Strengthening Hydromet and Early Warning Systems and Services in Tunisia

A ROADMAP

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This report was prepared by the Global Practice for Social, Urban and Rural Development, and Resilience (GSURR) – Middle East and North Africa (MENA) region/World Bank Group. It presents an approach to strengthen Tunisia's hydrometeorological (hydromet) and early warning systems and services (EWS) in accordance with the needs of the user community.

The report is based on a technical evaluation and detailed assessment of the needs and capacities of Tunisia's Meteorological and Hydrological Service Providers (i.e. the National Institute of Meteorology (INM); and Directorates within the Ministry of Agriculture, Water Resources and Fisheries (MARHP), namely the General Directorate of Water Resources (DGRE), the General Directorate of Dams and Hydraulic Works Department (DGBGTH)) which issue weather-, climate- and water-related forecasts and warnings. Other government agencies providing advisory services related to weather, climate, hydrology, disaster management, and agriculture are considered key hydromet stakeholders. Among stakeholders, the most important are the National Civil Protection Office (ONPC); Ministry of Agriculture, Water Resources, and Fisheries (MARHP) and its Directorates; the Ministry of Equipment and its Directorates; and the Ministry of the Environment (ME) and its Directorates; and various municipalities across Tunisia.

This report identifies gaps and challenges in the production and delivery of weather, climate, and hydrological information and services, and proposes a strategy to improve the country's institutional capacity to save lives and livelihoods and to support social and economic development. The authors consulted a number of government institutions and agencies (including several among those listed above) as well as development partners and donors. The report is the result of a collaboration between the Government of Tunisia and the World Bank.

The authors wish to thank the national agencies, ministries, and organizations, and our development partners and donors, for providing information and support, and for discussions during the report's assessment.

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ACRONYMS & ABBREVIATIONS

AAL	Average Annual Loss
ACAS	Agriculture and Climate Advisory Service
AdB	African Development Bank
AFD	French Development Agency
ALADIN	Aire Limitée Adaptation Dynamique Développement International (International development for limited-area dynamic adaptation)
AMCOMET	African Ministerial Conference on Meteorology
AMDAR	Aircraft Meteorological Data Relay
AMO	Aerodrome Meteorological Office
AMS	Aeronautical Meteorological Station
APAL	Agency for the Protection and Development of the Coast Areas
APCM	Arab Permanent Committee on Meteorology
APO	Aeronautical Protection Office
AROME	Applications of Research to Operations at Mesoscale
ARPEGE	Action de Recherche Petite Echelle Grande Echelle
AWS	Automatic Weather Station(s)
BPEH	Office of Planning and Hydraulic Balance
CAAO	Civil Aviation and Airports Office
CAP	Common Alerting Protocol
CHF	Swiss Franc
CNCT	Centre for Cartography and Remote Sensing
CONOPS	Concept of Operations
CRDA	Agricultural Development Regional Office
CREST	Coupled Routing and Express Storage
DGACTA	General Directorate of Development and Conservation of Agricultural Lands
DGBGTH	General Directorate of Dams and Hydraulic Works Department
DGGREE	General Directorate of Rural Engineering and Water Exploitation
DHU	General Directorate of Urban Hydraulics
DGRE	General Directorate of Water Resources
DRM	Disaster Risk Management
DTTA	Tunis Carthage Airport
ECMWF	European Center for Medium-range Weather Forecasts
EPS	Ensemble Prediction Systems
EU	European Union

EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EURO-CORDEX	Coordinated Downscaling Experiment - European Domain
EWS	Early Warning System/Service
FAO	Food and Agriculture Organization
GAW	Global Atmospheric Watch Program
GDP	Gross Domestic Product
GFCS	Global Framework for Climate Services
GFDRR	WB Global Facility for Disaster Reduction and Recovery
GFS	Global Forecast System
GIS	Geographic Information System
GIZ	German Development Agency
GSM	Global System for Mobile Communications
GSURR	Global Practice for Social, Urban and Rural Development, and Resilience
GTS	WMO's Global Telecommunication System
HPC	High Performance Computer
HR	Human Resources
HRV	High Resolution Visible
HTBM	Hydrometeorology in Tunisia: the Medjerda river basin
HYDROMET	Hydrometeorological
IBCS	Intergovernmental Board on Climate Services
ICAO	International Civil Aviation Organization
ICT	Information Communication Technology
IFS	Integrated Forecast System
INDC	Intended Nationally Determined Contributions
INM	National Meteorological Institute
IRI	International Research Institute for Climate and Society
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
KfW	German Development Bank
LAM	Limited Area Model
LDAS	Land Data Assimilation System
MARHP	Ministry of Agriculture, Water Resources and Fisheries
ME	Ministry of the Environment
MedCOF	Mediterranean Climate Outlook Forum
MENA	Middle East and North Africa
METAR	Meteorological Terminal Air Report
MFI	Météo-France International
MoU	Memorandum of Understanding
MSG	Meteosat Second Generation
MWO	Meteorological Watch Office
NAP	National Adaptation Plan

NCEP	National Centers for Environmental Prediction
NCOF	National Climate Outlook Forum
NFCS	National Framework for Climate Services
NGO	Non-Government Organization
NHS	National Hydrological Service
NMHS	National Meteorological and Hydrological Service
NOAA	US National Oceanic and Atmospheric Administration
NWC SAF	EUMETSAT Satellite Application Facility for Nowcasting
NWP	Numerical Weather Prediction
NWS	US National Weather Service
NWSAS	Aquifer System of the Northern Sahara
O&M	Operation and Maintenance
ONAGRI	National Observatory for Agriculture
ONAS	National Office for Sanitation
ONPC	National Civil Protection Office
OPMET	Operational Meteorological data
ORS	Operation Resolute Support
OSS	Sahara and Sahel Observatory
PDNA	Post-Disaster Needs Assessment
PML	Probable Maximum Loss
PWS	Public Weather Services
QA/QC	Quality Assurance / Quality Control
QMS	Quality Management Systems
R&D	Research and Development
RCC	Regional Climate Center
RCC-NA	Regional Climate Center for the North Africa region
RNA	Rapid Needs Assessment
SD	Service Delivery
SDGs	Socio Development Goals
SDS	Service Delivery Strategy
SECADENORD	National Society for the Exploitation of the Northern Water Canal and Adductions
SIGMET	Significant Meteorological Information
SINEAU	National information Systems for Water Resources
SMS	Short Message Service
SONEDE	National Water Distribution Utility
SOP	Standard Operating Procedure
SPECI	Aviation Special Weather Report
SYCOHTRAC	SYstem for COllecting Hydrological Data in Real-time and Flood Alert
SYGREAU	Management System of Water Resources
TAF	Terminal Aerodrome Forecast
TV	Television
UN	United Nations

UNDP	United Nations Development Program
US	United States
US$	United States Dollar
USAID	US Agency for International Development
VSOL	Value of Statistical Life
WAFS	World Area Forecast System
WAM	Wave Model
WB	World Bank
WBG	World Bank Group
WIS	WMO Information System
WMO	World Meteorological Organization
2G	Second Generation

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EXECUTIVE SUMMARY

Introduction

Tunisia is highly vulnerable to natural hazards. Hydrometeorological (Hydromet) hazards, such as various types of floods, droughts, heat extremes and heatwaves, and sea level rise pose a direct threat to lives; impact livelihoods by damaging and destroying infrastructure, assets, and land; and retard development. Underlying processes, including climate change, population growth, land use changes, and urbanization, mean that growing numbers of Tunisians face hydrometeorological hazards, especially in coastal areas, where the largest cities and economies are located. Tunisia depends on climate-sensitive agriculture, and much of its population and economic activity (e.g., tourism and export-oriented manufacturing industries) are located in flood-prone urban coastal zones. Despite a long history of adaptation to weather, climate, hydrological variability, and extreme events, disaster risk management remains an ongoing challenge.

