in 30 countries, where indicator datasets are complete. At the second step, the missing data in countries are replaced with the average score of specific indicators. The cluster analysis is re-run to compare the classification by the 30 countries to the classification involving all countries.

The dendrogram of 30 countries shows in Figure 19 that three major groups can be differentiated in: country ID from 1 to 17 fall under the first group, country ID from 2 to 27 represent the second group, and country ID from 9 to 24 are the third group. Table 4 displays the countries under the groups classified by the cluster analysis.

FIGURE 19
Dendrogram for 30 countries' cluster analysis (Performed with STATA 16.1)

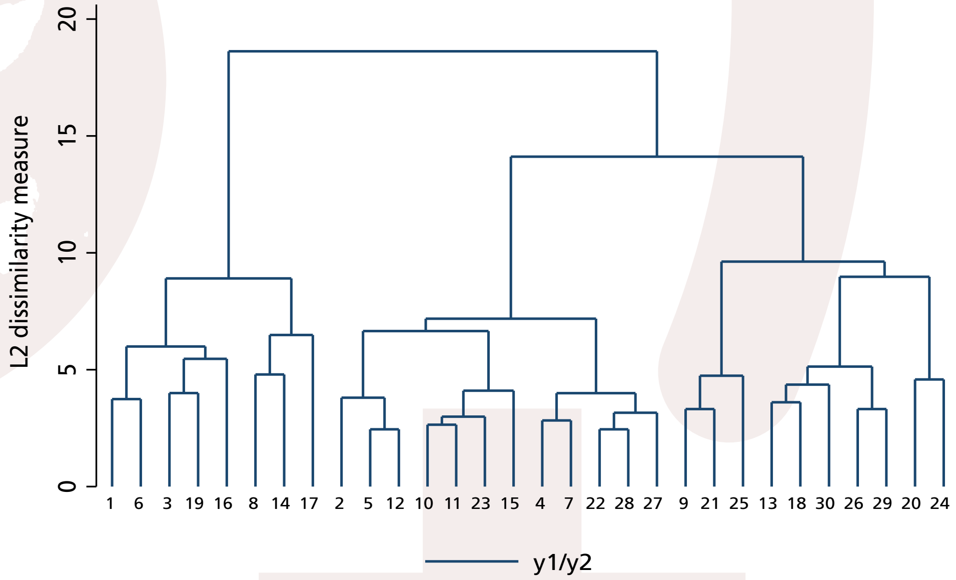

Table 4: Country groups (N=30) classified by the cluster analysis

Group 1	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Angola	2	1	2	2	4	4	2	4	3	4	4	4	1
Botswana	1	3	1	1	2	3	3	5	5	3	3	1	3
Congo, Rep.	1	1	1	2	4	5	4	5	2	5	4	2	6
Eswatini	4	2	2	2	1	5	2	4	3	1	4	2	8
Lesotho	3	2	2	2	1	5	1	4	5	5	5	2	14
Mauritania	1	2	2	2	3	3	1	5	3	1	3	4	16
Mauritius	5	5	2	1	1	5	1	5	5	1	1	1	17
Namibia	1	2	1	1	2	5	3	4	2	3	2	1	19

Group 2	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Benin	4	1	5	2	3	5	1	3	2	4	4	2	2
Burkina Faso	3	1	1	2	5	5	2	1	2	4	4	2	4
Cameroon	3	1	3	3	4	5	1	1	1	4	4	2	5

Cote d'Ivoire	4	1	2	2	5	4	2	3	1	4	4	2	7
Gambia	5	1	3	1	3	5	1	2	3	4	3	1	10
Ghana	4	2	2	1	4	4	1	2	2	3	3	1	11
Guinea	3	1	3	2	2	5	2	1	1	4	4	2	12
Malawi	5	1	1	1	3	3	2	1	4	3	3	1	15
Rwanda	5	2	2	2	4	4	3	2	2	5	3	2	22
Senegal	4	1	2	1	3	5	1	3	2	2	4	2	23
Togo	5	1	2	2	3	5	2	1	2	5	4	3	27
Uganda	5	1	1	2	5	4	4	1	2	5	4	2	28

Group 3	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Ethiopia	4	2	1	3	5	2	2	1	1	2	4	4	9
Kenya	4	2	2	2	5	2	3	2	4	2	3	3	13
Mozambique	2	1	2	2	3	2	3	2	5	3	4	4	18
Niger	1	1	3	3	3	1	2	1	3	5	4	4	20
Nigeria	5	1	1	4	5	3	1	1	1	4	3	3	21
Sierra Leone	4	1	4	1	2	1	2	2	1	5	4	3	24
South Africa	3	3	1	3	5	2	1	1	2	1	3	1	25
Tanzania	3	1	1	1	4	4	3	1	3	2	3	4	26
Zambia	2	1	1	1	2	5	4	1	4	3	4	3	29
Zimbabwe	2	2	1	3	4	3	5	3	3	2	3	2	30

Group 1 includes: Angola, Botswana, Congo, Eswatini, Lesotho, Mauritania and Namibia. The countries show serious risk associated to climate vulnerability, food import dependency, yield gap, irrigated land ratio and access to health system. Consequently, the typology of the group is related to food security. Therefore, any formulated investment package on developing multiple water use should put stronger focus on increasing the productivity and efficiency of agricultural production. The group is indicated as "Food security group".

Group 2 includes: Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Gambia, Ghana, Guinea, Malawi, Rwanda, Senegal, Togo and Uganda. The countries in the cluster show mixed type of concerns including population density, displacement, climate vulnerability, and irrigated land ratio and health system access. Investment package related to developing multiple water use needs to consider the population-induced conflicts over natural resources as well as climate vulnerability. Both irrigated agriculture and WASH-related interventions should be equally balanced to eliminate the uncertainties driven by rapid population growth. The group is indicated as "Redistribution group".

Group 3 includes: Ethiopia, Kenya, Mozambique, Niger, Nigeria, Sierra Leona, South Africa, Tanzania, Zambia, and Zimbabwe. The countries show homogeneity in underperforming in health system access, access to improved water, irrigated land ratio, displacement and population density. Consequently, the investment package related to multiple use of water should have heightened focus on developing WASH sector. The group is indicated as "WASH group".

At the second step, the missing data of remaining 24 countries are replaced with the average of the indicator scores. After the gap filling, clustering analysis for 54 countries is performed2. The dendrogram shows that the heterogeneity of the groups increased, but the 30 already categorized countries are pooled into the same groups. This confirms the definition of the 3 groups. The dendrogram in Figure 20 indicates that country ID from 1 to 33 are included in Group 1, country ID from 2 to 49 in Group 2, and country ID from 8 to 43 in Group 3.

FIGURE 20
Dendrogram for 54 countries' cluster analysis after gap-filling (Performed with Stata 16.1)

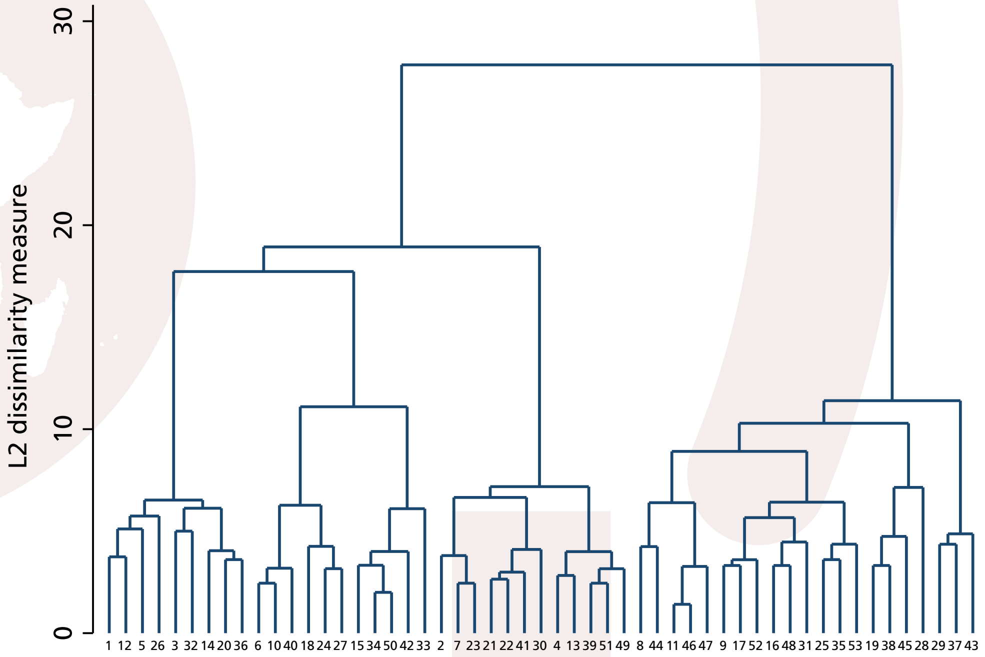

Table 5, 6, and 7 display the final grouping of the 54 countries with the scored indicators.

Food security group
Table 5: Summary table of group 1

	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Angola	2	1	2	2	4	4	2	4	3	4	4	4	1
Botswana	1	3	1	1	2	3	3	5	5	3	3	1	3
Burundi	5	1	2	3	3	3	2	5	2	4	4	2	5
Cabo Verde	4	3	3	2	1	5	1	2	2	2	2	1	6
Comoros	5	2	4	2	1	5	2	2	2	3	3	1	10
Congo, Rep.	1	1	1	2	4	5	4	5	2	5	4	2	12
Djibouti	2	3	3	2	2	5	2	5	2	5	4	1	14
Egypt, Arab Rep.	4	3	2	3	4	5	1	3	2	1	2	1	15
Eswatini	4	2	2	2	1	5	2	4	3	1	4	2	18
Gabon	1	2	2	2	4	5	1	5	1	3	3	1	20
Guinea-Bissau	3	1	2	2	1	5	3	2	2	3	5	2	24

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[2] Algeria is excluded from cluster analysis due to statistical bias, and included in the final classification based on qualitative assessment

Lesotho	3	2	2	2	1	5	1	4	5	5	5	2	26
Liberia	3	1	2	1	2	4	4	3	1	3	3	2	27
Mauritania	1	2	2	2	3	3	1	5	3	1	3	4	32
Mauritius	5	5	2	1	1	5	1	5	5	1	1	1	33
Morocco	4	4	1	2	2	5	1	3	2	1	2	2	34
Namibia	1	2	1	1	2	5	3	4	2	3	2	1	36
Sao Tome, a. P.	5	1	3	2	1	4	1	2	1	1	3	1	40
Seychelles	5	5	3	2	3	5	2	2	2	2	1	1	42
Tunisia	3	4	1	2	2	4	1	3	2	1	1	1	50

The average scores of indicators are summarized in order - from most underperforming (highest score) to most outperforming (lowest score). Climate vulnerability, food dependency ratio, population density, health system, irrigated land ratio and yield gap are the most underperforming indicators.

ClV	FoR	PoDE	HeSy	IrLaR	YiGa	PopA	DiP	AfT	Con	FoDe	WASH
4.5	3.65	3.1	2.95	2.6	2.45	2.4	2.2	2.05	1.9	1.9	1.65

The results of the analysis, including 54 countries, reiterate the conclusion of the first-run clustering: special emphasis on food security measures is strongly recommended for Group 1, while formulating investment package for multiple water use. It is important to note that all small island developing states (SIDS – Cabo Verde, Comoros, Guinea Bissau, Mauritius, Sao Tomé and Principé and Seychelles) are included in Group 1. SIDS rely merely on indigenous resources, many of them can supply domestic food demand only through trade. Due to their physical limits of food production systems, SIDS are more prone to extreme climatic events.

Redistribution group

Table 6: Summary table of group 2

	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Benin	4	1	5	2	3	5	1	3	2	4	4	2	2
Burkina Faso	3	1	1	2	5	5	2	1	2	4	4	2	4
Cameroon	3	1	3	3	4	5	1	1	1	4	4	2	7
Cote d’Ivoire	4	1	2	2	5	4	2	3	1	4	4	2	13
Gambia	5	1	3	1	3	5	1	2	3	4	3	1	21
Ghana	4	2	2	1	4	4	1	2	2	3	3	1	22
Guinea	3	1	3	2	2	5	2	1	1	4	4	2	23
Malawi	5	1	1	1	3	3	2	1	4	3	3	1	30
Rwanda	5	2	2	2	4	4	3	2	2	5	3	2	39
Senegal	4	1	2	1	3	5	1	3	2	2	4	2	41
Togo	5	1	2	2	3	5	2	1	2	5	4	3	49
Uganda	5	1	1	2	5	4	4	1	2	5	4	2	51
Algeria	2	4	2	2	3	5	1	4		1	1	2	54

The average scores of indicators are arranged in order - from underperforming to best performing indicators. The most underperforming indicators are climate vulnerability, population density, irrigated land ratio, displacement, health system access, internal exposure.

ClV	PoDE	IrLaR	DiP	HeSy	AfT	YiGa	FoDe	WASH	Con	FoR	PopA
4.5	4.17	3.92	3.67	3.67	2.25	2	1.83	1.83	1.75	1.75	1.17

The mixed typology of the group indicates high sensitivity driven by unpredictable population growth. Accordingly, Group 2 includes five of the nine countries experiencing the largest number of households with migrants according to the FAO study (FAO, 2017). Dealing with these large uncertainties in development projects requires balanced improvement of multiple water use, where irrigation and WASH sectors are equally emphasized.

WASH group

Table 7: Summary table of group 3

	PoDE	PopA	AfT	Con	DiP	ClV	FoDe	FoR	YiGa	IrLaR	HeSy	WASH	ID
Central African, R.	1	1	2	5	2	4	5	3	2	3	5	3	8
Chad	1	1	2	3	4	5	4	1	4	3	4	4	9
Congo, Dem. Rep.	2	1	2	5	5	3	2	2	3	3	4	4	11
Equatorial Guinea	3	2	2	2	3	4	2	2	1	3	3	4	16
Eritrea	3	1	2	3	3	5	2	2	5	3	4	4	17
Ethiopia	4	2	1	3	5	2	2	1	1	2	4	4	19
Kenya	4	2	2	2	5	2	3	2	4	2	3	3	25
Libya	1	4	1	5	5	5	2	2	2	1	1	3	28
Madagascar	2	2	2	1	1	1	4	1	3	3	4	4	29
Mali	1	1	2	3	4	5	1	1	2	2	3	2	31
Mozambique	2	1	2	2	3	2	3	2	5	3	4	4	35
Niger	1	1	3	3	3	1	2	1	3	5	4	4	37
Nigeria	5	1	1	4	5	3	1	1	1	4	3	3	38
Sierra Leone	4	1	4	1	2	1	2	2	1	5	4	3	43
Somalia	2	1	2	5	2	3	2	2	3	2	5	5	44
South Africa	3	3	1	3	5	2	1	1	2	1	3	1	45
South Sudan	2	1	2	5	5	4	2	2	2	3	4	4	46
Sudan	2	2	2	4	5	3	2	1	4	2	3	4	47
Tanzania	3	1	1	1	4	4	3	1	3	2	3	4	48
Zambia	2	1	1	1	2	5	4	1	4	3	4	3	52
Zimbabwe	2	2	1	3	4	3	5	3	3	2	3	2	53

The extended scoring to 54 countries reinforces the typology of Group 3 generated by the first-run clustering. Investment need related to WASH sector has a higher focus in multiple water use development. The most underperforming indicators are displacement, health system access, access to improved water, climate vulnerability, conflict and yield gap.

DIP	HeSy	WASH	ClV	Con	YiGa	IrLaR	FoDe	PoDE	AfT	FoR	PopA
3.64	3.45	3.36	3.27	3.00	2.76	2.64	2.50	2.36	1.82	1.73	1.64

According to the Global Peace Index, 5 from the 10 most conflict-prone countries are in Africa. Group 3 includes all these five countries (Somalia, South-Sudan, Central African Republic, Libya and Congo DR). Furthermore, almost each country shows high investment needs to enhance the access to improved water resources. Not merely due to the conflict, but countries are lacking facilities of health and WASH sectors from different reasons. Therefore, it is recommended to emphasize the WASH-related actions in formulated development plan of multiple water use to provide basic facilities in the countries.

In conclusion, the cluster analysis generated three groups with different composition of investment need: Food Security group, Redistribution group, WASH group. General rules can be observed from the grouping in terms of indicator pattern, i.e. countries in the Food Security group have reasonable access to WASH facilities but are more exposed to food insecurity, while countries in WASH group show general need to develop the access to improved water. The clustering helps identifying the optimal balance between irrigation and WASH components in investment packages for multiple water use development.

In order to further support the accurate planning of investment packages, the countries will be further analyzed by agro-ecological-zones and hydrological conditions in the next sections. Matching the investment need to water resources will define the physical boundaries of possible engineering solutions, thus, enhancing the feasibility of investment in multiple water use.

FINDING SMART IRRIGATION – SMART WASH SOLUTIONS TO INCREASE RESILIENCE

The previous sections provided recommendations on the assessment of vulnerability and exposure to the impacts of COVID-19. This has been taken forward and a stocktaking of possible technical solutions, as well as their physical, institutional and economic boundaries in order to assess their feasibility in different conditions is performed. These technical solutions form the core of investment packages and are to be effectively delivered to the field afterwards.

At first step, the physical boundaries are established including the climatic, topographical and hydrological conditions. Physical boundaries are considered hard conditions, as they can barely be influenced by human intervention. For instance, the total exploitable water source in the catchment is a hard condition of the capacity of irrigation system. Moreover, annual rainfall is a hard condition of water harvesting systems. Therefore, a water balance approach is applied, whereas water supply is compared to water demand/requirement. At a second step, institutional and economic boundaries are assessed based on the management requirement of technical solutions. Responsibility share over O&M activities is also elaborated in order to evaluate the possibility of responsibility transfer to users. As many of the solutions require decentralized distribution, irrigation management transfer must be properly explored. Finally, recommendations of technical solutions are matched with identified conditions.

PHYSICAL BOUNDARIES

The assessment of physical boundaries is based on a water balancing approach. Two sides of the equation, water supply and water demand/requirement, are assessed separately. Based on the well-recognized definition of multiple water use by FAO, multiple uses of water involve the practice of using water from the same source or infrastructure for multiple uses and functions. As the SMART Irrigation – SMART WASH approach combines multiple water use, water requirement is further specified to irrigation demand and WASH demand. It is difficult to provide country-level assessment due to the different agro-ecological-zones and hydrological conditions within the same country. Therefore, the selection of country-level engineering solutions must be based on micro data and consider the climate of the area of implementation. In order to achieve that, the paper reiterates the importance of global datasets at micro-level such as Hand-in-Hand GIS platform, which can be used in the further steps of implementing SMART Irrigation – SMART WASH.

In order to categorize the parameters of the physical boundaries, the following water balance equation is considered:

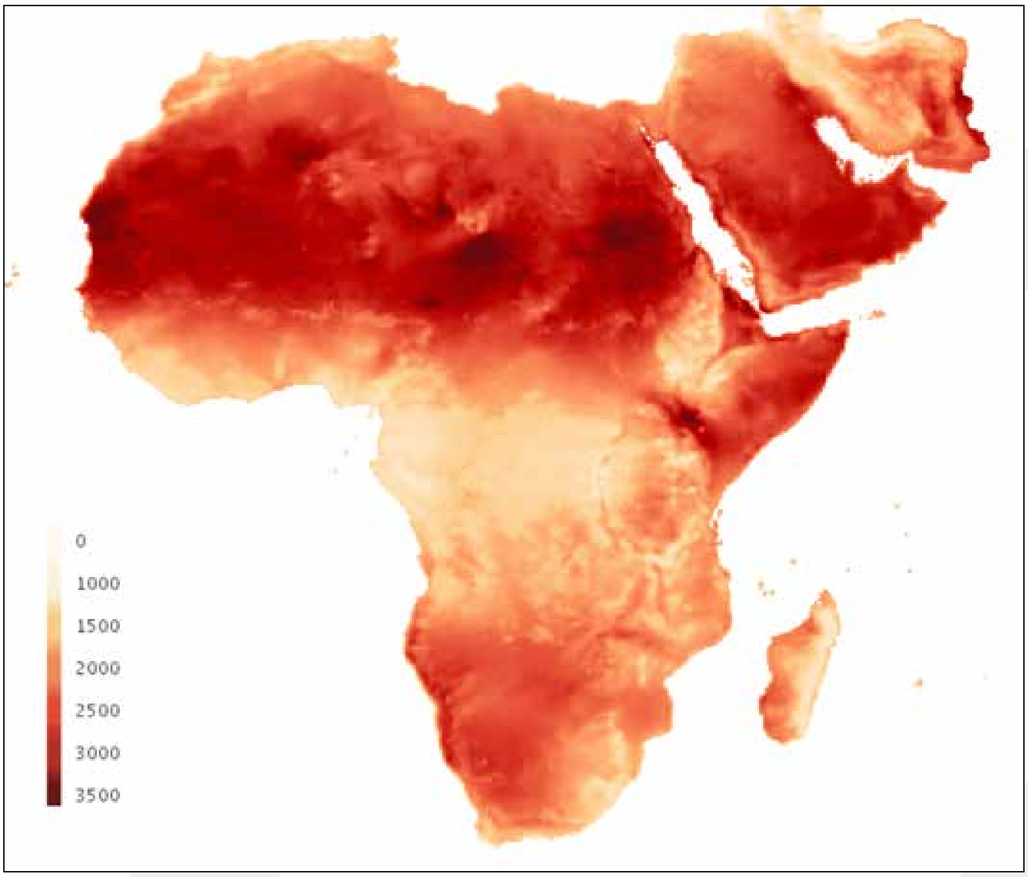
$$\text{precipitation} + \text{water resources} = \text{agricultural water demand} + \text{WASH water demand}$$

Water requirement

The right side of the equation includes the demand by agriculture and water need for WASH. By taking into account the driving factors of water consumption, investment packages can be constructed to meet water demand to the most possible extent.

Agricultural water demand: water demand is expressed as global reference evapotranspiration, in order to identify the continental trends about agricultural water need. The following map obtained from FAO, Water Productivity through its open access of remote sensing derived data (WaPOR) displays the Potential Evapotranspiration (ETo) in 2019.

FIGURE 21
Reference evapotranspiration in Africa

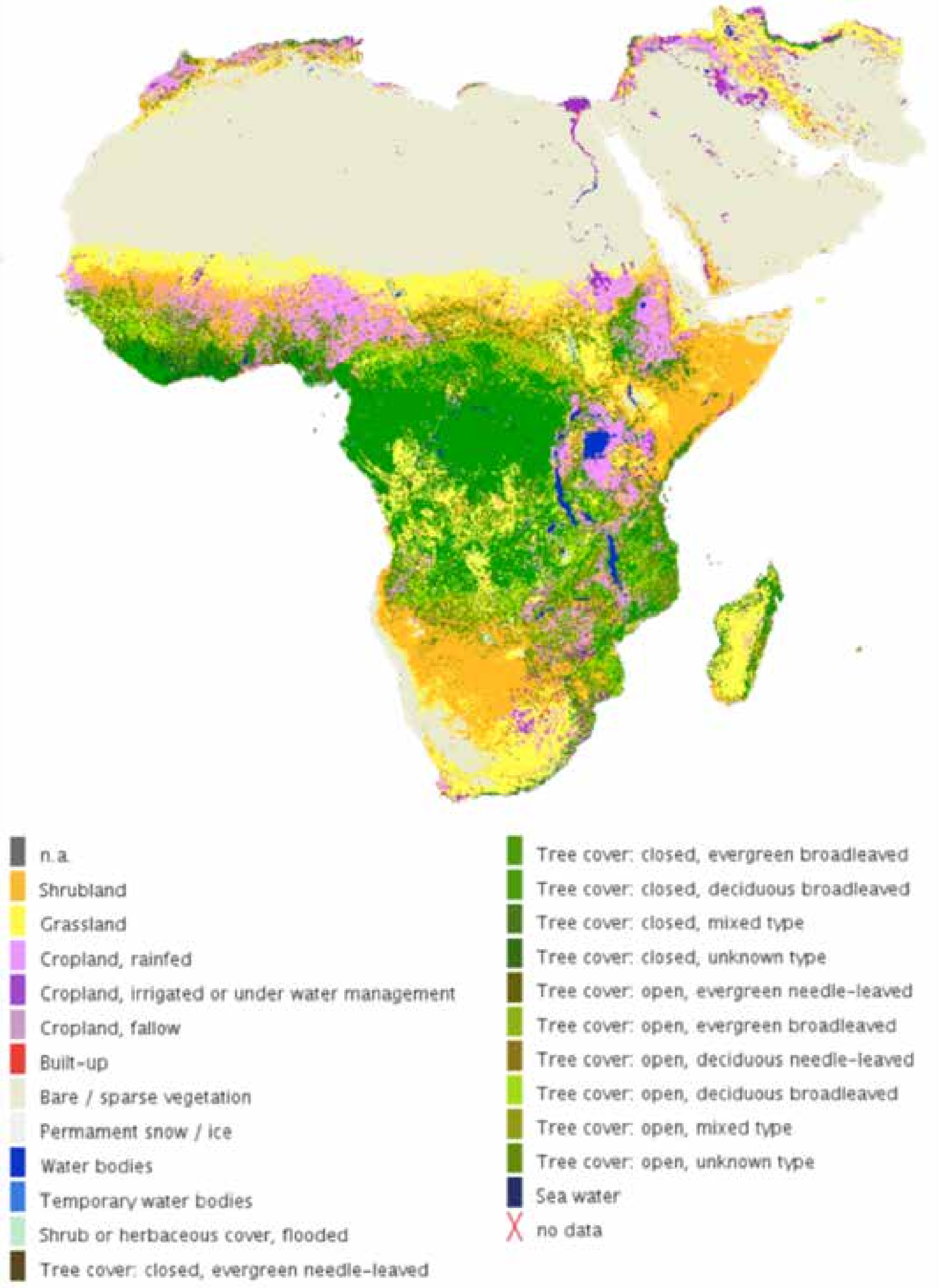


Source: FAO, WaPOR portal, 2020.

Most of the countries have higher than 2 500 mm potential evapotranspiration. North Africa, North Sub-Saharan Africa and South Africa are amongst the worlds' regions with highest potential evapotranspiration due to high average temperature, wind speed and low humidity. In order to assess how evapotranspiration affects agriculture, land use and spatial distribution of croplands must be evaluated.

The land cover map of WaPOR, FAO (based on Copernicus Global Land cover map) shows the land distribution amongst different land cover classes. Based on the narrative analysis of Copernicus, Africa Land Cover map, forests and bare vegetation dominate by sharing 33.94 percent and 29.76 percent of the lands respectively, 13.49 percent is covered by shrub-land, 13.26 percent by herbaceous vegetation and only 8.06 percent by cropland. Moreover, permanent water bodies cover only 0.79 percent. The countries with largest crop producing areas are Nigeria (45.5 million hectare), Sudan (19.9 million hectare), Niger (17.8 million hectare), Ethiopia (17.5 million hectare) and Tanzania (15.6 million hectare). However, the arable land per capita shows different picture. Corresponding to the cropped area size, Niger has the largest land endowment per capita (0.8 ha). It is followed by Sudan (0.48 hectare), Central African Republic (0.4 hectare), Togo (0.36 hectare) and Mali (0.35 hectare). Meanwhile, Nigeria has only 0.21 hectare per capita arable land.

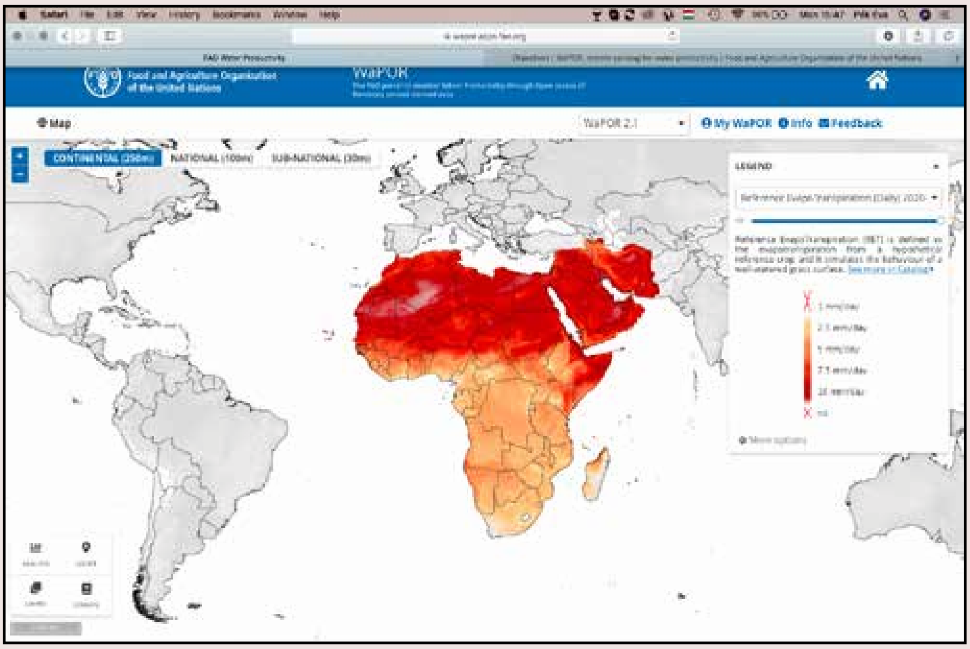
FIGURE 22
Africa land cover map



Source: FAO, WaPOR, 2020.

These countries have relatively small arable land compared to total land and population size, and agriculture is constrained both by limited land resources and high evapotranspiration compared to other continents, which requires efficient use of water resources. Consequently, water management investments must include interventions to decrease crop evapotranspiration. However, most of the ET-reducing techniques and methods can be applied only at farm-level, therefore, techniques must be packaged and provided along with sufficient knowledge transfer directly to farmers.

FAO-developed open-access portal to monitor water productivity is publicly available to acquire large number of datasets related to water productivity, water, land and climate on the globe (https://wapor.apps.fao.org/home/WAPOR_2/1). The application called WaPOR aims at creating an action framework to provide relevant and specific information on water and biomass status for stakeholders at different scale from policy to farm level. WaPOR portal provides tool for assessments requiring more in-depth information about the above-mentioned dimensions. Beyond the results, the portal also makes the metadata available for further analysis at country and micro-region level.



Water need for WASH: The water need for WASH is calculated based on the total population of the country. The calculation applies the recommendations of WHO about emergency water need for non-domestic use (WHO, 2013). Technical notes on drinking-water, sanitation and hygiene in emergencies categorize the water requirements for survival in emergency situations. Currently, there is no recommendation available for COVID-19 water requirement, but Table 8 includes indicative value for SARS isolation. Accordingly, the defined 100 l per isolation required until discharge of the patient is taken into consideration.

Table 8: Guidelines for minimum emergency water quantities for non-domestic use

Emergency case	Water need
Health centers and hospitals	5 liters/out-patient; 40-60 liters/in-patient/day. Additional quantities may be needed for laundry equipment, flushing toilets, etc.
Cholera centers	60 liters/patient/day; 15 liters/carer/day
Therapeutic feeding centers	30 liters/in-patient/day; 15 liters/carer/day
Operating theatre/maternity	100 liters / intervention
SARS isolation	100 liters / isolation
Viral Haemorrhagic Fever isolation	300-400 liters / isolation
Schools	3 liters/pupil/day for drinking and hand washing (use for toilets not included: see below)
Mosques	2-5 liters/person/day for washing and drinking

Public toilets	1-2 liters/user/day for hand washing; 2-8 liters/cubicle/day for toilet cleaning
All flushing toilets	20-40 liters/user/day for conventional flushing toilets connected to a sewer; 3-5 liters/user/day for pour-flush toilets
livestock/day	Cattle, horses, mules: 20-30 liters per head; goats, sheep, pigs: 10-20 liters per head, Chickens: 10-20 liters per 100
Vegetable gardens	3-6 liters per square meter per day

Source: WHO, Technical Notes on drinking-water, sanitation and hygiene in emergencies, 2013

FIGURE 23
Hierarchy of water requirements

Source: WHO, Technical Notes on drinking-water, sanitation and hygiene in emergencies, 2013

Furthermore, the Technical Note includes the Maslow pyramid of human water requirement for basic needs as shown in Figure 23.

Recommended water needs for sanitation and waste disposal (70 l) combined with the emergency requirement of isolation once per year (100 l) is calculated to the total population per country on annual basis.

The four most populated countries, Nigeria, Ethiopia, Egypt and the Democratic Republic of Congo share almost 40 percent of the continental annual WASH water need due to the high population. An interesting comparison translates the water need of top four countries with the highest and the lowest WASH demand into irrigated land. For instance, if total WASH demand of Nigeria was used for irrigation with average 4 500 m3 per hectare crop water requirement, almost 1.2 million hectares would be irrigated from the same amount of water. Proportionally, Ethiopia, Egypt and Democratic Republic of Congo would be able to irrigate 0.5-million-hectare land. The smallest countries with low WASH demand could irrigate 5.5 to 7.9-thousand-hectare land. Of course, this calculation is far-fetched theory, as spatial and temporal distribution of available water source heavily influence the convertible amount of water.

FIGURE 24
WASH water need of total population for emergency responses

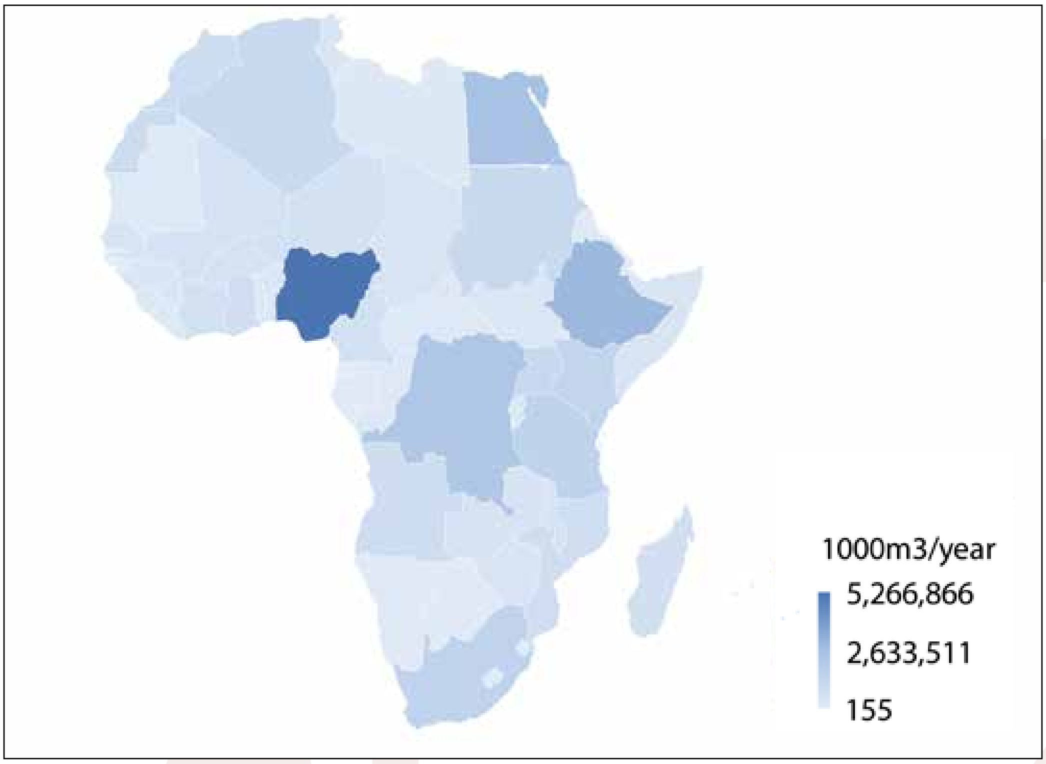
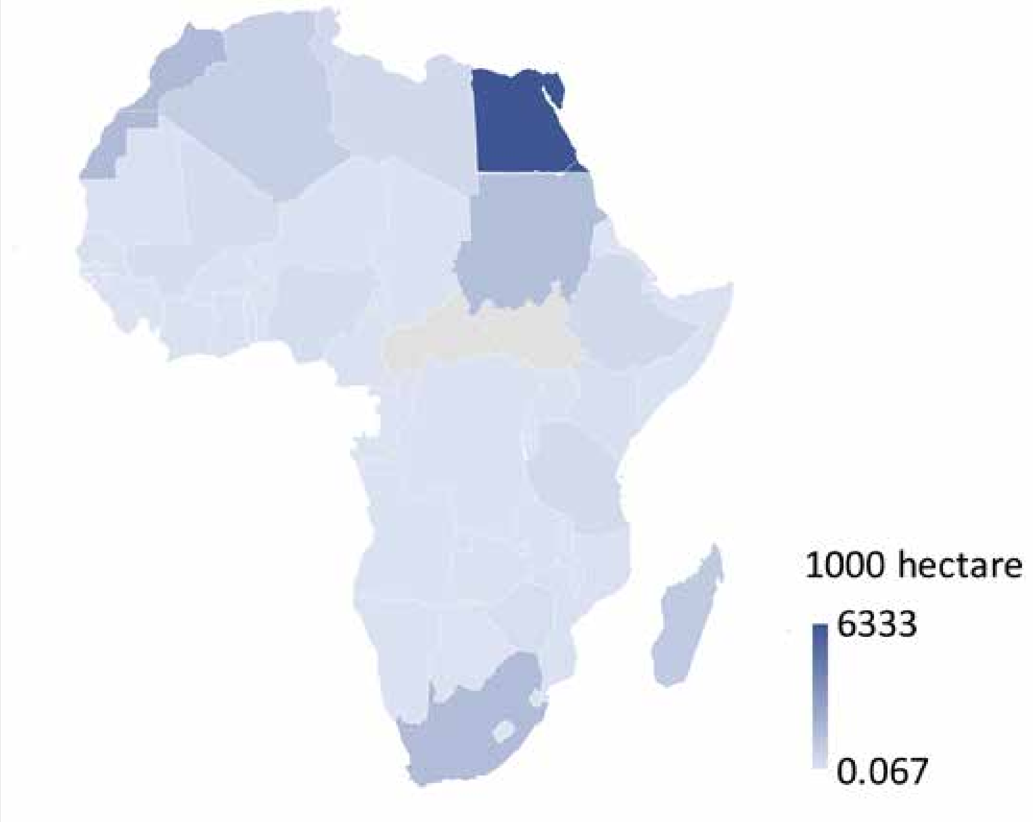


Table 9: Conversion of WASH demand to irrigated land

	WASH demand for emergency responses (1 000 m3 per year)	Irrigated area with 4 500 m3 per hectare requirement (ha)
Djibouti	25 243	5 609
Eswatini	29 642	6 587
Mauritius	32 493	7 220
Equatorial Guinea	35 846	7 965
Democratic Republic of Congo	2 288 293	508 509
Egypt	2 614 644	581 032
Ethiopia	2 937 319	652 737
Nigeria	5 266 866	1 170 414

FIGURE 25
Total harvested and irrigated land size



Source: FAO, AQUASTAT, 2020.