Tunisia has 11.7 million inhabitants, of which 67 percent live in coastal areas. By 2050, projections indicate that this number will increase to 13.8 million inhabitants, of which 73 percent will live in coastal areas. Conflict and social stresses have worsened poor service delivery, and better Hydromet services are urgently needed as the state is rendered increasingly fragile by a deteriorating climate. Extreme weather causes, *inter alia*, considerable economic losses, food insecurity, malnutrition, and displacement, and affects vulnerable populations disproportionately.

National Meteorological and Hydrological Services (NMHSs) provide Hydromet and early warning services and tailor them to different users. Given current and predicted Hydromet-related hazards, and as in other countries of the Middle East and North Africa (MENA) region, Tunisia needs Hydromet information to protect people, economies, and development gains. To contain growing economic losses from hydrometeorological hazards, adapt to climate change, and guide economic development across different sectors, Tunisia needs to invest in its multi-hazard early warning systems, and hydromet services. NMHSs are needed to strengthen resilience and development in Tunisia, and will benefit sectors such as disaster risk management (DRM), water resource management, agriculture, transport, energy, health, infrastructure, public works and tourism.

Following the flash floods of September 2018, the government of Tunisia requested Hydromet technical assistance from the World Bank to complement DRM efforts and other activities underway in the country.

Socioeconomic Impacts of Hydromet Hazards

Tunisia is highly vulnerable to natural hazards and climate change, which impact key sectors of its economy. According to preliminary findings of a national disaster risk profile conducted by the World Bank (WB), it is estimated that floods cause an average annual loss (AAL) of US$40 million (or 0.1 percent of Tunisia's 2018 GDP), while the probable maximum loss (PML) from earthquakes over a return period of 250 years is US$882 million (or 2.2 percent of Tunisia's 2018 GDP). Losses incurred between 2011 and 2018 as a result of floods, droughts, and fires were calculated at approximately US$541.3 million, and 94 percent of the mortality associated with disasters result from floods and earthquakes.

Services Provided

Meteorological and Hydrological Service Providers in Tunisia are expected to (i) provide data to clients (ii) assist clients to use and understand these data (iii) improve public and economic security through warning systems (iv) inform planning and decision making for climate-resilient development, and (v) optimize investments from government and development partners.

Public weather services by Tunisia's National Institute of Meteorology (INM) are good, and bulletins are issued in French, Arabic and English. At least twice a day, INM produces weather forecasts for the territory of Tunisia for the actual day D plus three days ahead. INM also issues medium-range forecasts for D+3 to D+6, as well as seasonal forecasts. These forecasts are posted on the INM's website (https://www.meteo.tn/), launched in French and English in May 2020. INM has a strong presence on TV and Radio, its website, and on Facebook and Twitter.

INM, in coordination with the National Civil Protection Office (ONPC), Office of Planning and Hydraulic Balances (BPEH), the General Directorate of Dams and Hydraulic Works Department (DGBGTH) and Ministry of Environment (ME), has developed a meteorological vigilance maps tool ("*Carte de Vigilance*") to inform people and decision-makers of weather-related risks in Tunisia, highlighting possible impacts/damages and associated self-protection measures (behavior).

INM is ISO 9001:2015 certified, and plays a leading role in the Regional Climate Center for the North Africa region (RCC-NA). Its main responsibility is to provide aeronautical meteorological services; however, it also offers agrometeorological products to the agriculture sector, daily marine forecasts in coastal areas, and beach conditions for the tourism sector. Its products are available on its website, and, in addition to those mentioned above, it serves the tourism, energy, and health sectors. Other than through social media, it has no formal mechanism to receive feedback from stakeholders.

Hydrological forecasts are provided by (a) the DGBGTH for dam control management and inundation risks, based on well-established hydrological and hydraulic modeling initiatives, supported by development partners JICA, Korea International Cooperation Agency (KOIKA), and KFW); and (b) the DGRE for flood forecasts in pilot basins and catchments, based on experiments and case studies of past events. Despite being well staffed, DGRE is unable to offer timeous forecasts or management services for Tunisia's strategic dams (in particular, Sidi Salem, Bouheurtma, Mellègue, Barbara, Sidi Barrak and Sejnene dams).

Following the AGIRE program supported by GIZ, a SYstem for COllecting Hydrological Data in Real-time and Flood Alert (SYCOHTRAC) has run over the last two years. SYCOHTRAC prioritizes visualization of time series and geographic features, exchange formats, automatic updating procedures and management of rights. With the support of development partners (GIZ, KfW and AdB), a National Information System for Water Resources (SINEAU) has been developed to process data needed to manage the nation's water resources, both in terms of quantity and quality. The SINEAU Portal elaborates on the water resources management system (SYGREAU), and SYCOHTRAC, both of which are managed by the DGRE; and receives further inputs from other Directorates within the MARHP, the general ministerial ONAGRI portal, and INM. Each year, BPEH, with the support of DGRE, DGBGTH, and other Directorates, prepares the national water sector report entitled 'Water sector review'; and studies following droughts and floods.

The current hydrological vigilance is based on the telemetry system managed by the DGRE, in which warning and overflow levels are set on the basis of feedback. Once the water level reaches the alert level, an alert message is automatically sent by SMS to initiate flood responses. Similarly, the volume of inflow at each dam, under flood conditions, is estimated by the DGBGTH. Each dam site calculates the outflow separately, based on information provided by the DGBGTH.

ME, with the support of UNDP, KfW and Expertise France, is setting up early warning systems (EWS) with ONPC in three communes (Ain Draham, Jendouba-Bou Salem and Tataouine), corresponding to three different contexts (sub-humid mountainous forested north west, upstream Medjerda wadi basin, and arid South). Risk management centers are being established, as well as meteorological stations (with the support of the INM, who will manage them).

This road map uses a series of progress models to measure the Meteorological and Hydrological Service Providers' capacities in several key areas (service delivery, observation and telecommunication, and modeling and forecasting). The Service Delivery Model draws on the model developed by the World Meteorology Organization (WMO 2014); the other progress models were developed by the World Bank based on the Service Delivery Model. All these models rate the Meteorological and Hydrological Service Providers' performance on a 1 to 5 scale (Undeveloped to Advanced).