According to the data of AQUASTAT, the irrigated land size shows large regional disparity. Six countries (Egypt, Morocco, South-Africa, Sudan, Madagascar and Algeria) share the 80 percent of total irrigated land in Africa. Due to their climatic, hydrological and socio-economic conditions, these countries are the largest users of water for agriculture. Among these countries, Egypt shares almost the 40 percent of total irrigated lands with 6.3 million ha. Salman *et al.* (2020) conducted a series of technical audits and assessments of irrigation modernization programme in Egypt. It is found that saving through modern irrigation systems averages 20-30 percent compared to non-modernized systems. The theoretical conversion of saved irrigation water used for WASH purposes is based on the assumption that high-performing systems can save minimum 20 percent. Based on the countries' irrigated land size, and assuming 4 500 m3 per hectare irrigation water use, the total irrigation water amount is calculated in the first step. From the total amount, 20 percent water saving is converted to WASH supply amounting to 25 600 liter annual consumption per capita (70 liter per day and 100 liter for isolation). Table displays the detailed steps of theoretical conversion.

Table 10: Conversion of water saving by irrigation modernization to WASH supply

	Irrigated land size (thousand ha)	Irrigation water amount with 4 500 m3 per hectare requirement (million m3)	Total water saving at 20% efficiency increase (million m3)	Population with WASH supply from water saving
Egypt	6 333	28 499	5 699	222 210 526
Morocco	1 711	7 700	1 539	60 035 087
South Africa	1 665	7 493	1 498	58 421 052
Sudan	1 563	7 034	1 406	54 842 105
Djibouti	0.582	2.62	0.52	20 421
Republic of Congo	0.582	1.94	0.39	15 087
Seychelles	0.43	0.99	0.20	7 719
Lesotho	0.22	0.30	0.06	2 350

Although, it must be re-emphasized that the conversion is only theoretical, the results show some important lessons. Countries with large irrigation intensity, such as Egypt, Morocco, South Africa and Sudan can supply from 54 to 222 million people merely from the water saving by modernized irrigation systems. Although this is a rough estimation, the analysis represents well why efficiency of irrigation systems must be improved to achieve a balanced development of irrigation and WASH sectors.

In conclusion, water demand for agricultural and WASH use show no meaningful overlap amongst countries, as agricultural water demand depends on climatic and land use data, while WASH demand depends on population size. The continent must tackle multiple challenges in terms of natural resource management such as the globally highest potential evapotranspiration and low rate of arable land. A further challenge is the increasingly growing population. 18 out of 20 countries with the highest yearly increase of population are in Africa, therefore, both agricultural water demand and WASH demand are expected to exponentially grow in the coming years.

Table 11: Evapotranspiration and WASH demand matrix for investment evaluation

	Countries with low WASH demand	Countries with high WASH demand
Countries with high evapotranspiration	High evapotranspiration and WASH	High evapotranspiration and high WASH demand
Countries with low evapotranspiration	Low evapotranspiration and low demand for WASH	Low evapotranspiration and high WASH

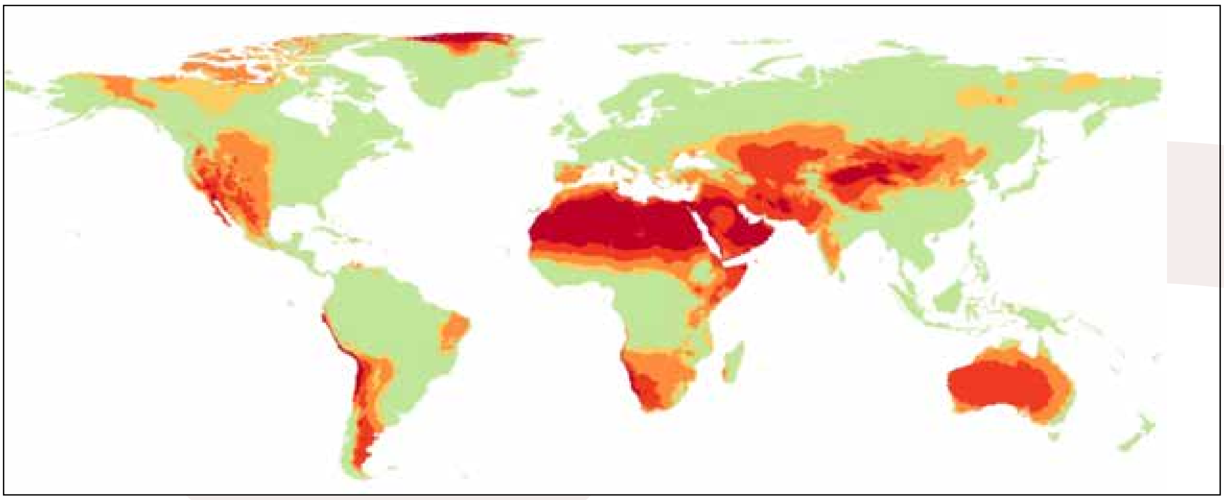
High evapotranspiration can be tackled mostly by on-farm techniques, such as mulching, evaporation-reducing land and irrigation management. Therefore, recommendations on investment packages incorporate water productivity maximizing techniques. Water productivity will be further enhanced. Furthermore, the investment packages take into consideration the countries with high WASH demand. Water demand for WASH must comply with minimum water quality standards in order to provide safe water for domestic use. Therefore, recommendations on engineering solutions also include water quality considerations in order to fulfil safety requirements.

Water supply

Precipitation: the definition here indicates the rate of precipitation that effectively reaches the land and can be utilized. The precipitation analysis applies continuous values instead of country-based assessment, as some of the large countries fall under different agro-ecological-zones. In this context, precipitation is analyzed with two major aspects: dryland and crop water use. Drylands are classified based on the aridity index: dry sub-humid, semi-arid, arid, and hyper-arid. The aridity index is calculated according to the ratio of annual precipitation and potential evapotranspiration, which was already presented in the previous section. Drylands are particularly exposed to water scarcity partially due to low rainfall. The following map in Figure 26 displays the Global Aridity Index by FAO, GeoNetwork. The global map renders the dataset related to evapotranspiration processes and rainfall deficit for potential vegetative growth. As the map shows, 45 percent of Africa's total landmass falls under drylands, of which the majority of North Africa and northern Sub-Saharan Africa are arid and hyper-arid.

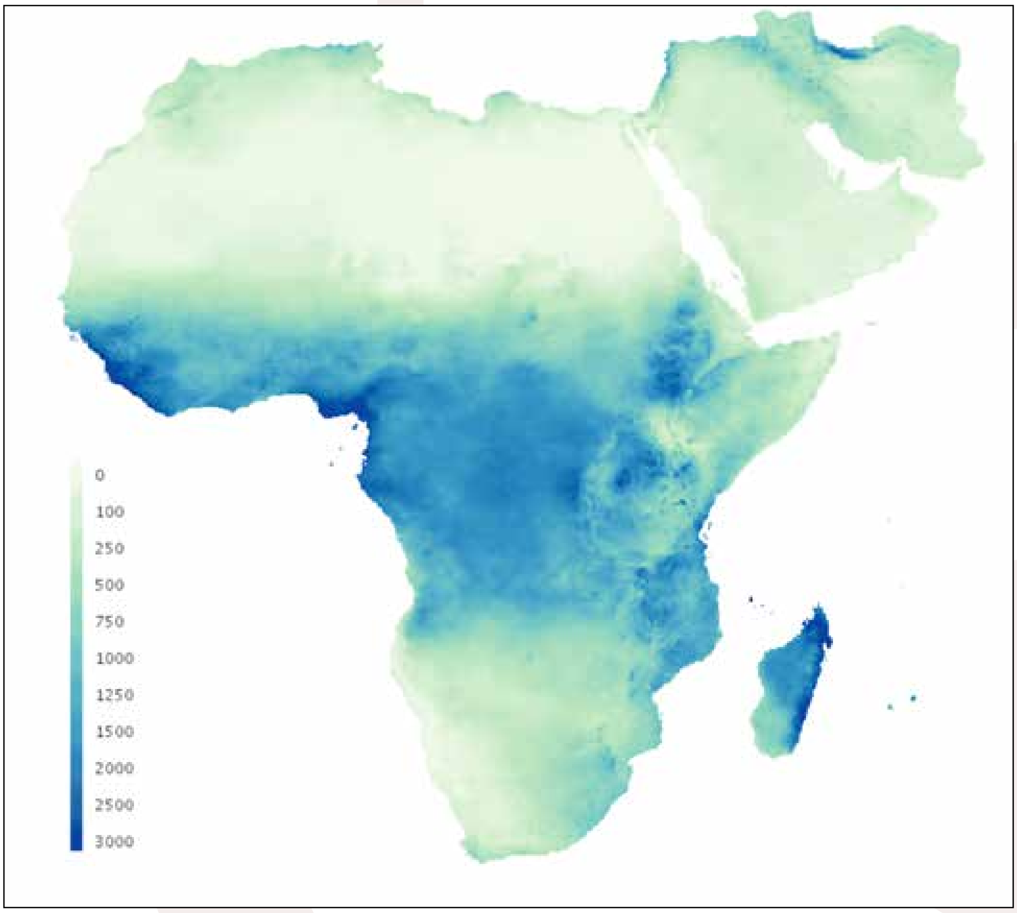
In terms of crop water use, effective precipitation is analyzed. Effective precipitation indicates the available rainfall by rootzone. As effectiveness depends on a number of factors, such as topography, soil type, farming system etc., the annual precipitation is analyzed in the first step. WaPOR annual precipitation map displays the large regional disparity in rainfall pattern (FAO, WaPOR). Corresponding to the aridity map, North-Africa, northern Sub-Saharan Africa and South Africa receive the least amount of annual precipitation. According to the rainfall pattern, the precipitation distribution is unevenly distinguished between humid and dry season. As most of the countries have cropping calendar including double-cropping, precipitation must be supplemented with irrigation to fully meet the agricultural water demand.

FIGURE 26
Global map of aridity



Source: FAO, GeoNetwork; Data source: CRU CL 2.0. Global Climate Dataset, 2020.

FIGURE 27
Annual precipitation in mm in Africa

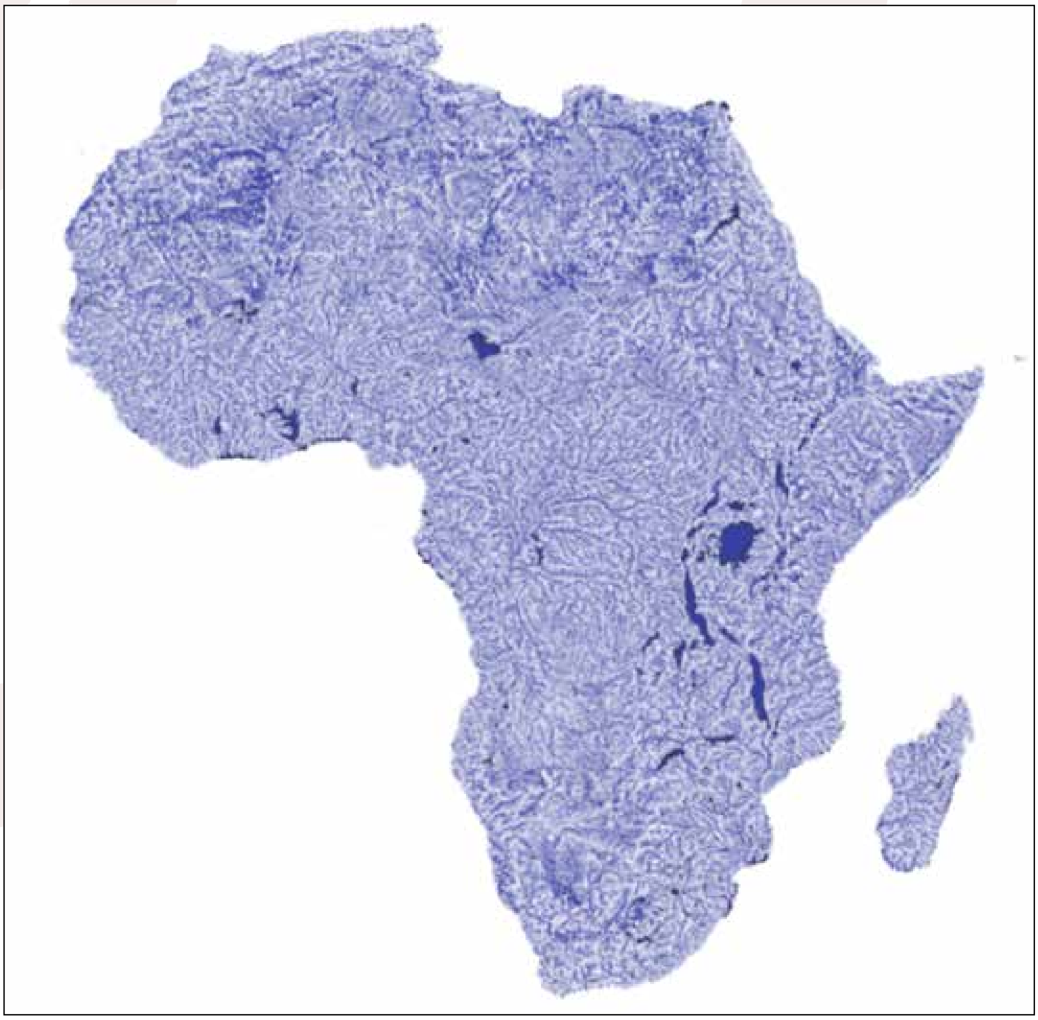


Source: FAO, WaPOR, 2020.

According to FAO Irrigation and Drainage Paper 25, the rainfall below 5 mm is not considered as effective. As many of these countries experience less than 5 mm daily rainfall in vegetative period, the water for agriculture is only available through the renewable water resources. Not only agriculture, but water resources and ecology are also exposed to this particular risk. Countries with low aridity index must create water development strategies while considering the severe constraint of low precipitation. Excessive water withdrawal might lead to rates of water extraction higher than recharge.

Water resources: the definition includes the exploitable water resource for human use but excludes the ecological water demand. Available water resources are difficult to estimate, as many of the countries have insufficient data on groundwater resources, as well as on water recharge. Therefore, the current analysis is based on available and validated data by the GeoNetwork and AQUASTAT of FAO. As most of the countries seek localized (within country) solutions to respond to the COVID-19 crisis, the manageable water resources are also analyzed at country level. Figure 28, applying the metadata of the GeoNetwork of FAO, displays the surface water bodies of the continent. Central regions are well endowed with river networks and surface water bodies, but similarly to the aridity map, North Africa, North Sub-Saharan Africa and South-Africa are exposed to water scarcity.

FIGURE 28
Surface water bodies in Africa



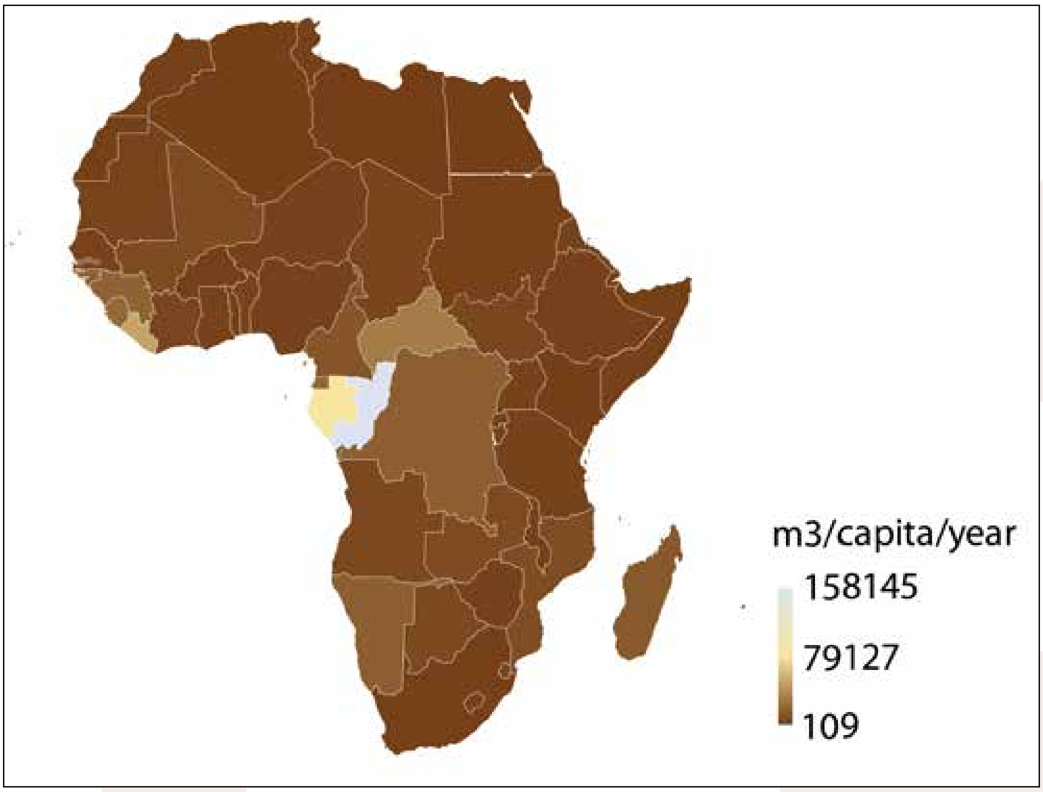
Source: FAO, AQUASTAT, Performed with QGIS 3.12, 2020.

However, it is important to note that large regional disparities are observed across Africa. North-African countries are extracting water at rates higher than the recharge. For instance, current water withdrawal (not considering fossil groundwater) is more than 8 times the annual renewable water resources in Libya. On the other side, many of the eastern countries underutilize the resources. For instance, only 0.5 percent of potential lands are irrigated in Uganda.

Figure 29 shows the differences of annual renewable water resources per capita amongst the countries in Africa. According to AQUASTAT, five countries share 62 percent of annual renewable water resources per capita in the continent: The Republic of Congo with the highest per capita (158 145 m3/capita), Gabon, Liberia, Central African Republic, and Sierra Leone. Therefore, the 10-point classification excluded these countries while defining the boundaries of classes, in order to display a more diversified picture about the water resources in Africa, whereas the darker the color the less the renewable water resources.

FIGURE 29

Renewable water resources per capita in Africa



Source: FAO, AQUASTAT, 2020.

Table 12 provides the interpretation of the value ranges.

Table 12: Renewable water resources classification

1000 m3/capita/year	class	countries
>15 895.8	1	Congo, Gabon, Liberia, Central African Republic, Sierra Leone, Equatorial Guinea, Guinea, Guinea-Bissau,
14 129.6	2	Congo D.R., Namibia
12 363.4	3	Madagascar
10 597.2	4	Cameroon, Sao Tome and Principe
8 831	5	Mozambique
7 064.8	6	
5 298.6	7	Mali, Zambia, Botswana
3 532.4	8	Angola, South Sudan, Gambia
1 766.2	9	Cote d'Ivoire, Eswatini, Chad, Mauritania, Senegal, Benin, Mauritius, Ghana, Tanzania
<1 766.3	10	Uganda, Niger, Nigeria, Comoros, Eritrea, Tunisia, Lesotho, Zimbabwe, Ethiopia, Burundi, Rwanda, Somalia, Sudan, Malawi, South Africa, Morocco, Burkina Faso, Kenya, Egypt, Cabo Verde, Togo, Djibouti, Algeria, Libya

The countries with least renewable water resources are Libya, Algeria, Djibouti, Togo, Cabo Verde, Egypt, Kenya, Burkina Faso, Morocco, South Africa, Malawi, Sudan and Somalia. In these countries, the renewable water resources are less than 1 000 m3 per capita per year. According to FAO, water scarcity is defined as < 500 m3 per capita and water stress is <1 000 m3 per capita in absolute term. Based on this definition, four countries are labelled as water scarce, and nine countries as water stressed.

INVESTMENT CATEGORIZATION

Based on the countries' agro-ecological-zones, the investment packages must be built on the conditions of the micro regions. Countries hit by water scarcity or water stress must find the most productive use of water while prioritizing the multiple water use amongst sectors.

Table 13: Rainfall and water resource matrix for investment evaluation

	Countries with high amount of renewable water resources	**Countries with moderate amount of renewable water resources**	**Countries with small amount of renewable water resources**
Countries with low precipitation	Water abundancy and exposure to aridity	Moderate water resources and exposure to aridity	Water scarcity and exposure to aridity
Countries with medium precipitation	Water abundancy and moderate rainfall availability	Moderate water resources and moderate rainfall availability	Water scarcity and moderate rainfall availability
Countries with high precipitation	Water abundancy and potential for rainfall exploitation	Moderate water resources and moderate rainfall availability	Water scarcity and potential for rainfall exploitation

Simplifying the investment evaluation matrix, investment needs and potentials can be grouped into four major categories:

1. Water resources and precipitation are not constraining factors: water tower category.
2. Water resources are not constraining, and precipitation is constraining factors: water management category.
3. Water resources are constraining, and precipitation is not constraining factors: rainfall management category.
4. Water resources and precipitation are constraining factors: water scarce category.

The above-mentioned grouping helps establishing the main characteristics of investment packages, based on available water resources. According to the vulnerability assessment, the four categories can be further divided into food security- or WASH-oriented investments.

"Guidelines on irrigation investment projects" by FAO (2018) is a practical tool for guiding the procedures and processes of investment operations. The Guidelines covers the entire project-cycle of irrigation investment from project identification to monitoring and evaluation. Although the technical document is published to support merely irrigation projects, useful and applicable information are presented.

Water tower	
Water resources	Available and predictable water resources
	No upper-limit for water use
	Periodicity of rainfall counterbalanced by water resources
	Surface water dominancy
	Precipitation contributes to agricultural water need
	Renewable water sources contribute to WASH need
Socio-economic	Decentralized water sourcing
	Community-based operation
	Low risk of inequity amongst users
	Low risk of water quality deterioration
	Affordability of water resources
	Possibility of crop diversification
Investment	Feasibility of large and long-term investment
	Simultaneous development of irrigation and WASH sectors based on potential and need
	Public and/or private investment
	High potential of scalability
	High potential of upgrade
	Multiple sector involvement (e.g. energy, fishery, etc.)
	Accelerated cost recovery
Engineering and O&M	Demand-driven capacity
	Fixed or in-built infrastructure (dams, weirs, canal distribution system, treatment plant, etc.)
	Possibility of rehabilitation and modernization of existing infrastructure
	Simultaneous water use between two sectors (agriculture and WASH)
	High potential of nature-based solutions
	Multiple outlets of infrastructure
Example	Mubuku gravity-fed irrigation scheme in Uganda supplied by Sebwe surface water resources, with high precipitation
	 ©FAO/Eva Pek

Water management	
Water resources	Available and predictable water resources Upper-limit for water use Surface water dominancy Renewable water sources for both agricultural water and WASH need
Socio-economic	Decentralized water sourcing within the system Centralized monitoring to avoid inequity and ensure affordability Required monitoring of water quality Possibility of crop diversification
Investment	Feasibility of large and long-term investment Investment equally balanced between irrigation and WASH sector Large potential of scalability Large potential of upgrade Public and/or private investment Priority sector involvement (e.g. energy, fishery, etc.) Accelerated cost recovery
Engineering and O&M	Demand-driven capacity Storage reservoirs in main distribution points Fixed or in-built infrastructure (dams, weirs, canal distribution system etc.) Possibility of rehabilitation and modernization of existing infrastructure Simultaneous water use between two sectors (agriculture and WASH) Multiple outlets of infrastructure
Example	El-Bared dam in Lebanon supplied by Nahr El-Bared, surface irrigation scheme with low precipitation  ©FAO/Eva Pek

Rainfall management	
Water resources	Upper-limit of spatial and temporal water availability Unpredictable water supply Rainfall resources and limited renewable water resources for both agricultural water and WASH need
Socio-economic	Localized and decentralized water distribution – based on rainfall pattern Community-based operation Mutual agreement on water share amongst users to avoid inequity Priority crop identification
Investment	Flexible investment (e.g. open-ended) Public investment Required knowledge transfer Low cost recovery
Engineering and O&M	Sectoral priority in terms of order of water use (WASH first and irrigation second) Supply-driven capacity Fixed storage infrastructure in optimal locations Appended infrastructure for water distribution Required early warning system and monitoring system component Fixed outlet of infrastructure
Example	Water harvesting reservoir in Jordan supplied by rainfall  ©FAO/Motasem Abukhalaf

Water scarce	
Water resources	Low water availability Severely restricted access to water Groundwater dominancy Insufficient rainfall
Socio-economic	Centralized distribution due to exposure to inequity Most productive use of water to achieve affordability Circular water use Priority crop identification
Investment	Security investment (e.g. early finance) Marginal cost approach Trade-off assessment Energy component (pumping) Public investment Low cost recovery
Engineering and O&M	Sectoral priority in terms of order of water use (WASH first and irrigation second) Supply-driven capacity Flexible or mobile infrastructure Water re-use facilities Early warning system and monitoring system component Necessary water metering and centralized asset management Localized water distribution (on-farm) Evaporation-reducing infrastructure (e.g. pipe)
Example	Sprinkler irrigation in Lebanon supplied by groundwater (well), with low precipitation and insufficient surface water resources  ©FAO/Eva Pek

©FAO/Luis Tato

Investment packages

Investment packages are divided into two levels of intervention, on-farm level and system level. The on-farm level packages aim at providing engineering solutions to decrease evapotranspiration, thus improving water productivity. The system level packages showcase possible engineering solutions customized to the groups of investment evaluation matrix. In every case, investments in multiple water use combine on-farm and system-level solutions in order to reinforce the objective and sustainability of SMART Irrigation – SMART WASH development.

ON-FARM INVESTMENT PACKAGE

The crop evapotranspiration is calculated from the potential evapotranspiration and crop coefficient as the following:

$$ET_c = ET_o \times K_c$$

Whereas, ET_c is the crop evapotranspiration, ET_o is the reference evapotranspiration, K_c is the crop coefficient.

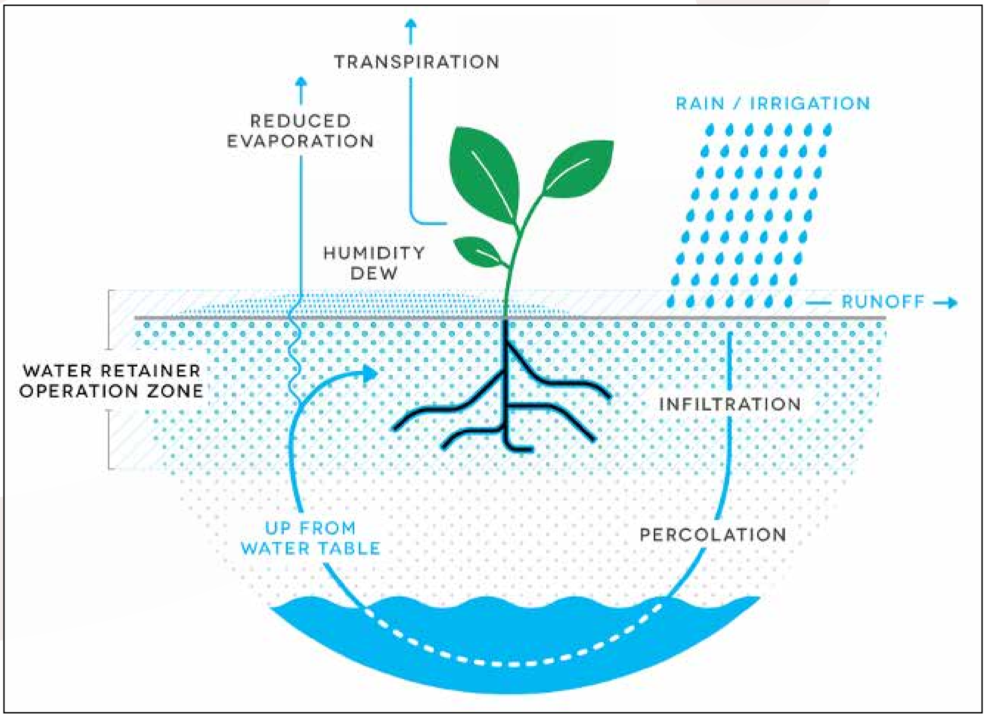
Two innovative applicable solutions addressing the two components of the crop evapotranspiration, evaporation and transpiration, are provided. These solutions are applicable in every country regardless of their hydrological background, and will have a spill-over effect on sanitation making more resources available to the sector. The number of on-farm practices to improve agricultural water management is ample. On-farm water management practices, land management practices, smart irrigation tools are widely available and utilized. In the first step, the analysis is kept selective, targeting saving on the consumptive part of water use (evapotranspiration), and delivering the latest innovations, without being redundant with the existing literature. It does not mean that the toolbox of SMART Irrigation – SMART WASH must be limited to certain techniques and methods, but it requires a dynamic process to evolve.

The private sector partnership forms a strategic direction of FAO's work to bring the state-of-art innovations aboard, which are in line with its corporate strategic objectives. Implementation, evidence-based analysis and follow-up of such innovations can enhance efficient technology uptake, informed end-users and guaranteed benefits. Under the FAO Strategy for Partnership with the Private Sector, FAO initiated cooperation with innovative private companies working in the same field. Two identified innovative solutions (reduced evaporation and reduced transpiration) are incorporated in the analysis in order to showcase possible strategies to increase water productivity and water use efficiency through affordable farm-level technologies.

Reduced evaporation – Water Retaining Technology (Water Retainer White book, 2020): In order to provide sufficient water supply at root zone level, water balance of the soil must be maintained. The driving factors of water losses are runoff, deep percolation and evaporation. These together constrain the total available water (TAW), and, consequently, the readily available water (RAW). Therefore, these factors must be effectively controlled to avoid the stress. In irrigated areas, the supplementary water can be easily provided to keep-up good soil water balance, but rainfed areas are bound by spatial and temporal distribution of precipitation, therefore, they are exposed to potential risk of decreasing soil water content. Retaining water in root zone and prolonging its availability are crucial to avoid water stress of plants.

Figure 30 provides screenshot of the mechanism of capitalizing available humidity from air and soil by water retainers.

FIGURE 30
Flowchart of water retaining



Source: https://www.waterandsoil.eu/how-it-works/

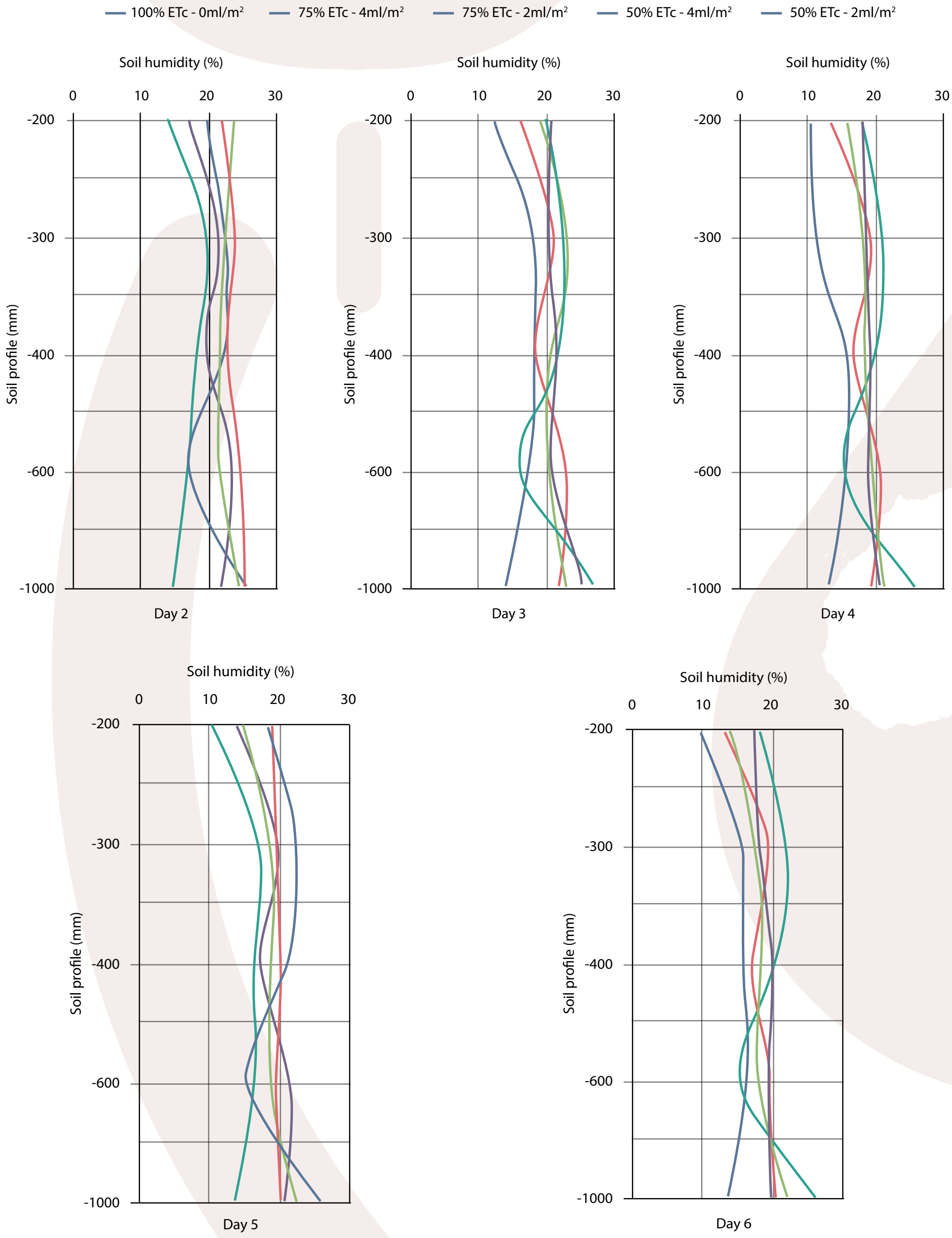
The technology is constructed to trap humidity from both morning dew and soil humidity. The technology consists of organic soil-conditioning product, which can remain effective during 3 months after application. Water retainer bound to roots and soil grains allows the infiltration of water into the soil, while it traps the vapor upward in the capillaries. Through the condensation of vapor streams, the binder of the technology retains the water in the form of droplets for absorption. Given that the technology operates at root-zone level, the effect can be maximized.

Figure 31 presents the impact mechanism of the water retainer on soil humidity according to the White Book of water retainer. Through randomized controlled trial, the effect of conditioning was measured under five different irrigation strategies:

1. Control plot irrigated at 100 percent ETc without water retainer treatment
2. Treated plot irrigated at 75 percent ETc with 4 ml/m^2 water retainer
3. Treated plot irrigated at 75 percent ETc with 2 ml/m^2 water retainer
4. Treated plot irrigated at 50 percent ETc with 4 ml/m^2 water retainer5
5. Treated plot irrigated at 50 percent ETc with 2 ml/m^2 water retainer

The results are presented in two-dimension chart, where soil humidity is indicated at different depth.

FIGURE 31
The impact mechanism of water retainer on soil humidity



Source: Water Retainer White Book.

It can be concluded that water retainer increases the humidity of treated soil compared to the non-treated soil. By the day 5 of the application, the soil humidity of control plot (dark blue line) significantly drops from 20 percent to 10 percent at 200 mm depth.

Exploiting the potential of water retainer technology can provide significant benefits in terms of soil-water balance, plant health, yield, water use efficiency and water productivity per applied water amount. Consequently, it has high potential to increase climate resilience and preserve water resources. The technology can provide affordable solution for farmers in countries with limited water resources. In countries where agriculture relies on precipitation, maintaining soil-water balance is the most appropriate strategy for drought escape.

Case study of Pakistan: in-house field trials in rainfed conditions (extracted from Water Retainer White Book)

Water retainer technology was investigated through replicated field trials for rainfed groundnut in Pakistan. The effect of water retainer was measured on average height of the plant, yield and soil moisture content. The treatment was conducted with six treatment trials and one control farm. The conditioning was applied either at once (1st application) or two times (2nd application).

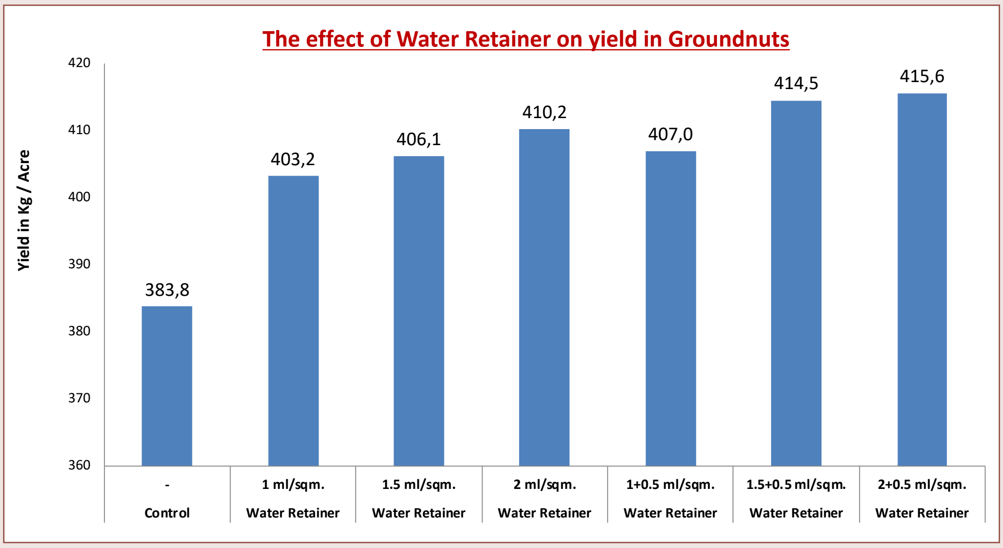
The result of groundnut plant height showed that each monitoring farm reached higher plant height than the control farm. The difference was monitored through 12 weeks and measured in every 2 weeks after application. After maturing, the highest plant height was reached by the one-dose treatment with 1.5 ml/m^2 water retainer.