According to the Service Delivery Progress Model of the WMO Strategy for Service Delivery (WMO 2014), the current level of INM's meteorological service delivery capability is between Level 3 (Development in progress) and Level 4 (Developed). In order for INM to deliver services which meet users' needs, its capability should be at Level 5 (Advanced), which is the level that investment Phase 3 as proposed in this road map is designed to meet. The current hydrological services capability is between Level 2 (Development initiated) and Level 3 (Development in Progress). In order to deliver services at a Developed level, the capability of hydrological services should be raised to Level 4 (Developed) by the time Phase III is complete. All three Phases are described in more detail below.

Observing Networks

Tunisia needs a properly designed national meteorological and hydrological network based on users' requirements.

INM's existing surface observation network consists of 28 synoptic stations (12 aeronautical and 16 non-aeronautical); 12 agrometeorological stations; 24 climatological stations; 2 Port Stations; which require upgrading. INM also operates a secondary network of volunteers who monitor 90 conventional rain gauging stations. INM shares data from 28 stations on the WMO Global Telecommunication System (GTS). INM has a modest calibration laboratory that requires upgrade and two functioning upper-air stations: in Tunis-Carthage and in Touzer. There are no lightning, lidar, nor GAW systems, nor an AMDAR program.

INM uses Meteosat Second Generation (MSG) satellite remote sensing products, which need to be upgraded to the third generation. INM does not operate a weather radar network. However, under the framework of the HTBM project for "Hydrometeorology in Tunisia: the Medjerda river basin", the government of France donated an X-band weather radar to Tunisia to measure rainfall with the objective of water management and hydrological risk assessment.

The rainfall network of DGRE is currently made up of 64 automatic and 712 manual daily stations located throughout the country. In addition, Tunisia has a hydrometric observation network developed over the last 30 years; the oldest of these stations date back to 1898. This network is currently composed of 53 hydrometric measurement stations.

The DGBGTH has 6 telemetry stations and 37 manual hydrological stations (which measure evaporation, rainfall, water level for inputs, and other parameters) on its dam network. The measuring stations are mainly made up of gauge piezometers. However, these are particularly vulnerable to hydraulic clearing during floods and to the sedimentation that follows.

Since 2008, INM manages a seismic network of 16 stations installed with government funding, and an additional 3 stations supported by development partners. There is a need to install stations at Sea.

Current observation and telecommunication capabilities are at Level 2 (Development Initiated) in the Observation and Telecommunication Progress Model. To deliver services and support forecasting systems at Level 5 (Advanced), the capability of these systems should also be raised to Level 5 (Advanced) by the end of Phase III.

Modeling and Forecasting Infrastructure

INM's main global weather forecasting models are the French ARPEGE-France model at 0.5° and 0.1° horizontal resolution received via MESSIR-Comm (supported by Corobor) and displayed in the Synergie (2008) visualization system (also supported by MFI), which is outdated. Through a password-protected website, INM also has access to graphical products from the ECMWF IFS (Integrated Forecast System, 9km deterministic and 18km probabilistic), and is considering full access to ECMWF digital data through a license agreement. For severe weather forecasting, INM primarily uses the ECMWF Ensemble Prediction System (EPS), including the extreme forecast index.

A new HPC (24 nodes) was purchased and delivered to INM in August 2019 with an estimated computing capacity of 38 Tflops. Since then, INM has run the AROME model at 2.5km horizontal resolution and 60 vertical levels, and 1.3km. Next steps include data assimilation.

For seasonal forecasting, INM uses "ARPEGE-CLIMAT" coupled to the oceanographic model "NEMO", which receive observation and re-analysis data from ECMWF and laboratory MERCATOR, respectively. INM, as an institution responsible for the study of climate change, has elaborated an evaluation of future climate on the basis of the scenarios of the EURO-CORDEX Project.

Experiments in hydrological modelling have been done by academics or resource persons under projects supported by development partners. In particular, under the framework of (a) flood control in the Medjerda River – upstream area (supported by KfW and implemented by DGBGTH); and (b) integrated basin management for flood control in the Mejerda River – downstream area (supported by JICA and implemented by DGBGTH). More recently, DGRE has used MIKE for flood forecasting.

While the likelihood of a tsunami is low, its impact on Tunisia would be great; and there is a need to build tsunami monitoring and modeling capacity at INM.

Current modeling and forecasting capabilities fall under Level 2 (Development Initiated) for hydrology and Level 3 (Development in Progress) for meteorology. To deliver services at an Advanced Level (5), the capability of the forecasting systems should be raised to Level 4 (Developed); this would enable the performance of functions as stated in Phase III of the road map.

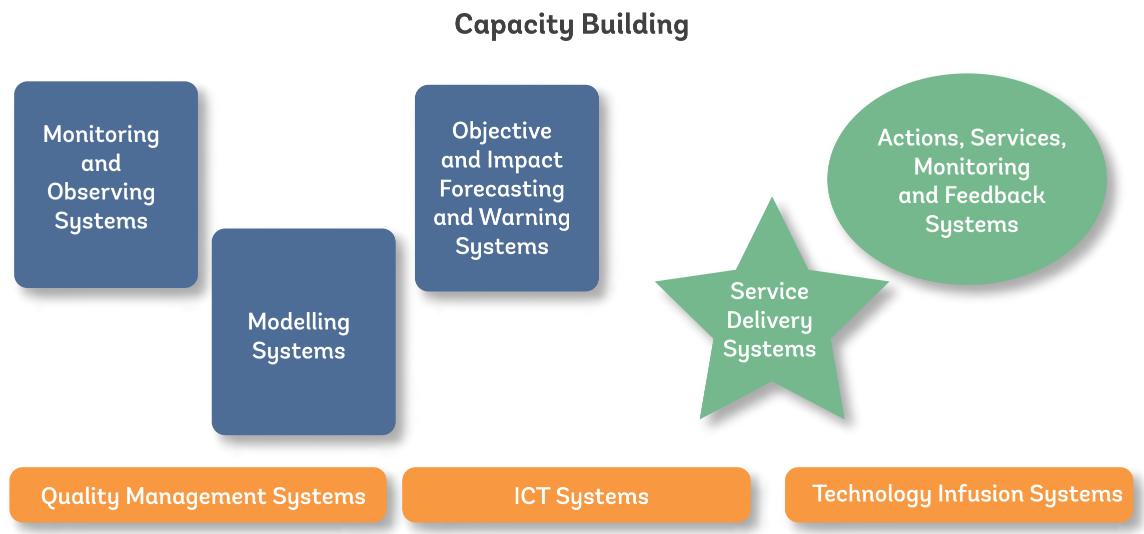
Additional Challenges

A challenge faced by Meteorological and Hydrological Service Providers in Tunisia is the Government's unawareness of the value of these services for public safety and weather-, climate-, and hydrology-sensitive economic development. To compete for and optimally use scarce public resources, Meteorological and Hydrological Service Providers must justify the investment of public funds to support their basic infrastructure, operations, and development of services. To demonstrate the benefits to users, however, they must first provide these services, which is currently difficult to do in the absence of sufficient support.