S.#	Treatment/ Product	Dose/sq.meter (ml)		Average Plant Height (cm)					
		1st application	2nd application	2 WAA	4 WAA	6 WAA	8 WAA	10 WAA	12 WAA
T1	Control/UTC	-	-	7.11	14.33	17.66	17.99	18.33	18.66
T2	Water Retainer – (application with sprayer)	1.0	-	7.33	15.23	18.55	18.88	19.11	19.33
T3	Water Retainer – (application with sprayer)	1.5	-	7.49	15.45	19.33	19.46	19.77	20.11
T4	Water Retainer – (application with sprayer)	2.0	-	7.62	15.24	19.66	19.77	19.87	19.98
T5	Water Retainer – (application with sprayer)	1.0	0.5	7.29	15.01	18.66	18.99	19.76	19.88
T6	Water Retainer – (application with sprayer)	1.5	0.5	7.33	15.22	18.49	18.99	19.88	20.01
T7	Water Retainer – (application with sprayer)	2.0	0.5	7.39	15.11	18.29	18.78	19.33	19.77

The results of soil moisture content in rainfed conditions showed that the soil moisture content was higher in the monitoring fields than the control fields in every case. The trial concluded that the effect of the retaining spans three months from the first application.

S.#	Treatment/ Product	Dose/sq.meter (ml)		Average Plant Height (cm)			
		1st application	2nd application	Before application (15.05.2018)	4 WAA (13.06.2018)	8 WAA (17.07.2018)	12 WAA (11.08.2018)
T1	Control/UTC	-	-	10.4%	12.3%	14.5%	17.2%
T2	Water Retainer – (application with sprayer)	1.0	-	11%	12.6%	14.8%	17.8%
T3	Water Retainer – (application with sprayer)	1.5	-	9.5%	13.3%	14.5%	17.3%
T4	Water Retainer – (application with sprayer)	2.0	-	11%	12.9%	15.1%	17.9%
T5	Water Retainer – (application with sprayer)	1.0	0.5	11.5%	12.8%	14.8%	18.2%
T6	Water Retainer – (application with sprayer)	1.5	0.5	10%	13.1%	15.2%	18%
T7	Water Retainer – (application with sprayer)	2.0	0.5	11.%	12.5%	14.9%	18.4%

The experiment investigated the effect of water retainer on yield. The results concluded that the technology has positive effect on yield. The two-dose application with 2 and 0.5 ml/m2 water retainer resulted in 8.3 percent increase of groundnut yield.



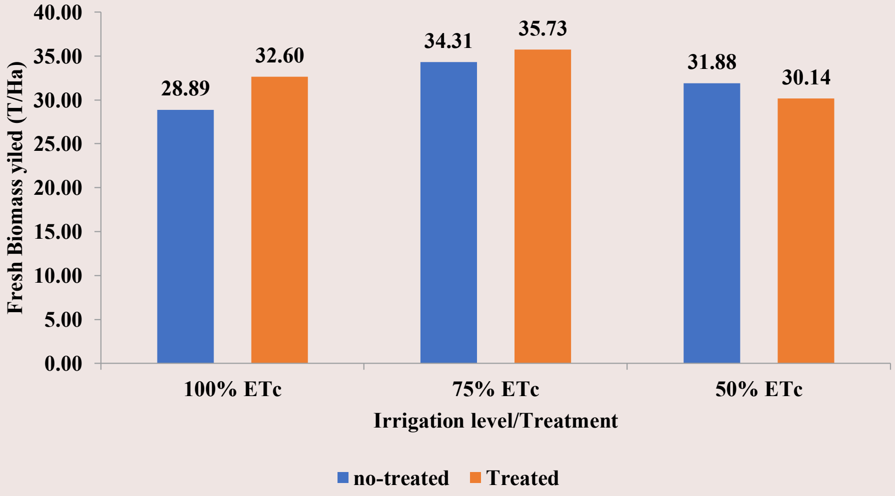
The effect of the water retainer technology has been widely investigated in different climatic zones with substantial water saving. Therefore, the application of water retainer is useful not only for rainfed agriculture, but also to increase the water use efficiency of irrigation systems and water productivity of irrigated farming.

Case study of Morocco: corn production in irrigated area (extracted from Water Retainer White Book)

Experiment with silage corn was carried out in Sidi Allal Tazi of Regional Agricultural Research Center, Morocco. The randomized controlled trial investigated the effect of water retainer under three irrigation strategies: well-irrigated control at 100 percent ET_c, deficit irrigation at 75 percent ET_c and 50 percent, Etc. Treated sub-plots received 2 ml/m^2 water retainer after sowing. The effect of water retainer was measured on fresh biomass yield and water productivity.

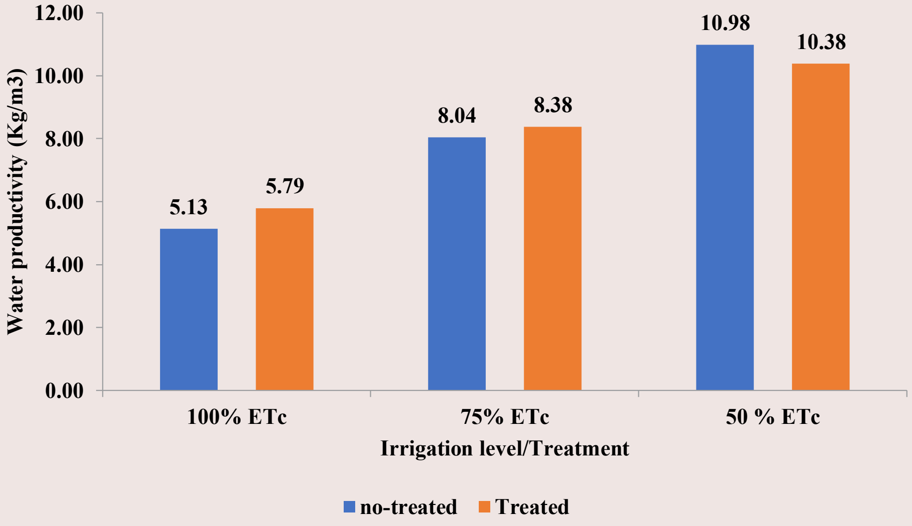
The results of the experiment show that water retainer has yield increasing effect in case of full irrigation and deficit irrigation. The treatment increased soil moisture, plant height, shoot and ears weight, ear to shoot ration fresh biomass yield and water use efficiency under different regimes.

Fresh biomass yield (t/ha) of treated and no-treated plots under 100%, 75% and 50%ETc irrigation regimes



Related to water productivity per applied water amount, the results show positive treatment effect under full irrigation and deficit irrigation.

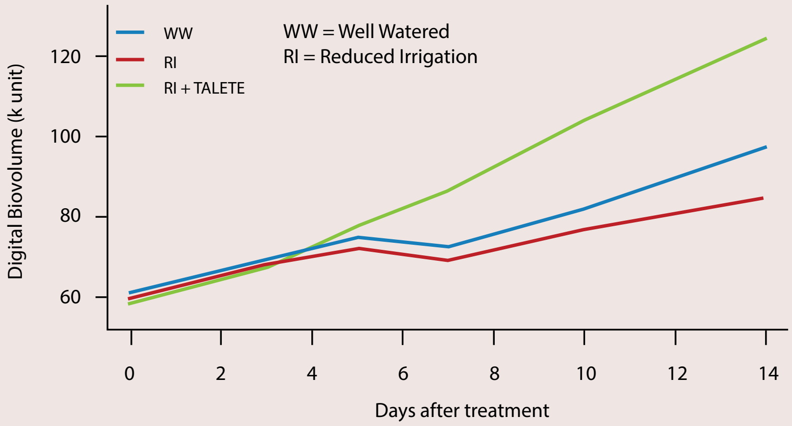
Water productivity (fresh weight FW basis) of treated and no-treated plots under 100%, 75% and 50%ETc irrigation regimes



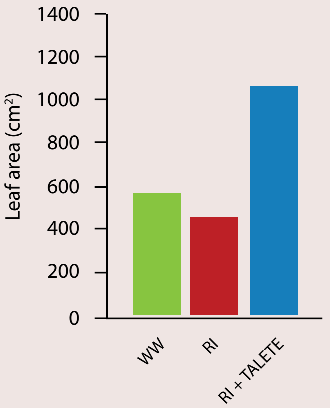
Reduced transpiration – Biostimulants: The other part of crop evapotranspiration, the transpiration, needs to be also addressed in order to minimize the water loss and ensure that water uptake of plants produces the maximum possible biomass. Biostimulants are effective micro-organism to stimulate natural processes to benefit from nutrient uptake, to maximize the effect of uptake, to improve stress tolerance and to enhance crop quality (European Biostimulants Industry Council). In case of insufficient water supply or considerable cost of irrigation, alternative strategies such as deficit irrigation must be introduced. However, farmers do not necessarily have to compromise with reduced yields – even if water supply significantly decreases. According to Genot (2020), available biostimulants can be effective tools to avoid water stress in critical periods of crop growing. Dehydrins and early responsive to dehydration genes play an important role to increase water binding capacity, provide stability to proteins and macromolecules and drive rapid change in the activity of cells depending on the presence, absence, and concentration of water. Biostimulants can play a major role in induction of water responsive genes and in increase in stomatal conductance while increasing photosynthesis (Genot, 2000).

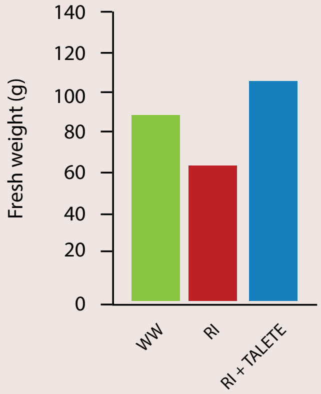
Case study of Italy: Phenomic analysis on tomato
(extracted from Talete: the action item of Valagro's values, Benoit Genot, 2020)

The treatment effect of biostimulants was measured on digital biovolume of tomato in experimental fields. The differences in digital biovolume between control and treated plants were observed. The results showed positive and consistent treatment effect from day 7 of the experiment.



The observed increase in digital biovolume after biostimulant treatment indicated evidenced benefits on plant growth and development under limited irrigation supply.





A number of alternatives to biostimulants exists already, which can effectively help to improve drought resistance by reducing transpiration. For instance, one alternative innovation is the manipulation of stomatal development for stress tolerance. Through the reduction of stomatal numbers, the plants can further improve drought and heat stress tolerance, thus stabilizing yield (Hughes *et al.*, 2017).

SYSTEM-LEVEL INVESTMENT PACKAGE

The investment package is built on the groups defined by the investment evaluation matrix: water tower group, water management group, rainfall management group, and water scarce group. Engineering solutions are systematically collected from existing best practices, adjusted and complemented in order to response to the COVID-19 situation. The package is also complemented with recommendations to tackle increasing water demand by agricultural water use or WASH demand. The analysis includes alignment with the defined country groups according to the vulnerability scale. Although many of these technologies allow sufficient flexibility to contextualize their design, their limitations must be taken into account in order to find the right match between recommended investment and vulnerability.

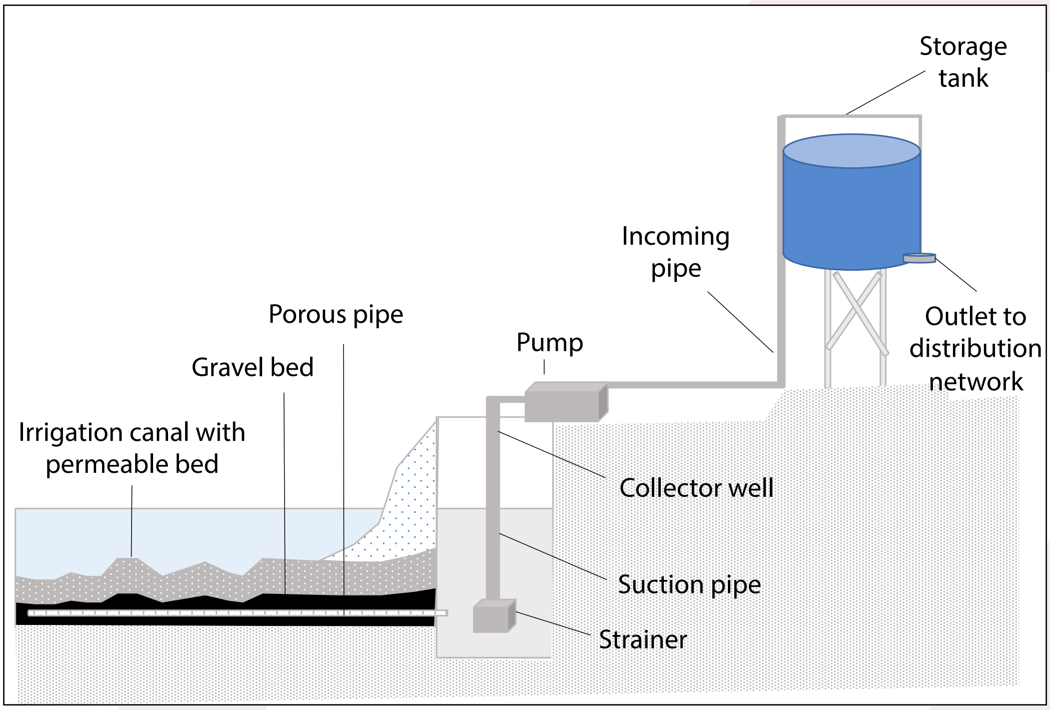
This section is based on a systematic review of existing technologies, which are also showcased in different regions. However, the searches process returned over hundreds of technologies. After reviewing them, selected technologies are presented. It is worth mentioning that this section should be read as a non-exhaustive “toolbox” of potential technologies. In addition, recommended local solutions require feasibility assessment based on multiple criteria. This is particularly important in Africa, where multiple water use has high unexploited potential, although it is not yet sufficiently advocated. Therefore, the further step of SMART Irrigation – SMART WASH approach is to scale the solutions to local level, and work out the detailed design that should properly fit into the given conditions. In order to complement the presented engineering solutions, further documents are proposed, which can provide support in deciding on “fit-for-purpose” practices.

Water tower group

A. Grey solutions

Infiltration gallery connected to irrigation canal by Fadul and Reed in Domestic water supply options in Gezira irrigation scheme (Fadul and Reed, 2010): Options for Gezira irrigation scheme in Sudan were sought, whereas the majority of the villagers in the around 1 200 unregistered villages around the scheme have no access to clean domestic water supply. These villagers rely on the irrigation water of the scheme. As a consequence, over 50 percent of the population is infected with water-borne diseases. One of the proposed technological solution is the infiltration gallery on the main irrigation canal. Along the main irrigation canal, infiltration galleries are installed as multiple water source points for domestic water use. The system is described as perforated pipes laid in a bed of gravel below the bed of the canal. The pipe is connected to collector tank and water is lifted through pump. The theory behind the infiltration gallery is that a soil and gravel bed acts as a natural filter to remove the sediment and bacteria. Since infiltration beds are under the canal, they do not influence the hydraulic characteristics. Figure 32 shows the original sketch of the infiltration gallery. It can be placed at different sections of the canals in order to distinguish the irrigation outlets from the WASH distribution points. A further possibility in gravity-fed system is the underground storage tanks, which can be based on the theory of communicating vessels. This would allow a self-managing system without pumping.

FIGURE 32
Infiltration gallery sketch



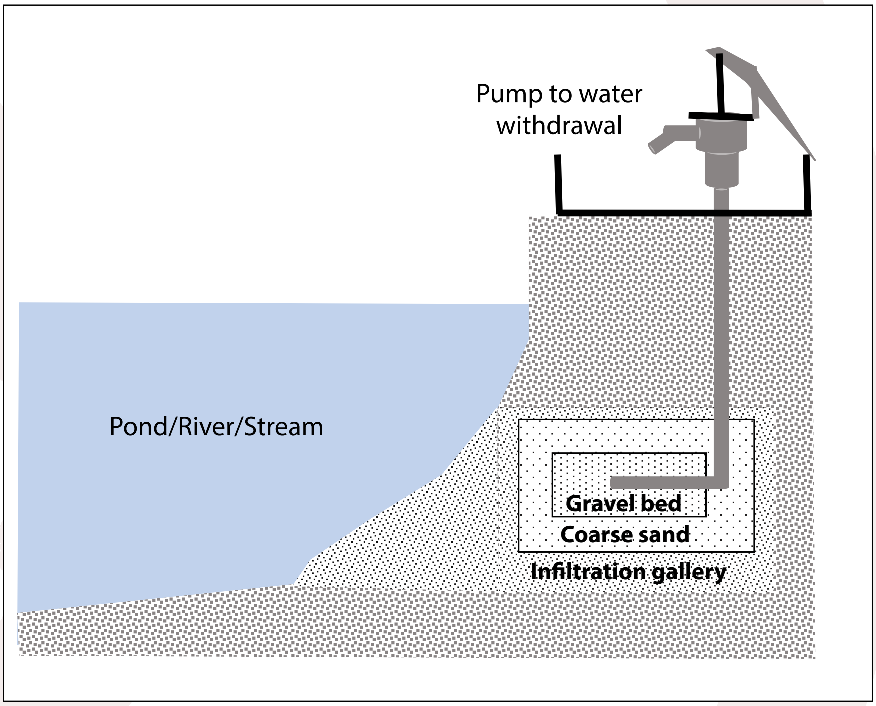
Reproduced from Fadul and Reed, 2010.

The system itself can also be adjusted to provide completely safe water with purification technologies inside the storage tank. Furthermore, sequential storage tanks can further improve the effectiveness of the technology.

Alignment with vulnerability analysis: Recommended groups are Food security group, Redistribution group, WASH group.

Direct water pumping from infiltration gallery - implementation guidelines by WaterAid (WaterAid, 2006): WaterAid Bangladesh provides practical implementation guides for designing infiltration gallery (IFG). The guidelines promote community-managed safe water supply skimmed of the ponds, rivers, streams. The IFG, which can also be modified as riverbed well, runs underground and can be lifted by either manual or automated pumps depending on the depth of the gallery. This type of infiltration gallery is more restricted in terms of site selection, but one of the main advantages is that it does not require distribution pipes. If the irrigation system does not have a long distribution network, but water is sourced directly from the storage or through short canals, the on-spot IFG is more practical. Wherever water quality of the freshwater source complies with the required minimum standards, the treadle pump technique can be a cost-efficient and easy solution for communities to lift water from the gallery.

FIGURE 33
Infiltration gallery sketch

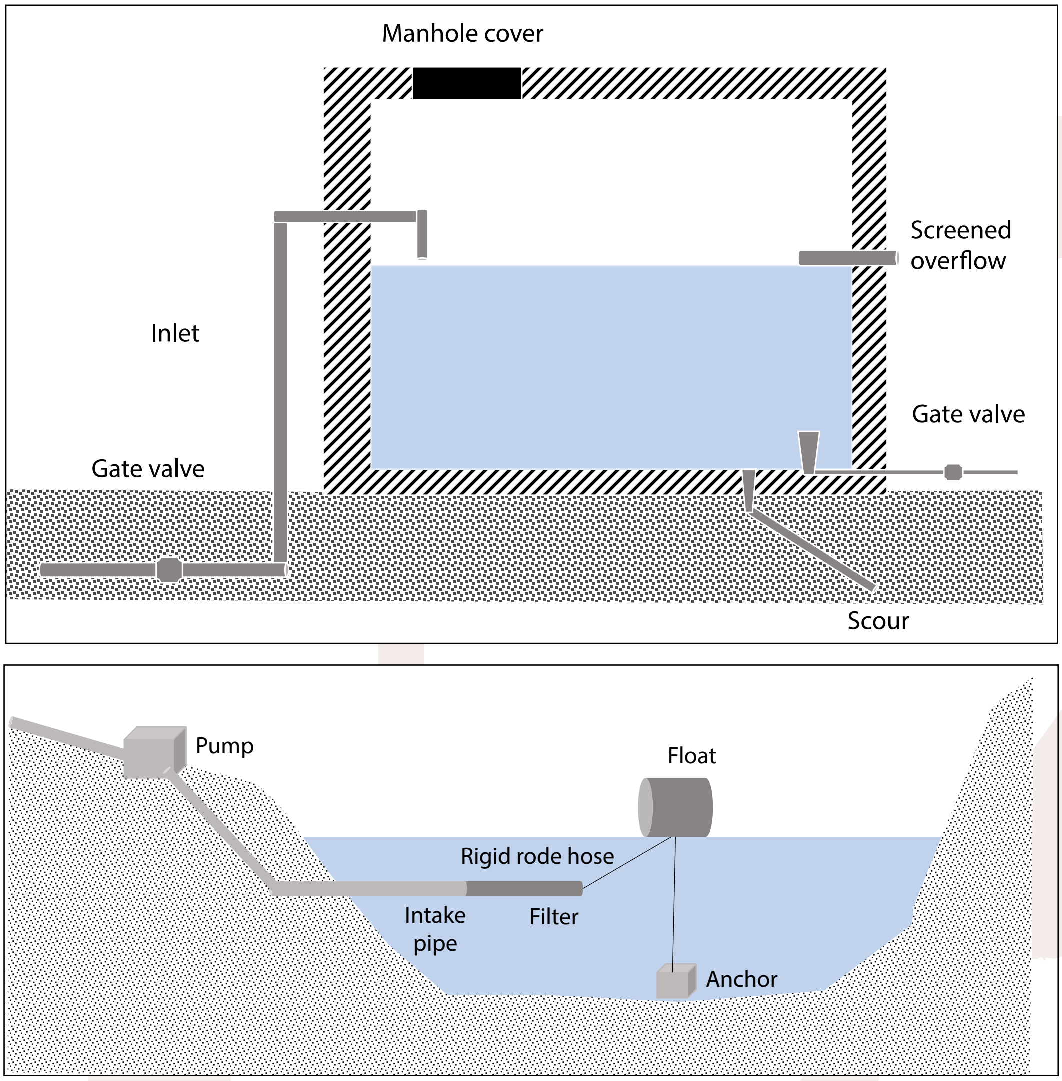


Reproduced from WaterAid, 2006

Alignment with vulnerability analysis: Recommended groups are Food security group, Redistribution group.

Flexible floating type intake in Water for World Technical Note by USAID and Peace Corps (Peace Corps, 1985): The Flexible floating type intake is an easy solution to ensure the water sourcing from the same water level, like syphoning. While suspending a floating object on flexible pipe, the rigid rod keeps the intake pipe under the water level of the pond. In case of large variation of water level, this flexible option can help adjusting the water intake level. However, the technology suggests only a filter at the intake, which might be insufficient to prevent water-borne diseases. Therefore, this technology is recommended to be combined with simple infiltration gallery and storage chamber, in which water can be treated before human use.

FIGURE 34
Flexible floating pipe in irrigation pond combined with storage chamber for cleaning



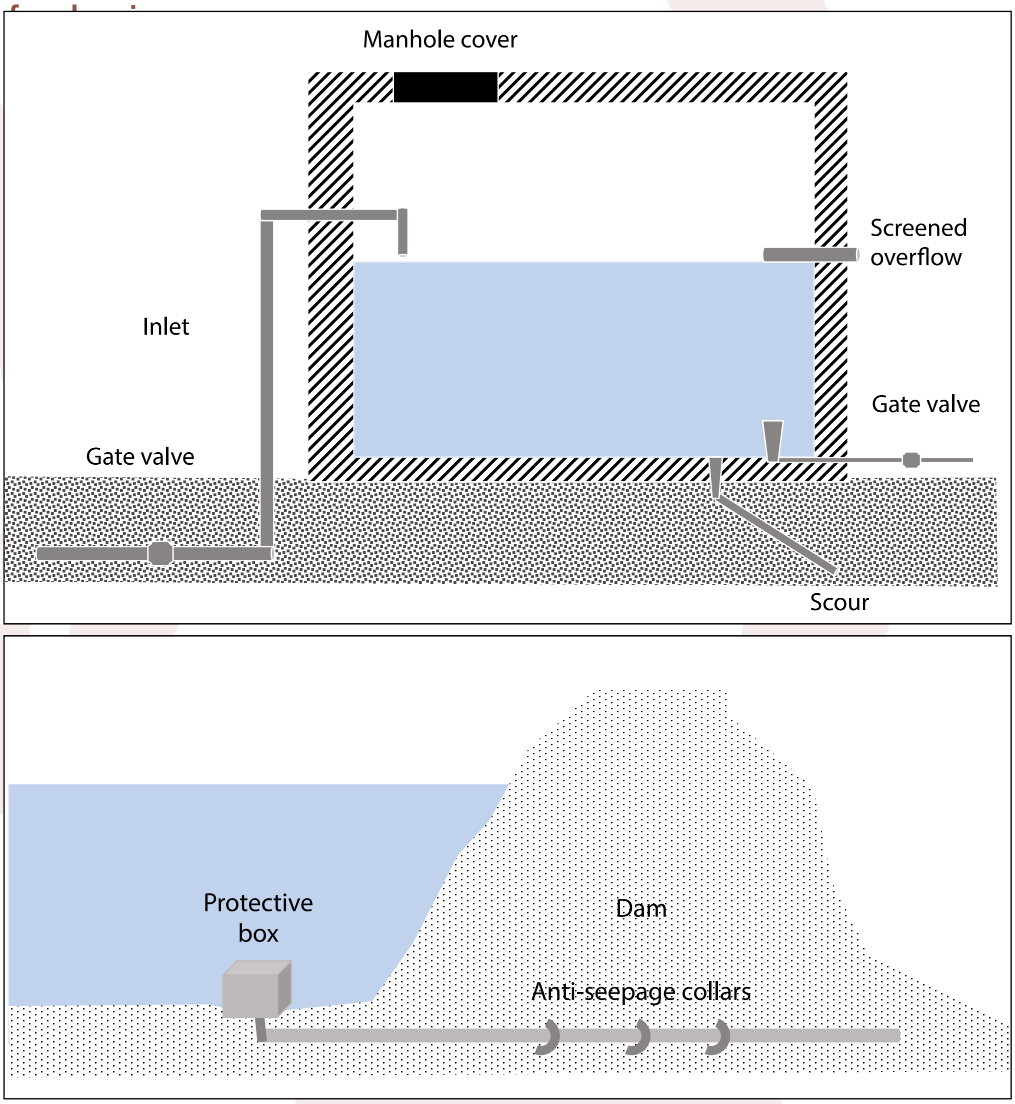
Reproduced from USAID, Technical Note; Peace Corps, Water and Sanitation Technologies, cross-reference in A Layman's Guide to Clean Water.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

Fixed type of intake in Water for World Technical Note proposed by USAID and Peace Corps (Peace Corps, 1985): The fixed type of intake has its advantage in conveying water without pumps. Based on the theory of communicating vessels, water can be delivered directly to the fields. This would save significant energy and release the financial burden of farmers posed by energy costs. In flat areas, where conveyance is not bound by topography, the fixed intake is able to source water even if the water level is low. The other advantage of the solution is that in-built filtering structure can be applied through the conveyance to provide clean water at offtake side. However, this solution is only feasible if the water pond is close to the users, so the conveyance structure is sufficiently short in order to avoid sensitive infrastructure. Similarly to the previous solution, storage chamber for treatment is recommended to ensure the cleaning of water for WASH purposes.

FIGURE 35

Fixed type of intake in irrigation pond combined with storage chamber



Source: USAID, Technical Note; Peace Corps, Water and Sanitation Technologies, cross-reference in A Layman's Guide to Clean Water

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

B. Blue-Green solutions

Integrated wetland and floodplain use as nature-based solution in response to climate change in agricultural water management, fishery, irrigation and paddy rice by Research Institute for Fishery, Aquaculture and Irrigation, Hungary (HAKI – Research Institute for Fishery, Aquaculture and Irrigation in Hungary, (Korosparti *et al.*, 2012): The climate change has unpredictable impact on the flow regimes of major rivers in Hungary. The Tisza River – the second largest flow passing through the country – has been controlled for hundreds of years. The cut-offs of the River's bends resulted in land gain for agriculture and valuable wetlands preserving the ecosystem. However, the upstream deforestations and the unpredictable changes in flow regime have been resulting in larger floods than ever, thus, leaving agricultural lands under water. Beyond flood protection, the Research Institute HAKI has been investigating the opportunity of nature-based solution for aquaculture, fishery and rice production in reformulating flood plains. The integrated solution provides multiple opportunity to use water for non-consumptive fishery and consumptive irrigation and flood irrigation. Although the current production cycle includes merely practices for agricultural water management. The captured runoff after flooding can be also utilized for domestic purposes in countries where safe water is not available. Whereas water resources are permanently available, flows can be controlled and diverted to floodplains for multiple use. The difference between wetlands and floodplains is that floodplains return to terrestrial habitat, while wetlands remain permanently wetted. Both floodplains and wetlands can be used for multiple water use with the restriction that sufficient water recharge must be allowed in order to maintain the water level, thus protecting ecosystem.

FIGURE 36

Integrated water resource management in Hungarian floodplain

©Korosparti

Alignment with vulnerability analysis: recommended group is Food security group.

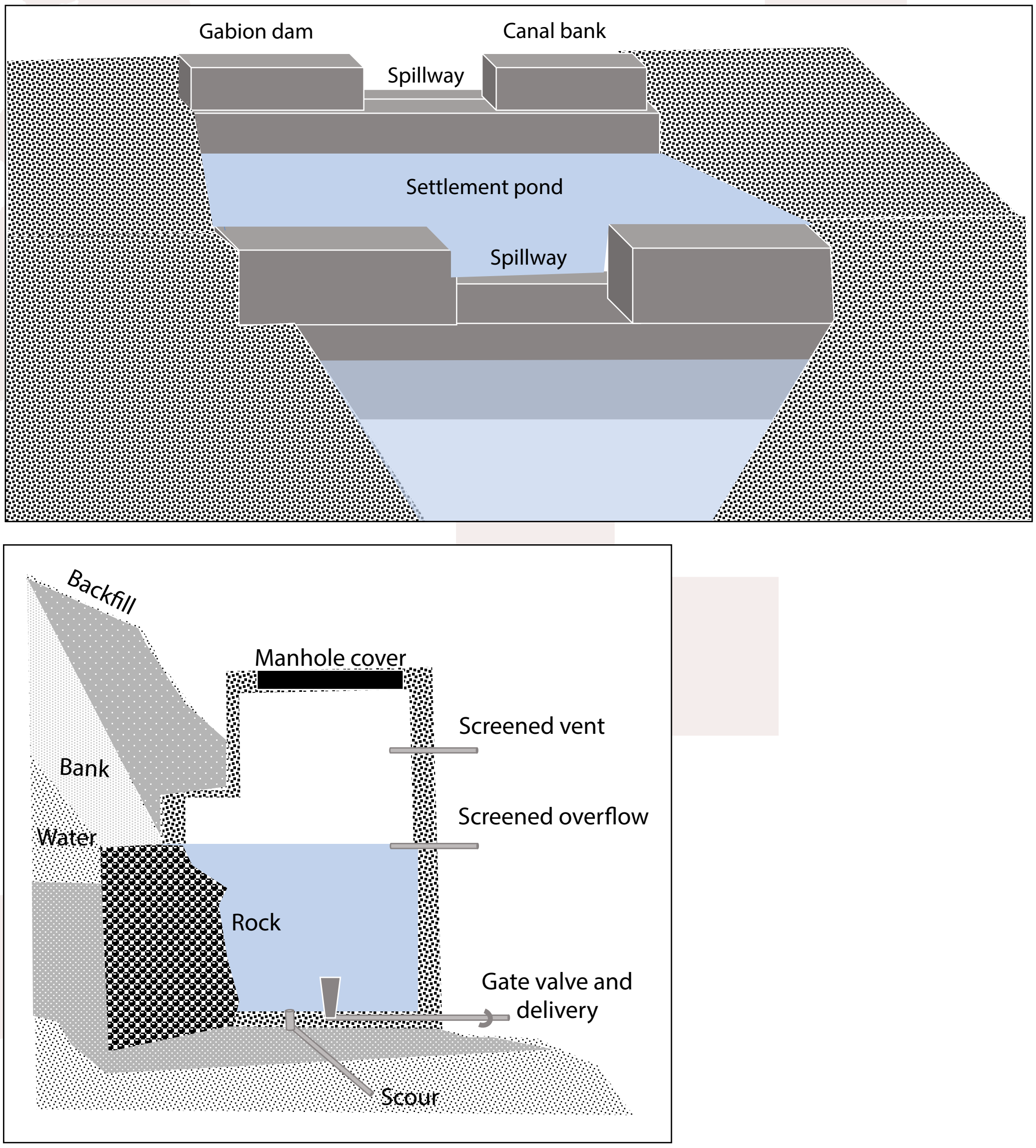
Water management group

A. Grey solutions

Gabion check dams proposed by FAO and USA Indian Health Service, (FAO, Field guide for hill land reclamation and water management; Peace Corps, Water and Sanitation Technologies): Check dams are effective means to control flows. Whereas precipitation is low, and available water supply is based on surface or groundwater resources, the spatial optimization of water resources is important. Check dams designed according to local context enable the storage of water, while they are constructed with overflow spillway to release flow exceeding its capacity. Check dams have several advantages that help natural cleaning of water. Gabions are porous consolidation structures filled with stones. While the upstream part of the dam functions as a sediment settling pond, the passing flow can be further cleaned with filtering structures. Sequential employment of gabion check provides multistage cleaning, thus, multiple water ponds for water withdrawal. Combining the ponds with the above-mentioned infiltration galleries can function as a structure for multiple water use. Peace Corps recommended the solution of USA Indian Health Service, which can be combined with check dams. The storage reservoir is constructed with inlet, delivery, over-flow and drainage pipes. The structure includes valve to regulate the water in the proposed masonry tank, a delivery pipe that can be connected to pipe network releasing flow to different locations, an overflow pipe to release overflow and drainage pipe to drain sludge out of the tank.

FIGURE 37

Check dam constructed to control and store water, combined with appended infiltration tank

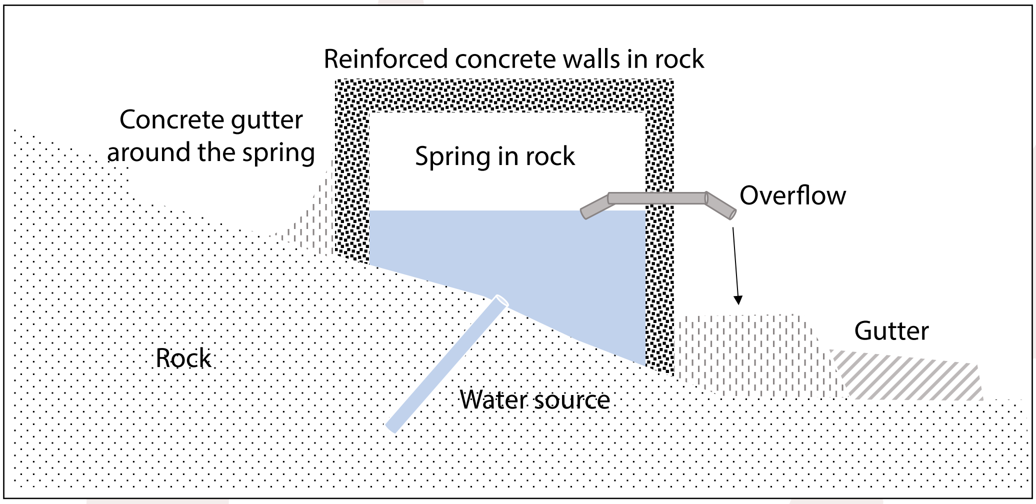


Source: FAO, Field guide for hill land reclamation and water management; Peace Corps, Water and Sanitation Technologies.

Alignment with vulnerability analysis: Recommended groups are Food security group, Redistribution group.

Constructed spring by Salvato, J.A., Nemerow, N.L., Agardy, J. in Environmental Engineering (Salvato *et al*., 2003): The construction and protection of spring is proposed to provide a clean water source for multiple use. By protecting the source from pollution, water can be diverted to different users. While creating diverting ditches, the necessary amount of water can be conveyed directly to WASH purposes, although this requires a pipe network to maintain water quality. The rest of the flow can be conveyed for irrigation purposes through less expensive structures such as irrigation canals. In order to provide safe water, a manhole is recommended for periodic water sampling and bacteriological examinations. The largest advantage is that this technology provides preventive intervention to preserve water quality. Therefore, it is particularly advised in those countries where the risk of water pollution is high. However, if local communities are far from the source of water, the conveyance can be expensive and also vulnerable.

FIGURE 38
Properly constructed spring

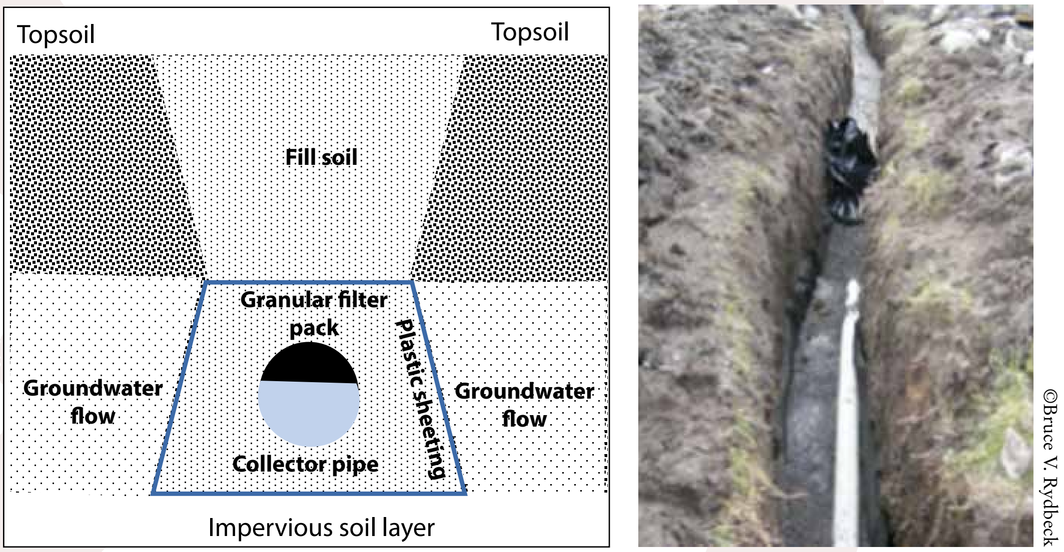


Source: Salvato *et al*. 2003

Alignment with vulnerability analysis: Recommended groups are Redistribution group, WASH group.

Trench spring collector proposed by Rydbeck and Guapi in improved techniques for spring protection developed by rural Ecuadorian communities (Rydbeck and Guapi, 2012): The springs can be also protected in situ to provide clean water supply. Trench spring collectors capture the groundwater flows in the permeable strata under the topsoil. The trench collectors have an advantage in presence of steep slopes and in those places where the source of spring cannot be accessed easily. They provide more protection for water than the surface infiltration gallery, since they remain underground. Moreover, trench collectors are less influenced by the topography since they can be constructed with proper levelling. Many countries have significant spring water resources hidden that can be better utilized with proper and protective infrastructure. Similar to the constructed spring, the trench collector protects the water sources and can be connected to a larger network to deliver water to end-users. In addition, trench collectors are more flexible since water can be sourced from multiple locations of the collector, thus providing multi-outlets to different uses.