Proposed Modernization of Hydrometeorological Services and EWS

A typical National Meteorological and Hydrological Service (NMHS) is composed of a complex "system of systems," aligned with the value chain, as shown in **Figure 1**. This generic illustration of a weather, climate, and hydrological system of systems can be used to identify the current status of any NMHS and to visualize investments required in each system, component by component, to achieve a particular level of improvement. The complexity of each system varies depending on the size, level of development, and resources of the NMHS concerned. But the system-of-system building blocks are interdependent. Users' requirements are an essential ingredient for the design and implementation of the entire system. A key requirement is for staff with the capacity to under-

FIGURE 1. Schematic of an NMHS as a System-of-Systems



Source: Rogers et al. 2019.

stand and operate the system. This road map for Tunisia uses a system-of-systems approach to arrive at the three phases for modernizing Meteorological and Hydrological Service Providers.

A substantial modernization program for any NMHS should include three components, namely (i) enhancement of the service delivery system; (ii) institutional strengthening and capacity building; and (iii) modernization of observation, ICT, and forecasting infrastructure (Rogers and Tsirkunov 2013). The development of this road map is in line with this principle. The activities proposed aim to strengthen the Meteorological and Hydrological Service Providers' institutional basis: to develop the capacity of staff; to technically modernize the observation, ICT, data management, and hydromet forecasting infrastructure, facilities, and procedures; and, most importantly, to improve the delivery of hydromet and early warning services to users and sectors most affected by weather, climate, and hydrology—mainly agriculture, transport, energy, water resources management, and tourism.

Three phases (each phase building on the previous one) to modernize the Meteorological and Hydrological Service Providers, alongside support to the ONPC for improved EWS, have been presented in this road map. The level of complexity and required resources is different for each phase, as shown below.

Phase I: immediate to short-term activities. This phase invests in high-priority activities to improve basic public services through new technologies and staff training (immediate to short term: two- to three-years duration). This phase requires an additional 14 staff, its investment cost is estimated at US$20.5 million, and the annual operating cost is US$1.03 million.

Phase II: medium-term activities. This phase makes investments to modestly improve the provision of weather, climate and hydrological services that meet the public service needs of the most important user communities, including disaster management, transport, agriculture, and water resources management (medium term: two-years duration on top of Phase I). The implementation of this phase is expected to follow Phase I and will cost US$16.65 million. Phase II requires an additional 11 staff and has an operating cost of US$1.86 million per year (after the implementation of Phases I and II).

Phase III: long-term activities. This phase invests in providing data, forecasts, and warning services for the safety of the public, and support to develop the most important socioeconomic sectors (long term: two-year duration on top of Phases I and II). The implementation of this phase is expected to follow Phases I and II and will cost US$5.4 million. Phase III requires an additional 6 staff and an operating cost of US$2.13 per year (after the implementation of Phases I, II and III).

The first two phases build the capacity of the institutions concerned to meet their primarily public service responsibilities. The third phase builds the capacity of public weather, climate and hydrological services to provide tailored products, either alone or in partnership with other institutions.

To achieve the anticipated results of Phase III, two main conditions need to be met: (i) the government must be able to direct available resources to modernize the Meteorological and Hydrological Service Providers' observation, ICT, and forecasting infrastructure, and improve service delivery; and (ii) the government must recruit 31 specialists and technicians, and fund the operation of the new, modernized systems.

Developing a Concept of Operations is essential for detailed planning and implementation of each phase.

Socioeconomic Benefits of Improved Hydromet Services and EWS

It is now common practice for hydromet service providers to undertake cost-benefit analyses to secure and optimize the use of investments. These analyses have uniformly shown that the benefits of hydromet services outweigh the capital and operational costs of providing them.

To make the best use of investments, hydromet services should be modernized to deliver services which employ all possible means to reach end users with practical, user-friendly products.

Recent assessments of the benefits of hydromet services have applied different methodologies, as described in Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services (WMO *et al* 2015). These include further-refined, sector-specific, and benchmarking approaches. The cost-benefit analysis indicates that the three proposed investment phases are economically efficient, meaning they will produce socioeconomic benefits greater than their costs. In all cases the longer-term benefits exceed the costs.

1 INTRODUCTION TO THE ROAD MAP AND TO TUNISIA'S GEOGRAPHY, WEATHER, CLIMATE, HYDROLOGY, AND RELATED FEATURES

1.1 Introduction to the Road Map

This analytical work consists of a diagnostic of the capabilities of, and the gaps and challenges faced by meteorological and hydrological service providers in Tunisia, who are responsible for the provision of weather, climate, and hydrological (hydrometeorological) products and services. It proposes a technical strategic framework to improve hydromet and early warning systems and services (EWS) in support of Tunisian people; safeguard their lives, livelihoods, and property, and protect economic investments. Such framework would help government authorities in Tunisia in their decision-making processes.

The road map consists of nine Chapters. The geography; the weather, climate and hydrological hazards affecting Tunisia, and their socioeconomic impacts on the Tunisian people are introduced in Capters one to three. The assessment of user needs for hydromet information is presented in Chapter four.

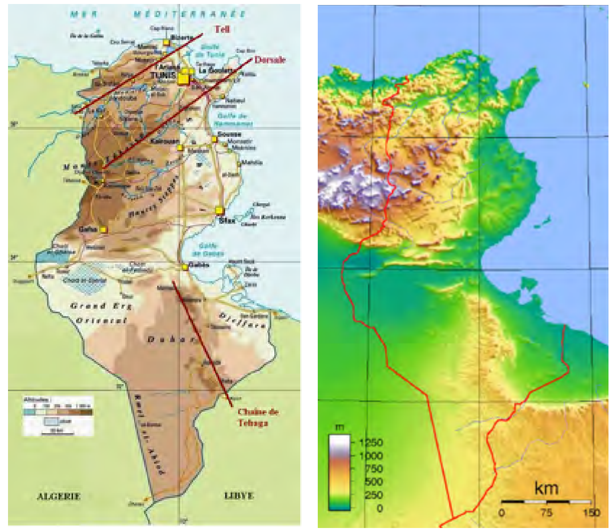
An overview of the institutional and organizational structure of meteorological and hydrological service providers in Tunisia is given in Chapter five, and the in-depth technical analysis of their current status is provided in Chapter six. The modernization of hydromet and EWS is discussed in Chapter seven, which also presents a road map with three proposed successive development phases designed to transform meteorological and hydrological service providers in Tunisia into technically modern and sound entities that can meet their public service mandates. A socioeconomic benefits analysis of the proposed modernization is provided in Chapter eight. The conclusions and way forward are presented in Chapter nine, followed by several annexes that provide additional details. Throughout this document, Service in capital letter means the institution, while service in lower case indicates the action of packaging and delivering the information. In addition, meteorology refers to aspects of weather and climate.

1.2 Tunisia's Geography

Tunisia is in north Africa, on the edge of the Sahara desert, at the eastern end of the Maghreb mountain ranges and on the southern shore of the Mediterranean Sea. With a surface area of about 162,155 km², and elongate in shape along its north/south axis, it is located in the transition zone between the sub-humid Mediterranean climate and the arid Saharan climate, with a strong overall north/south hydro-climatic gradient of rainfall and evapotranspiration, and hence of hydrological conditions. This overall north/south climatic organization is sub-structured under the influences of relief and of the sea, and these influences are themselves seasonal and subject to extreme events (Slimani *et al* 2007; Baccour *et al* 2012).