FIGURE 39
Cross-section of a typical trench spring collector and construction of trench collector



©Bruce V. Rydbeck

Source: Rydbeck and Guapi, Improved techniques for spring protection developed by rural Ecuadorian communities.

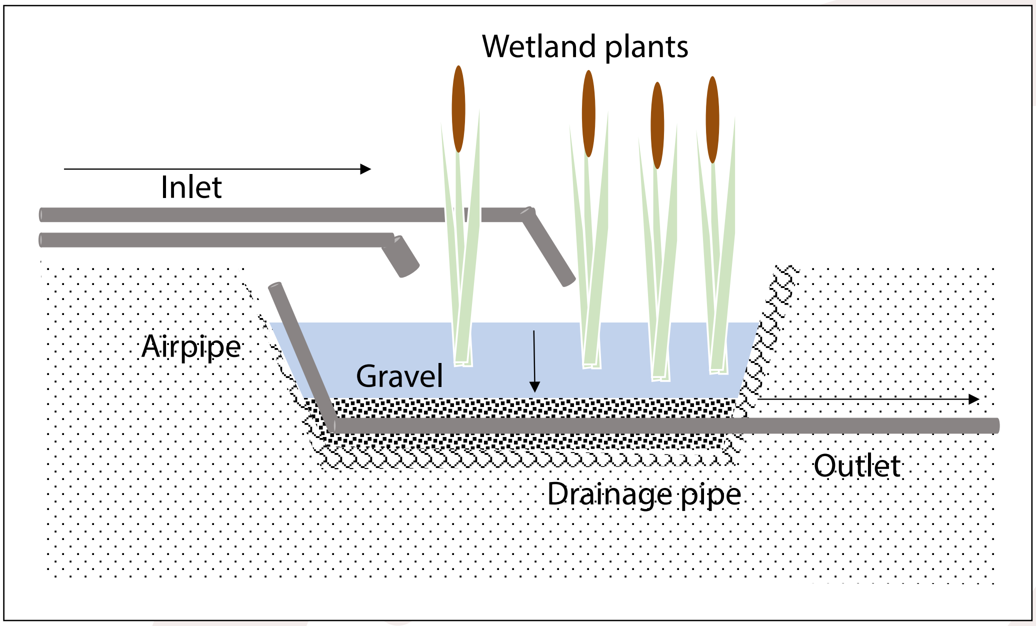
Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

B. Blue-Green solutions

Constructed wetland and root zone technology by (Eawag *et al*., 2013) in Sustainable Sanitation and Water Management: Wetlands are widely applied as ecological solutions for wastewater management. Constructed wetlands are based on root zone technologies to reduce biochemical oxygen demand, suspended solids and pathogens in contaminated water. The wastewater is conveyed into constructed ponds that purifies the water through biological procedures to achieve higher quality effluent. Constructed wetlands are usually equipped with mechanical filters, while the biochemical cleaning is done by the roots of wetland plants and clay bedding. Wetlands can be constructed in the form of free surface flow, horizontal subsurface and vertical subsurface system. In urbanized areas, where domestic water is considered as source of irrigation water or vice versa, wetlands are simple, inexpensive and natural solutions for treatment. Often connected to other treatment facilities, such as septic tanks, filters or treatment plants. Constructed wetlands are optimal not only for multiple water use, but also to produce biomass for energy sources. Depending on the type of used plants – usually reeds or energy plants – the cutting of the plants can provide cheap energy for communities.

However, wetlands are only sustainable if the inflow is maintained at the required level and water loss through evaporation and evapotranspiration can be allowed. Moreover, the design of wetlands must consider the peak water supply in order to avoid flooding or overtopping.

FIGURE 40
Constructed wetland in surface system



Source: SSWM Toolbox, Eawag, Stauffer and Soubler.

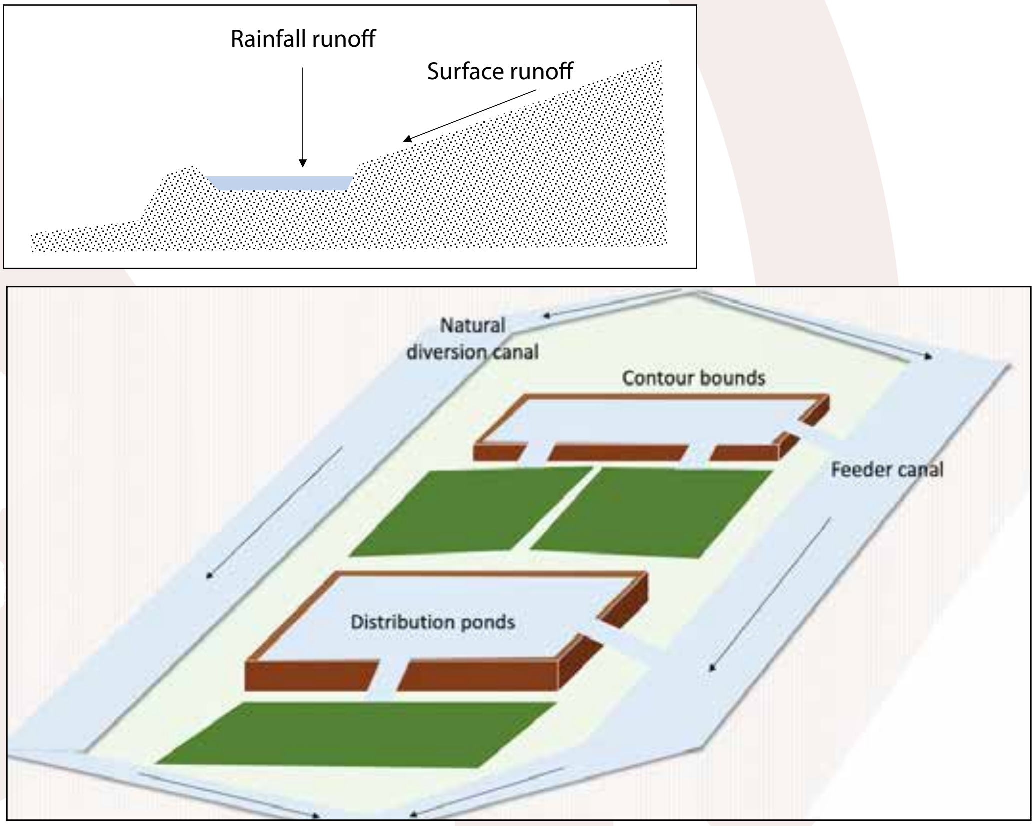
Alignment with vulnerability analysis: recommended groups are Food security group and Redistribution group.

Rainfall management group

A. Blue-green solutions

Rainfall harvesting ponds by FAO (FAO, Pond construction for freshwater fish, Training Series): Water harvesting ponds are constructed to collect, convey, and store rain. Similar to the check dams and storing ponds of surface water, rainfall ponds are effective means to capture rainfall and surface runoff. By considering the temporal and spatial supply of rainfall, water retaining can be utilized in multiple ways such as groundwater recharge, underground storage, and surface ponds. However, rainfall ponds require water treatment in order to provide safe water for WASH. Surface methods can apply the same infiltration gallery technology as the surface runoff ponds. Furthermore, the stored water can be diverted into main distribution points, each of them supplying related communities. The distribution of harvested water provides also the possibility to distinguish water for irrigation and water for WASH. Distribution ponds for WASH purposes can be connected to treatment structures in order to provide safe water. Distribution ponds for irrigation can be diverted to the lands. This setting optimizes the water supply according to the capacity of treatment infrastructure.

FIGURE 41
Rainfall harvesting pond

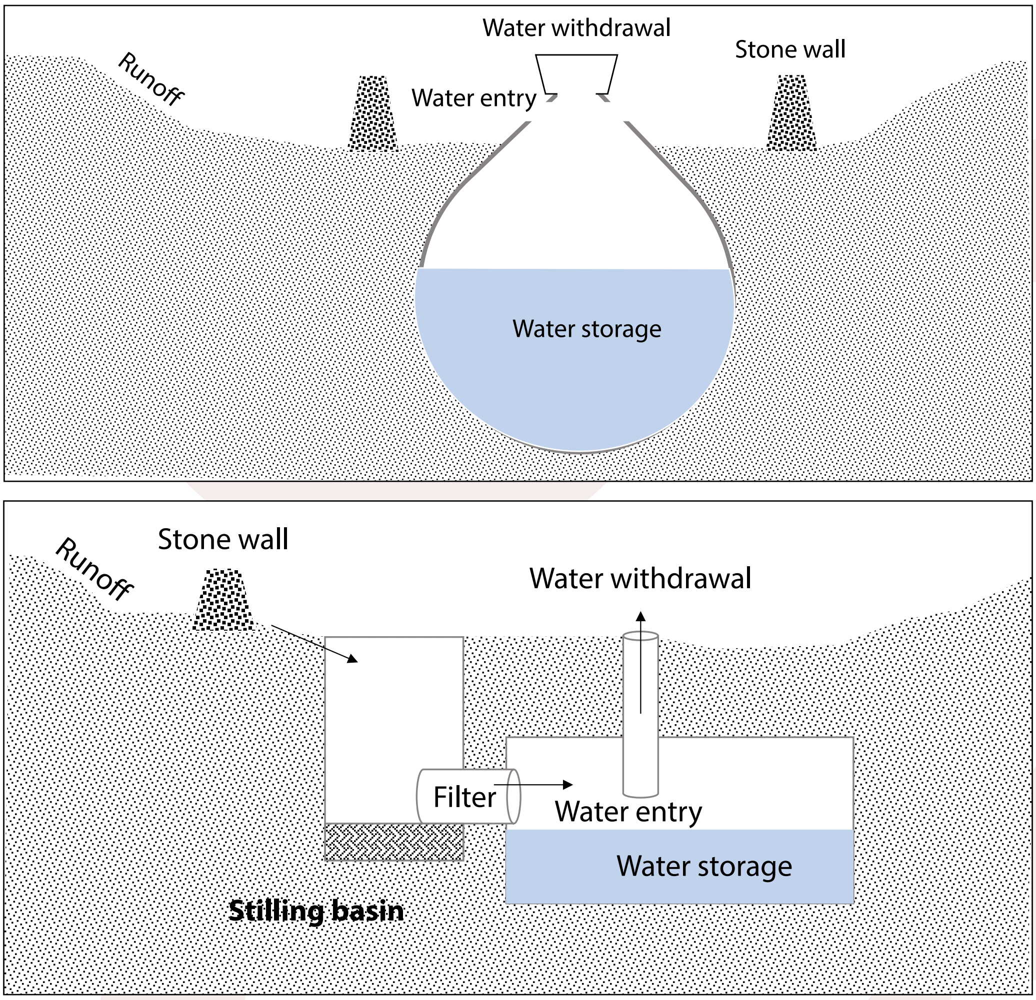


Source: FAO, Pond construction for freshwater fish.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group.

Underground rainfall harvesting by Oweis, Hachum and Bruggeman in Indigenous water-harvesting systems in West Asia and North Africa (Owies *et al.*, 2004): Underground storage of harvested water has multiple advantages in hot climatic zones, whereas evaporation of surface water is high. Underground cisterns have been constructed since ancient times. Revamping this traditional method has potential to increase the water availability throughout the year. Multiple cisterns can be also deployed next to each other, while separating the water for multiple uses. Similar to the urban treatment systems, the cistern can be disinfected such as shallow wells. This treatment can ensure that safe water is stored in the cistern and can be readily used by the community. The water can be fetched either by manpower, manual pumps or diesel pumps. Although cisterns have many advantages in terms of minimum evaporation losses, easy disinfection and maximum water capture, the capacity of the cisterns is usually small, therefore it is recommended only for small-scale agriculture. Furthermore, the design capacity must follow the peak rainfall regime in order to be fully functional. Counter bounds around the water withdrawal points must be constructed to preserve the overflow.

FIGURE 42
Traditional cisterns for rain harvesting

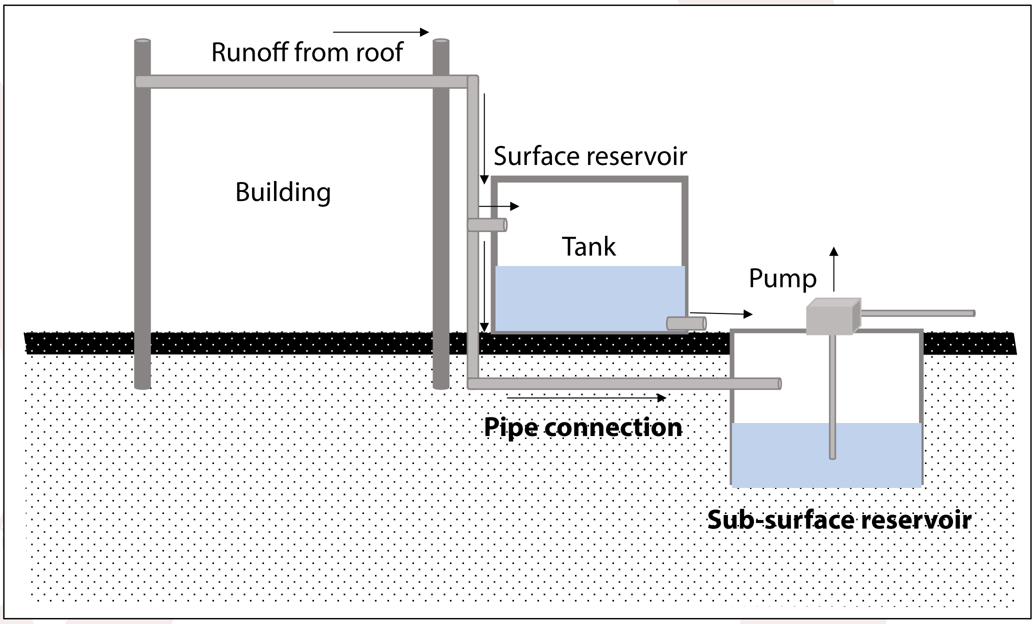


Source:Oweis *et al.*, 2004.

Alignment with vulnerability analysis: recommended groups are Redistribution group, WASH group.

Domestic rainfall harvesting by (Oweis *et al.*, 2004) in Indigenous water-harvesting systems in West Asia and North Africa: Solutions were providing for household cisterns in those areas where agriculture is carried out in urban areas. Rooftop rainfall harvesting is largely practicing for domestic water supply. However, the practice can be adopted for multiple water use. The rooftop runoff can be conveyed to multiple tanks: surface reservoirs and subsurface reservoirs. The surface tank applied for irrigation purposes can be connected to conveyance systems such as open canals, while the subsurface tank can be treated through disinfection wells. This sequential installation of tanks can help prioritizing the water use since subsurface reservoir is always filled even if the surface reservoir is still not operated at its maximum capacity. The pump connected to the subsurface reservoir – either manual or electric – can provide clean and freshwater if needed. Similar to other cisterns, the capacity of the system is small and must be designed according to peak rainfall supply.

FIGURE 43
Traditional rooftop technology for rain harvesting

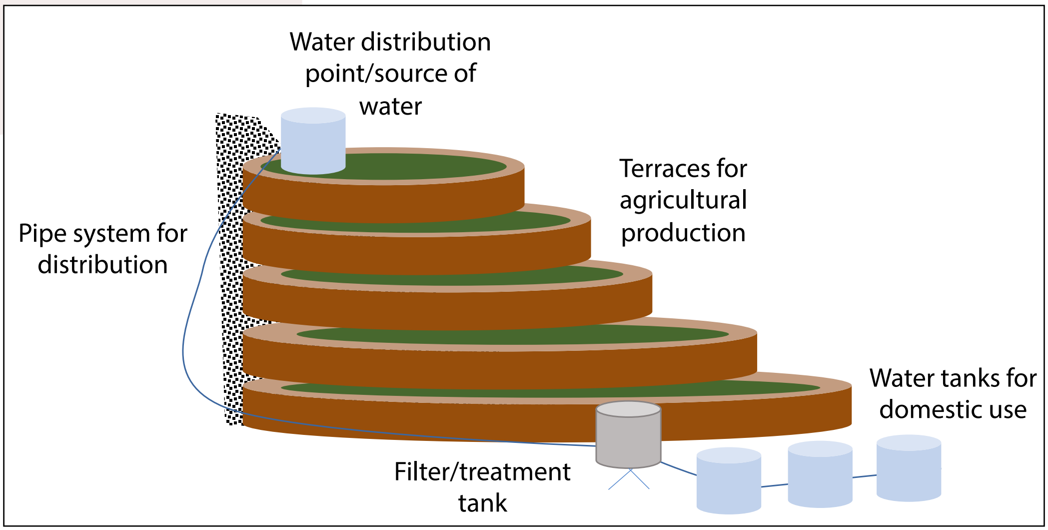


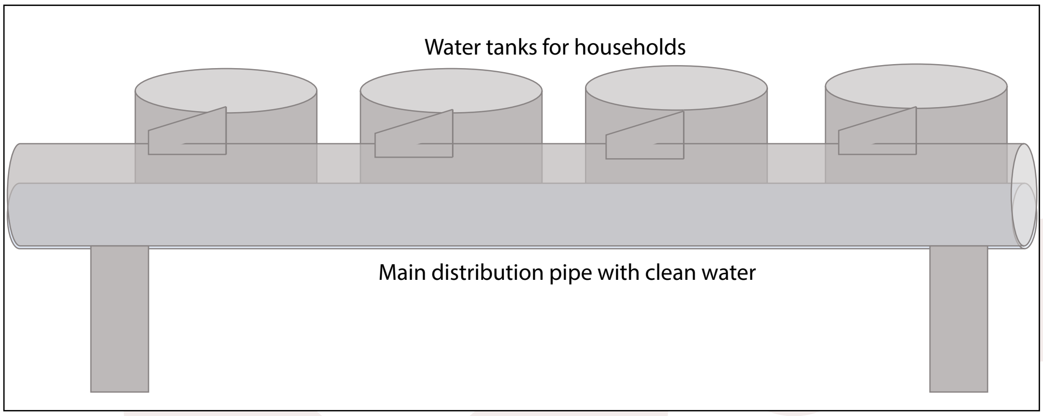
Source: Oweis *et al*., 2004.

Alignment with vulnerability analysis: recommended groups are Redistribution group, WASH group.

Terraces for multiple water use proposed by FAO and USA Indian Health Service, (FAO, 2020-g). Traditional terraces are widely practiced solutions to capture rainwater and surface water runoff in hills and mountainous areas. While terraces can be used for cropping, water tanks installed on the top or constructed spring can preserve water quality for domestic use. Main water distribution points can be connected to pipe systems delivering water to households and canal systems diverting water through terraces. After filtering or treating the delivered water, sequential water tanks on main pipes can be deployed to serve households directly.

FIGURE 44
Terraces for irrigation and multiple water distribution tanks for household purposes





Source: FAO.

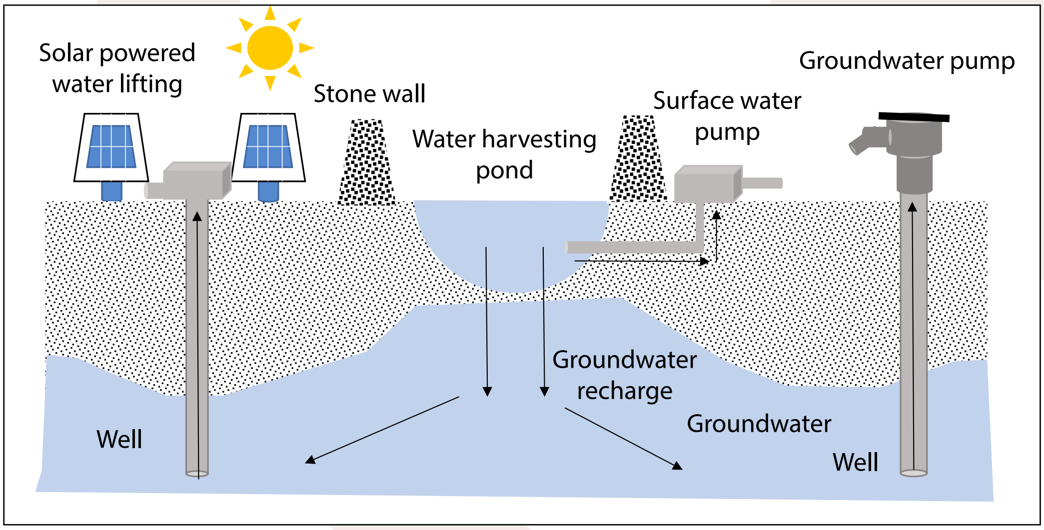
Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

Water scarce group

A. Grey solutions

Three-pronged approach by FAO (FAO, 2017-a): FAO implemented a project in Jordan to introduce combined application of techniques for sustainable and efficient use of agricultural water resources. The water harvesting component of the project constructed a harvesting pond, storing rainfall and runoff water. The conjunctive use of water includes the surface water from the pond and groundwater resources lifted by a solar-powered system. The optimal combination of rainfall water and groundwater preserve the vulnerable groundwater resources, minimizes the undesirable physical and environmental effects and balances the water demand and supply. The system is equipped with water level logger to assess the depth of available groundwater sources. This centralized monitoring system helps maintaining the recharge of groundwater resources, thus avoiding overexploitation. In order to minimize the evaporation losses, the project also deployed drip irrigation in the area. The system combined with treatment unit can be distinguished for both irrigation and domestic use.

FIGURE 45
Sketch of three-pronged approach schematic overview and field implementation

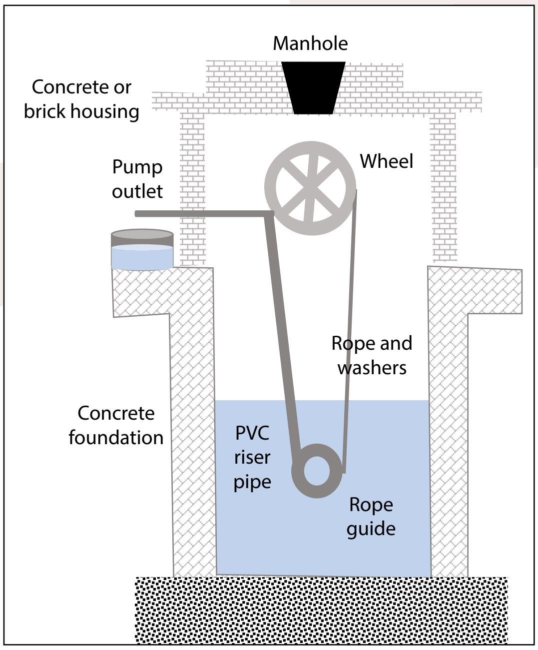


Source: FAO.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

Elephant pumps by Pump Aid, Water for Life (Pump Aid, 2019): Pump aid launched its first elephant pump project in 1998 to address the water security and safety issues in Malawi. Since then, the charity group raised funds to deploy more than 32 000 elephant pumps all over in Africa. The relatively simple design of elephant pumps allows sufficient amount of water for both irrigation and domestic use. Unlike many other manual pumps, elephant pumps have a large delivery capacity (1 l/s). Another advantage, as compared to fixed pumps, is that the sump can be deepened down to 50 m in case of dropping water table. The manually operated pumps do not require excessive human power. Moreover, the pump can be connected to solar or wind power. In water scarce areas, where households and irrigation both depend on groundwater, the elephant pump is an optimal solution to fetch water Furthermore, groundwater tables can be monitored in order to avoid overexploitation.

FIGURE 46
Elephant pump design



Source: Pump Aid.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

B. Blue-Green solutions

Fog water harvesting by UNDP (UNDP, 2016): Countries without enough water resources and rainfall are increasingly encouraged to transform dew and fog into water. Fogs have the potential to provide freshwater in drylands, mountains and coastal areas through inexpensive methods. The mesh net is constructed to capture the fog carried by the wind and collect it in underlying gutters. The pipes then lead to water to storage tank. The easy-to-maintain structures supply water for both irrigation and WASH use. Moreover, harvested fog has a positive impact on ecosystems while counterbalancing desertification. Harvested water can be readily used or can recharge the groundwater. Furthermore, the technology can be connected to pipe networks to convey water directly to the users or to the fields. UNDP project in Yemen showed promising results of fog harvesting. According to the reports, 3x2 meter mesh screen to condense the fog can provide enough drinking water for a family of seven in a local context. This innovative idea is still in its kick-off phase, thus requires the investigation of its local adaptability.

FIGURE 47
Fog harvesting screen in Yemen

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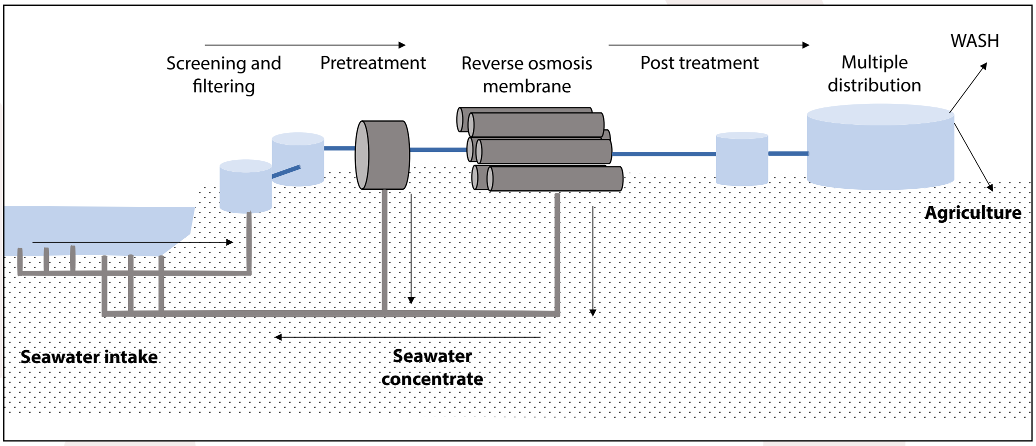
Alignment with vulnerability analysis: recommended group is WASH group.

Desalination of saline water by Beltrán, J.M., Koo-Oshima, S. and Steduto, P., Land and Water Discussion Paper 5 (Beltrán – Koo-Oshima, 2004): Water desalination is an increasingly popular technology in water-scarce regions, where desalination was introduced primary for drinking-water supply. However, agriculture remains the main driver of water use in developing countries, accounting for more than 80 percent of total water withdrawal in Africa and Asia. Therefore, the investigation of its potential for agriculture is a milestone to accommodate the rapidly advancing technologies for both agricultural and WASH uses such as electro-dialysis and reverse osmosis methods. Although the economic feasibility of the desalination is much argued, the strong efforts put into the development of the technologies have already showed promising results. For instance, the recommended use of renewable energy can significantly decrease the operating costs. Furthermore, the design of plants that considers the economies of scale can provide a viable business model. However, seawater concentrate must be treated carefully to reduce the environmental impacts. Therefore, the technology is recommended only if sufficient capital is available to design high-performing plants, if the produced revenue of cropping and WASH services is sufficient to cover both investment and operating costs, and if the environmental impacts can be contained. Desalination plants can provide water for both sectors at the same time through multiple distribution of water through separated conveyance systems.

FIGURE 48
Reverse osmosis technology for desalination

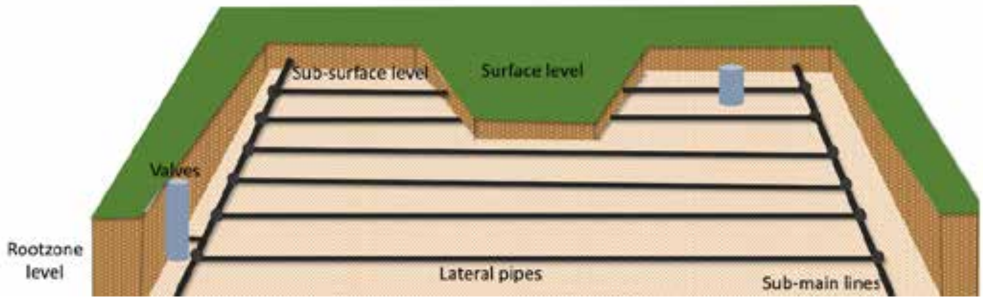


Source: Sydney Water/AAP, Prevention Web, The Conversation Media Group, https://www.preventionweb.net/news/view/63628.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

Domestic wastewater reuse in sub-irrigation systems as nonconventional water resource management by University of Utrecht in combatting global water shortages: Domestic wastewater in underground irrigation (Narain-Ford, 2019): Wastewater reuse is becoming a frequent subject of hot debates as nonconventional water resource use is gaining popularity in the light of water scarcity. The opinions are distinct, as well as the country policies related to wastewater reuse. Solutions were provided tackling the main concern of the topic by claiming that sub-irrigation systems have no direct contact between human and water. The soil acts as a buffer and filter through break down and minimizing the spread of chemicals. The sub-surface drip system is fed by domestic collector pipes and provides water directly at root zone level. However, the safe use of wastewater depends on many factors such as type of pollutants, chemical contamination, potential of antibiotic resistance etc. Therefore, the technology is only recommended if wastewater quality is under monitoring. If wastewater does not reach the minimum standard requirement, its treatment is necessary before application.

FIGURE 49
Sub-surface irrigation system



Source: Narain-Ford, 2019.

Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

IMPROVING WOMEN'S LIVELIHOOD

Hippo water roller by Hippo Roller social enterprise (Hippo Roller: https://www.hipporoller.org): Market of water roller grew out from the idea to help rural poor, who used to walk tens of kilometers per day to fetch water, and carry heavy bottles home. With its 90-liter capacity, it can serve a household of up to seven individuals while releasing the pressure on women, since 90 percent of water collected for homes in Africa is carried out by women, according to UN DESA. Therefore, such support can significantly improve women's working conditions. Beyond the household need, hippo roller is sufficient for small-scale farming and gardening. The hippo roller can last 20 years, thus, greatly exceeding the average useful life of any plastic material. It is also made from 100 percent reusable and recyclable plastic in line with sustainability requirement.

FIGURE 50
Woman rolling hippo water can

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Alignment with vulnerability analysis: recommended groups are Food security group, Redistribution group, WASH group.

SUPPORTING DOCUMENTS

Many stocktaking documents are already available, and provide a thorough assessment of existing technologies. The number of technologies is ample and all technologies can be turned into different alternatives. The presented "toolbox" should, therefore, be seen as a dynamic process that can be extended over time. The current Discussion Paper should be considered as a living document to be regularly reviewed and updated. This iterative process would require a continuous follow-up based on desk research, field experiences or innovation incubation. More references are provided below to guide the identification of such technologies. However, it must be noticed that these documents are written in different contexts and only those in line with the objective and twin-track approach of SMART Irrigation – SMART WASH should be taken into consideration:

The series of source books of **alternative technologies for freshwater augmentation by the United Nations Environment Programme** present a number of feasible technologies (UNEP, 1997). The sourcebooks incorporate four major chapters: freshwater augmentation technologies, water quality improvement technologies, wastewater treatment technologies and water conservation. From large-scale to micro-scale technologies, the recommendations are analyzed in technical sheets including the technical description, sector, extent of use, O&M, level of involvement, costs, effectiveness of technology, suitability, cultural acceptability, advantages, disadvantages, further development of technology and information sources. The documents also present case studies of implemented technologies in different countries, thus guiding the readers to understand both the potential and limitation of technology deployment.

Rainwater Harvesting Handbook from Assessment of Best Practices and Experience in Water Harvesting by the African Development Bank gives detailed descriptions of a number of feasible solutions related to rainwater harvesting in Africa. Starting with the overview of water harvesting concepts (domestic water harvesting, surface catchment, small scale dams, micro catchment and external catchment), the document provides a multi-criteria framework to select appropriate solutions. Not all the solutions are feasible for multiple water use, (e.g. in-situ water harvesting is an on-farm technology that does not allow to allocate water to different uses). However, the document indicates the engineering solutions that are appropriate for multiple water use. Based on a case study approach, the in-depth technical description is given for each technology, similar to the above-mentioned UNEP document. Setting a strong scope on the geographical focus, the Handbook focuses only on the available solutions in Africa. This illustrative Handbook provides strong basis for scaling the technologies to local level and for the identification of potentials and limitations in specific contexts.

FAO Land and Water Division compiled and published a comprehensive webpage on effective response strategies to COVID-19: **The FAO Land & Water response to COVID-19**. The webpage details the water-related actions along ten thematic areas to reinforce integrated system approaches to sustainable agricultural land, water and soil management. A number of the thematic areas belongs to the field of water management: home gardens/vertical farming, hydroponics and aquaponics, solar-powered irrigation, waste-to-resource actions, building water access through multiple water use, applied digital technologies, water quality and food safety. Each topic incorporates a vast body of knowledge, practice and experience, which can be further elaborated to find appropriate technologies in the framework of SMART Irrigation – SMART WASH.

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Conclusions

The SMART Irrigation – SMART WASH approach is developed to provide a response to the pandemic crisis within its impact on health and food production. The harmonized development of water resources through multiple water use techniques plays a key role to mitigate the adverse impacts in developing countries, whereas food production systems are often fragile, the countries rely on import to meet domestic food demand, access to safe water is not available or affordable, health systems are underdeveloped, and institutions are too fragile to establish appropriate infrastructure. The analysis endorsed the importance of complementary interventions between emergency and development projects to reinforce each other's' objectives. The SMART Irrigation – SMART WASH concept sets a scope for the formulation of development strategies.

The analysis started with the assessment of countries' vulnerability based on objectively defined indicators to decide on the potential geographical focus of the interventions. The indicators were selected according to their relations with food production, fragility, and health. The methodology of indicator-based vulnerability assessment is flexible enough for out-scaling and up-scaling. However, their selection must be well-balanced in order to avoid biasness to any of the sector. The countries were assessed based on their scale of vulnerability to food insecurity or health system fragility, in order to understand their investment needs. Afterwards, the spread of pandemic was analyzed up to date. The findings reiterated the concern of Africa CDC: "measures can have adverse consequences for social and economic activity that could outweigh health benefits, especially in resource-constrained settings". The map of vulnerability was overlapped with the map of pandemic risk in order to find the geographical hotspots. The overlap showed that due to the different levels of country development and pandemic spread, Triangular or South-South cooperation are the most effective investment strategies to support countries. This development concept at regional level would certainly help to realize expected benefits of development projects.

Based on the vulnerability assessment, a cluster analysis was performed to sufficiently reduce the numbers of required investment packages by pooling countries into characteristics-based clusters. The two major outcomes of using cluster analysis are: 1) the described typology of groups, and 2) the defined number of groups with similar countries. Three types of clusters were identified, grouping countries with similar pattern of outperforming indicators: Food security group, Redistribution group, WASH group. The clustering helped assigning a sufficient weight to the two sectors (irrigation and WASH) while formulating the investment packages.

The analysis included proposed investment directions, based on the climatic and hydrological analysis of countries. Through a water balance approach, water requirement and water supply were evaluated in Africa. Both side of the equation incorporated the irrigation and WASH-related demand and supply. The water requirement analysis concluded that evapotranspiration-reducing investments can maximize the benefit of water. The water supply defined four investment categories to guide the possible engineering solutions: water tower group, water management group, rainfall management group and water scarce group. The investment categories were evaluated by investment principles of four dimensions: water resources endowment, socio-economic, investment and engineering. The analysis provides a toolbox of SMART Irrigation – SMART WASH solutions, including innovative techniques and methods. However, this toolbox is a dynamic process, which should evolve over time.

One of the promising directions is to extend the scope of the paper by including a wider range of WASH sector (i.e. bio-solid, water quality considerations or energy nexus). The extremely diverse field of water management, indeed, develops constantly. As new fields of sciences, innovations, technologies are emerging, the need for more interdisciplinary approaches is increasingly growing. Therefore, it is recommended to see the current paper as a living document that can always extend its coverage.

The analysis emphasized that investment in reducing water requirement requires on-farm technologies, while investment in water supply should be scaled at system level. From the on-farm investment side, two techniques (water retainer and biostimulants) were introduced in order to minimize the evaporation and transpiration – together evapotranspiration. The resulting significant water saving can be re-allocated to WASH purposes, thus creating an optimal balance between the two sectors. The system-level development provided a stocktaking of existing and potential engineering solutions to manage water resources per investment group (water tower, water management, rainfall management and water scarce). Finally, the engineering solutions provided recommendations on matching investment with the defined vulnerability groups (Food security group, Redistribution group and WASH group).

In conclusion, the discussion paper of SMART Irrigation – SMART WASH:

- Provided a methodology to define the geographical focus of multiple water use investment for mitigating the pandemic crisis;
- Conducted a clustering analysis to define country groups with similar performance in irrigation and WASH sectors;
- Analyzed the climatic and hydrological background of countries to guide engineering solutions;
- Defined the investment criteria based on climate and hydrology; and
- Developed investment packages in line with investment criteria and country clusters.

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16
LAND AND WATER DISCUSSION PAPER

SMART IRRIGATION SMART WASH

Solutions in response to the pandemic crisis in Africa

Uncertainties related to the impacts of COVID-19 on daily life are increasingly growing. Inherent effects have grown beyond the well-defined spear of health risks and have shocked the livelihood and food security in several countries. Particularly in the poorest countries, the impact is more devastating due to the limited availability of resources to slow down the spread of the disease. These countries require immediate actions to safeguard food security and human health. Irrigation has a great role in improving crop productivity and ensuring food security. However, expanding irrigation could impact the availability of water for sanitation and hygiene which has a central role in slowing down the spread of the disease. It is, thus, clearer that irrigation development should also comply with the requirement of extended need of water for sanitation and hygiene. Developing multiple water use would certainly allow to fight the pandemic while ensuring the basic needs of food security in rural communities. To support the concept of multiple water use, a new initiative called SMART irrigation – SMART WASH is proposed for corporate solutions to enhance irrigation and provide WASH facilities to vulnerable communities, thus, responding to the critical needs in times of pandemic crisis.

For the implementation of SMART irrigation – SMART WASH concept, geographical hotspots of the COVID-19 were identified in the African continent which is currently the most vulnerable region to face the negative impacts of this pandemic. Twelve internationally established and recognized indicators were used to identify the vulnerability of each country in the African continent. The indicators were divided into two domains: (a) improving food security and (b) increasing health facilities. The indicators are scored individually in each country and each of them is analyzed separately and visualized on a continental map. The results are then aggregated into a final score that shows the degree of vulnerability in Africa countries.

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