This overall latitudinal gradient, overlaid with microclimatic and seasonal variation, combine with relief and pedo-geological characteristics to determine most elements of the physical, ecological, agricultural and human geography (**Figure 2**); of the hydrology; and hence of the related risks.

FIGURE 2. Tunisia's elevation, and Major Features

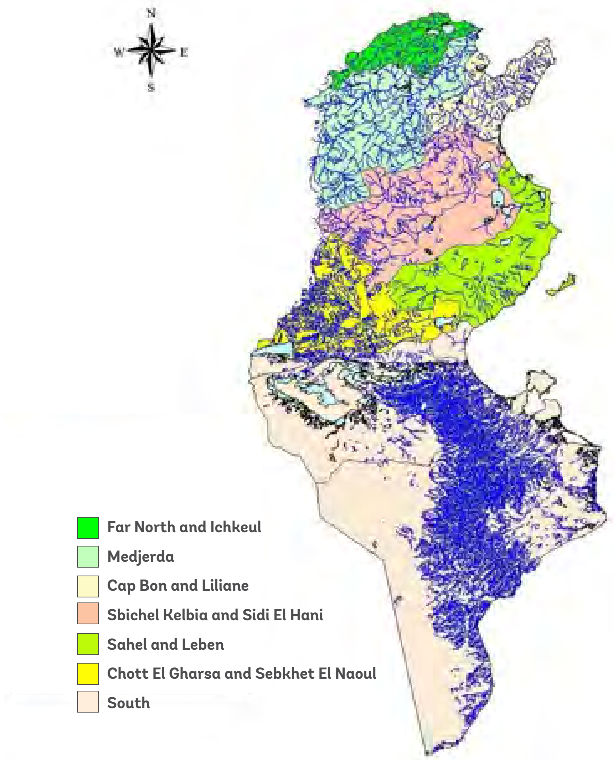


Source: Slimani et al. 2007

Tunisia is at the eastern end of the Atlas mountains (**Figure 3**) which imprints several orographic groups and ridges[1] with roughly (south-)west/(north-)east alignments, with important drainage systems in between, flowing West/East and reaching coastal sedimentary areas through which waters flow to the Mediterranean Sea, or form endoreic wetlands (lakes, lagoons, sekhas, chotts), or infiltrate karstic and sediment reservoirs along valleys and in coastal plains (Merla 2015; Camacho *et al* 2015). Small coastal drainage systems are further shaped by local conditions, sometimes on steep slopes when mountains are close to the sea, and sometimes with different orientations (especially on the North coast of the country, on the Cap Bon peninsula and on Djerba Island).

[1] A geographical feature consisting of a chain of mountains or hills that form a continuous elevated crest for some distance which influence local weather patterns.

FIGURE 3. Map of Major Catchments



Source: DGRE 2009

The northern part of the country displays the Tell mountains, with peaks and plateaus along the Algerian border and fragmented ranges towards the east within which lies the drainage system of the UNESCO World Heritage tidal Ichkeul lake; the Medjerda wadi (river) basin and the Miliane wadi basin.

The south-west/north-east Dorsal ridge is a natural boundary between northern and Central Tunisia. It contains the highest peaks of Tunisia close to the Algerian border (Jebel Chaâmbi, 1544m) and runs through the Cap Bon peninsula into the Mediterranean Sea. Between the Dorsal ridge to the north and the Gafsa chain, central Tunisia is a typical steppe landscape with high plains to the west and large drainage systems flowing to the east down to large plains. The major catchments are from north to south: wadis Nebhana, Merguelli and Zeroud flowing into the Kairouan plain, and now dammed (Bouzaiane and Laforgue 1986; Leduc *et al* 2007).

The central-Tunisian coastal band is composed of low steppes in vast plains, with local depressions, sekhas, and sedimentary groundwater systems.

Southern Tunisia has a varied topography, transitioning to the Sahara desert. In the west, isolated west-east ridges dominate the Chotts, large endoreic evaporation-dominated depressions. Towards the east, the vast Dahar plateau and the Matmata cornice lead to the immense Jeffara coastal plain and groundwater system which are transboundary with Libya. Further south is an uninhabited desert area which overlies the transboundary Northern Sahara Aquifer.

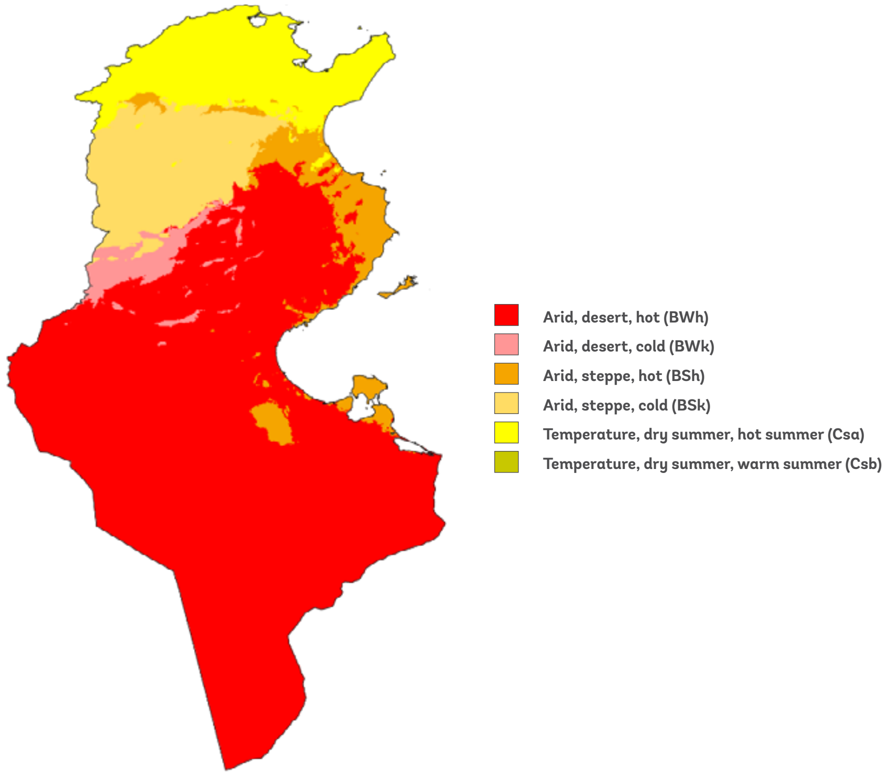
1.3 Weather and Climate (Meteorology)

Tunisia is influenced by air masses from different origins, with strong seasonality. Perturbations from the Atlantic ocean, mainly in winter, bring varying amounts of moisture from the west, depending on their exact trajectory over North Africa and the Atlas mountains, and generate orographic rainfall over Tunisia, mainly in the north (Slimani et al 2007; Feki et al 2012; Feki et al 2017).

In summer, tropical southerly air masses heat up over the Mediterranean; local air movements over the Mediterranean basin are influenced by the Gulf of Genoa, Balearic sea, and the Gulfs of Syrtes and Gabès, combined with surrounding high pressure centers. In some circumstances, these movements raise air temperatures and cause evaporation over the Sea, driving moisture inland from the east and causing orographic rain. These dynamics often combine with convective processes, which increase the variability of rainfall's intensity, frequency and distribution.

In the north, Tunisia has a hot-summer Mediterranean climate, where winters are mild (rarely exceeding 20°C) with moderate rainfall (up to 700mm/year in the Mediterranean areas), and summers are hot and dry (with temperatures in July and August often exceeding 40°C). In the south, there is a hot desert climate with extremely hot summers (with regular 45°C temperatures), warm winters during daytime (with cold night-time temperatures in the desert) and very low annual rainfall (less than 10mm/year) (**Figure 4**).

FIGURE 4. Köppen Climate Classification Map of Tunisia



Source: Beck et al. 2018; doi: 10.1038/sdata/sdata.2018.214

Based on historical climate conditions, recent trends (over the past few decades) and projections for Tunisia are as follows (ESCWA et al. 2017):

- Mean annual temperatures rose by about 1.4°C in the 20th century and the number of warm days per year has also increased. By 2050, the mean annual temperature in the country is projected to continue to increase, with a hotspot emerging on the Tunisian border with Algeria, where local temperature increases in the summer could be as great as 5.3°C. Increases in the number of hot days (especially in July, August, September) and long heat waves; and decreases in the number of cool days (i.e. increase in warm nights) are projected by mid-century.
- Over the last few decades, Tunisia has experienced a significant decrease in winter and early spring rainfall, with the number of dry days increasing to over 330 per year from 1997–2008. Annual rainfall has decreased by 5 percent per decade in the northern part of Tunisia since 1950, while heavy rainfall has become more frequent. A reduction in rainfall is very likely by 2050, along with an increase in the frequency of heavy rainfall in northern Tunisia. Southern Tunisia is expected to experience high rainfall variability.
- Nearly two-thirds of Tunisia is semiarid to arid, and droughts can be frequent. The country has experienced over 25 dry years since 1907, with the worst drought in over 50 years lasting from 1999 to 2002. The combination of higher temperatures and declining rainfall is projected to reduce water resources in Tunisia by 2050. Projections also suggest a drying trend in the region, particularly along the Mediterranean coast, driven by large, expected decreases in summertime precipitation. Under this scenario, North Africa (including Tunisia) will be affected by more frequent, intense and longer-lasting droughts, especially in summer.
- Sea levels have risen across the Mediterranean by an average of more than 3.1 mm each year since 1992, although older records indicate considerable local variability. Sea levels are projected to rise between 3 and 61 cm by 2050, depending upon local heat and salinity levels of the Mediterranean. Due to coastal zone char-

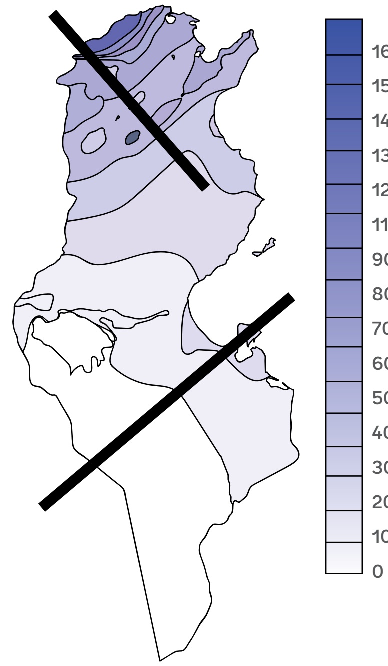
acteristics, between 1 percent and 3 percent of land in Tunisia will be affected by a 1-meter sea level rise.

Tunisia has put climate change at the top of its political and economic agenda. It is the fourth Arab country to have published its Intended Nationally Determined Contributions (INDC) for a reduction in greenhouse gas emissions. In addition, Tunisia's limited energy resources create an opportunity to develop renewables and to improve usage efficiencies in line with its new job strategy to reduce youth unemployment. Tunisia is also the first country in the MENA region to include recognition of climate change in its new Constitution: "A sound and balanced environment while contributing to the safety of the climate by all available means". In 2018, The Ministry of Agriculture, Water Resources and Fisheries (MAHRP), the Ministry of Environment (ME) and the Food and Agriculture Organization (FAO) of the United Nations, began to develop the second chapter of the National Adaptation Plan, related to food security (BPEH 2019).

1.4 Hydrology, Water Resources and Related Infrastructures

Tunisia's average rainfall of 230 mm/year represents a total water volume of 36 billion m3 and is highly variable: about 36 percent of this rainfall falls on 3 percent of the land surface in the extreme north, while 6 percent is received by 62 percent of the land surface in the south **(Figure 5)**.

FIGURE 5. Map of Annual Rainfall (1/10 mm) and Gradient Structured by Latitude, Relief and Distance from the Sea



Source: Slimani et al. 2007

The balance between rainfall and evapotranspiration, seasonal and interannual variability in rainfall, frequency of high intensity rainfall, and the heterogeneity and geology of the land surfaces receiving rain, lead to rapid runoff and high transfer back to the atmosphere.

During heavy rains, rainfall patterns over river catchments influence the dynamics of runoff and flooding (Cudennec 2005: Chargui *et al* 2009; Aouissi *et al* 2018)) at levels of resolution uncaptured by observation networks. The assessment of recent and ongoing changes in these dynamics reveals complex patterns of both subtle change and stability (Chargui et al 2013; Cudennec et al 2016; Chargui 2018).

Heavy rains in small, mountainous catchments produce flash floods with complex spatio-temporal runoff dynamics; other floods inundate wadis and downstream plains, while others recharge groundwater on plains and in large valleys, or fill coastal lakes, lagoons, sebkhas, and chotts.

Coastal rains may be hazardous when influenced by marine moisture, convection and coastal orography, inducing flash floods. From the groundwater perspective, recharge depends on such floods, and is thus dependent on both rainfall's interannual variability and extreme rainfall events (Leduc *et al* 2007).

Historically, traditional techniques were used to harvest, store, and distribute water for agriculture and domestic use, using topography and hydraulic means. Soils and crops were irrigated using dykes, canals, walls, terraces, cisterns and aqueducts (Ben Mechlia 2004). These traditional techniques mitigated variability, and conferred local-level resilience on small farming communities governed by tribal regulation mechanisms (Romagny 2006; 2007).

In the late 1970s–early 1980s, a national strategy to manage water resources emerged as part of Tunisia's development planning to reinforce and mobilize green and blue water resources[2], develop non-conventional resources, and protect the environment. Soil and water conservation have been extensively developed to increase green water availability through policies supporting traditional and modern techniques. The mobilization of surface blue water stands at around 2,500 million m3/year thanks to large dams, hill dams and lakes, which mitigate fluctuating supply due to Tunisia's highly variable rainfall (BPEH 2014; 2015; 2016; 2017 ; 2018). Use of groundwater has been encouraged over the last decades for domestic use and irrigation, and now accounts for 63 percent of overall use (UNESCWA 2019). North-south interconnection infrastructures are in place and are being further developed (BEPH 2019) to pursue country-wide supply.

Flood protection in Tunisia dates back to the Middle Ages (Boularès 2015). In recent decades, the cities of Tunis and Gabès have emerged as examples (Oueslati 1999; ONAS 2020) of modern flood control, which includes the use of dikes along wadis such as the Medjerda wadi.

These projects have complemented socio-economic development in recent decades, and while data sharing between stakeholders lags behind (UNESCWA 2019), professionals are aware of the challenges and competencies required to manage water resources and infrastructures.

Nonetheless, Tunisia remains vulnerable to severe events, and to conflicts and tradeoffs between objectives, regions and stakeholders, some of which played a role in the 2011 revolution. Challenges include the conflicting needs of upstream users and downstream consumers such as cities and the tourism sector, crop irrigation needs, groundwater exploitation (BPEH 2019), ageing infrastructures, siltation and sedimentation. The following findings and references (WMO/GFCS 2014; WB/GFDRR 2018; Perera *et al* 2019; Dixon *et al* 2020) indicate the need to modernize hydromet and hydroclimatic services.

To this end, Tunisia has conducted two national strategic studies *Eau 2000* and *Eau 2030* (UNESCWA 2019), and is developing a participative 2050 Water Strategy with the MARHP which is part of a wider national policy regarding Agenda 2030 and its Socio Development Goals (SDGs), architecture, targets and indicators (République Tunisienne 2019).

[2] Green water – vapor fluxes as evaporation and transpiration; Blue water – liquid water.

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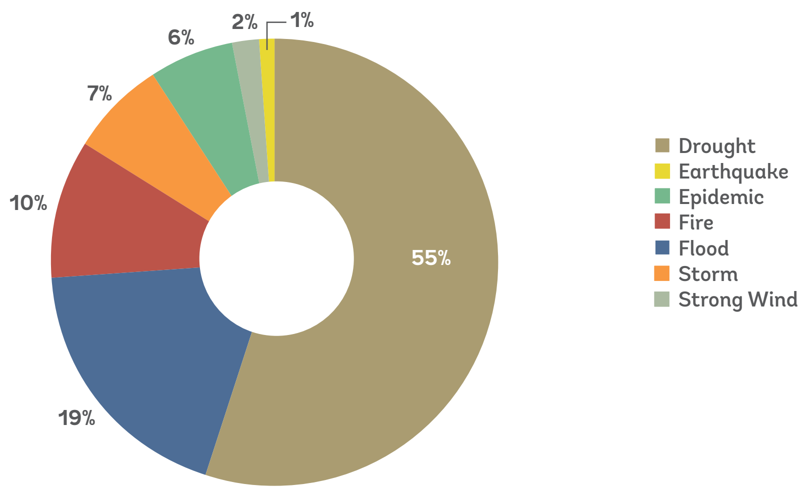
2 WEATHER-, CLIMATE- AND HYDROLOGICAL-RELATED HAZARDS AND RISKS

Tunisia is in a highly disaster-prone region and is exposed to a wide range of hydromet-related hazards, including floods, droughts, earthquakes, forest fires, snowstorms, windstorms, heat/cold waves, and sandstorms (**Figure 6**). Tunisia has experienced more frequent and more severe extreme temperature and rainfall events as a result of climate change. These have led to weather-, climate- and water-related hazards which have increased in Tunisia over the last decade.

FIGURE 6. Number of Hydrometeorological Hazards (1957–2018)



Source: WB 2020

Historically, Tunisia's climate records began in the Middle Ages, and include hydromet events in the country's recent history. These records attest to the spatio-temporal variability in such events, their frequency, important processes and variables, and the heterogeneity of Tunisia's natural systems, factors increasingly shaped by recent climatic and landscape changes.

The Autumn flood of 1969 was one such event (Boudhraâ *et al* 2015), pre-dating the advent of major dams, and affecting a large part of the country. The flood caused 542 fatalities, destroyed 70, 540 houses and left 340,000 people homeless. A discharge of 1,910 L/s/km^2 for an 8,950 km^2 basin was a record for Northern Africa, and the Medjerda wadi flowed permanently for a few months.

Autumn 1969 extremely severe synoptic event is a milestone as it covered a large part of the country, hit Tunisia before the setting up of the major hydraulic infrastructures which exist nowadays, and was extremely severe in terms of hydrometeorological processes and impacts. In September, INM recorded 10-day accumulated rainfall up to 400 mm in certain regions, and 30-day accumulated rainfall in October up to 500 mm over large areas, with measured intensities up to 80 mm/hour. Some direct hydrometric observations have been made, especially in the Zeroud wadi basin.

The Medjerda wadi is permanently flowing, which is quite unique in Northern Africa (except the Nile), and makes it a strategic basin for human settlements and agriculture since antiquity. Setting up of modern hydraulic infrastructures (dams, dykes) for local and remote uses (through dam interconnexion), sometimes in a multiobjective rationale (especially the Sidi Salem dam), has changed the hydrologic (including sedimentary) functioning and the vulnerability to hazards over the last decades and a strong upstream-downstream interdependency. Depending on the rainfall (and snow) regime, and the geographic-hydrographic organization, slow floods essentially occur upstream and from northern tributaries in winter, and rapid floods essentially occur from southern tributaries in spring and autumn (GoG and GoT 2016; Rodier et al 1981). **Floods in Medjerda wadi** from the various tributaries contribute differently to the shape of the main hydrograph depending on the space-time dynamics of rainfall, which induces difficulties for operational management.

Between 27–31 March 1973 floods with a maximum discharge of about 3,000 m3/s were recorded, and these were followed frequently by others. Between 16–20 January 1990 over 500mm of unseasonal rain caused **widespread floods** in the south and central regions.

The volume of sediments transited by the El-H'tab wadi (central Tunisia) at its exit from the Kharroub djebel (Khanguet Ezzazia) due to this event, was estimated at 355,010 m3 for a watershed of 2,200 km2 (Hamza 1993), which represents a specific degradation of about 161 m3/km2 (1.61 m3/ha).

Localized heavy rainfall and floods, especially over coastal cities, define risks at smaller spatio-temporal scales. In September 2017 rain over the Gulf of Gabes and Matmata escarpment flooded wadis flowing toward the Gabès gulf and Jeffara valley, with flows of up 350 m3/s causing erosion, geomorphic changes and damage to infrastructure.

The "Grand Tunis" area regularly experiences intense rainfall, and is vulnerable because of its position at the base of a major watershed, and an historical drainage system which has not kept pace with city growth. Between 16–24 September 2003 heavy rains at Tunis-Carthage inundated large areas of Tunis, and floods re-occurred in October 2007 and September 2019 (MARHP 2019).

In September 2018, **catastrophic flash floods** in the Cap Bon region caused six deaths and major damage to Nabeul city (GoT et al 2018; DGRE 2018) following historic rainfall. Analysis showed that the discharge potential of certain wadis had been amplified by installments, hydraulic defenses were undersized and un-maintained, and that coastal urban zones were vulnerable to extreme runoff, coastal geomorphology and coastal-oceanic weather systems.

Post-disaster analysis showed that installments in some wadi valleys increased the vulnerability and the discharge potential, that some preferential flow paths had been forgotten, that some local hydraulic infrastructures and equipment were under-sized and lacking cleaning routines. Especially, the analysis confirmed the possibility of extreme local rainfall-runoff events enhanced by particular meteorological-oceanic circumstances, coastal particular geomorphology and vulnerability of a coastal dynamic urban zone.

Tunisia also has a history of 20th century droughts (Mouelhi and Laatiri 2014; OSS 2013), and experienced severe droughts in the 1920s, 1940s, 1960s and 1980s (Hénia 2001); in the 1940s and 1980s droughts persisted for many years, with the 1940s drought the most severe of the century with below-average rainfall for up to eight successive years in some areas; the drought at the end of the 1980s was severe and country-wide in impact. These droughts had impacts on agriculture and health, and may also cause locusts to swarm.

Some stations experienced 6 to 8 successive dry years. During four successive years (from 1944-45 to 1947-48), the 400 mm isohyet remained north of the middle and lower Medjerda valley, i.e. more than 150 km north of its average position, south of the Dorsale (Hénia L., 2001). During the 1980s, years with below-average rainfall prevailed over many years. The end of this decade (1987-88 to 1988-89) experienced a severe drought with an intense deficit in rainfall that affected the whole country. These events seriously impact various socioeconomic and environmental sectors in the country, spanning through agriculture to health. An individual peculiar event of locust invasion happened in Tunisia in March 1988, as a results of 2 consecutive drought years.

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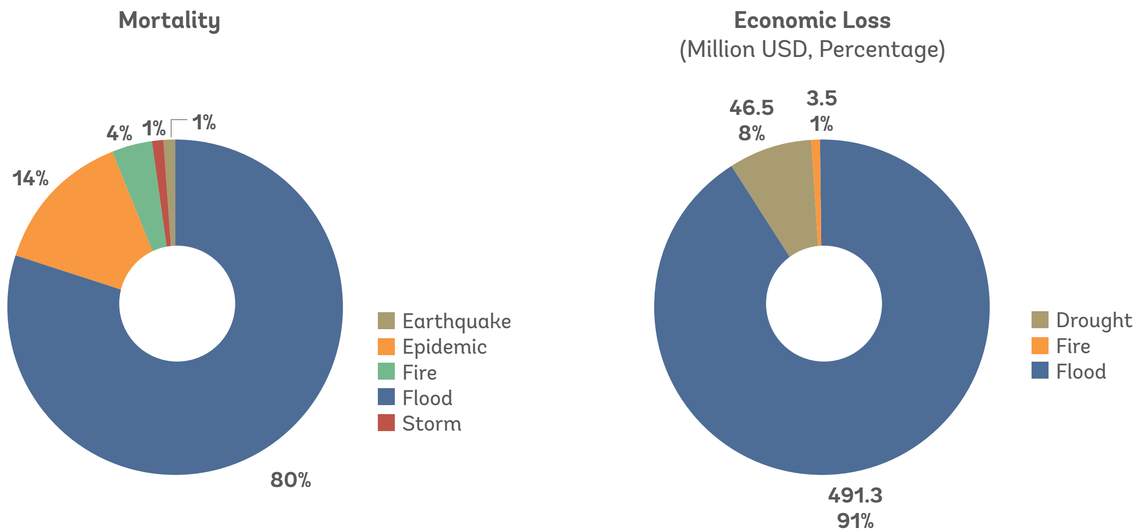
3 SOCIOECONOMIC IMPACTS OF HYDROMET HAZARDS AND DISASTERS

Tunisia is highly vulnerable to natural hazards and climate change, with impacts felt across key sectors of the economy. According to preliminary findings of a WB national disaster risk profile it is estimated that floods may cause an average annual loss (AAL)[3] of US$40 million (or 0.1 percent of Tunisia's 2018 GDP), while the probable maximum loss (PML)[4] from earthquakes over a return period of 250 years is US$882 million (or 2.2 percent of Tunisia's 2018 GDP).[5] Losses incurred between 2011 and 2018 as a result of floods, droughts, and fires were calculated at approximately US$541.3 million, and mortality primarily due to floods and earthquakes amounts to 94 percent (**Figure 7**).

[3] Average Annual Loss (AAL) represents the expected loss per year, averaged over many years.
[4] Probable Maximum Loss (PML) represents the loss amount for a given annual exceedance frequency, i.e. loss expected at a certain annual probability or return period.
[5] As a comparison, a WB study estimated that Morocco's AAL for floods is US$ 433 million and US$ 88 million for earthquakes (WB 2013).

FIGURE 7. Mortality and Economic Losses (2011–2018)



Source: WB 2020

Between 2011 and 2018, Tunisia recorded over 2,550 fires which devastated about 34,000 hectares of forest. In 1957 an earthquake in the Jendouba governorate with a magnitude of 5.6 on the Richter scale caused the loss of 13 lives and the collapse of buildings (ME 2018).

Tunisia has a more diverse economy than other Maghreb countries, with agriculture, industry, mining and tourism as important sectors. Climate change will significantly affect two of these sectors – agriculture and tourism (and related services).

Tunisia's agriculture is primarily rainfed and is thus highly vulnerable to rainfall variability, long droughts and increasing temperatures (Verner 2013). The agricultural sector contributes 11–12 percent of GDP, generates around 6 percent of export earnings, and employs an estimated 16 percent of the labor force (Resolve and GIZ 2013; Van des Gaast 2018). The droughts caused by climate variability and change will particularly affect rainfed cereal farming, with an anticipated reduction of approximately 30 percent in agricultural land area and lower production of crops such as wheat and barley (SNC 2013; Verner 2013). However, climate change will also impact on Tunisia's agricultural exports. Tunisia is a major world producer and exporter of olive oil (globally ranked fifth in 2018) and dates (accounting for 24 percent of global trade) (Ben Ahmed Zaag 2017; Jacobs and Klooster 2012) Currently about 40 percent of all cultivated land is used to grow olives (Van des Gaast 2018). It is predicted that climate change will cause olive production to drop by 50 percent, and that the land area suitable for olive cultivation will decrease by 42 percent in the southern part of the country (Resolve and GIZ 2013). Similar trends are expected for other crops as a result of the rising temperatures and decreasing rainfall attending climate change. Together, higher global food prices and lower local yields will reduce economic growth in Tunisia. Farm incomes are projected to fall by 2–7 percent annually on average from 2000–2030. While farming households will be hardest hit by climate change, rural non-farm and urban households will also be affected by rising global food prices due to climate change.

The Tunisian coast hosts two thirds of the country's population, over 70 percent of its economic activities, including tourism, and most of its irrigated agriculture. By 2100, the anticipated sea level rise (see Chapter 1) will directly affect 5 percent of the Tunisian population, its water resources, natural ecosystems, coastal infrastructure, agriculture (e.g. reduction by 10 percent of irrigated areas) and tourism. Due to the importance of coastal tourism such a rise may have a significant impact on the economy. Droughts, floods, heat waves, and strong winds in combination with climate-induced decreases in water availability and increased water costs are likely to have negative effects on tourism in coastal areas. Climate change (**Figure 8**) will intensify the pressure on Tunisia's water resources to meet the demands of a growing urban population and the agriculture, industrial and tourism sectors (World Bank 2018).

The September 2018 flash floods in the Nabeul governorate caused the death of six people. A Rapid Needs Assessment (RNA), conducted by the Government of Tunisia in partnership with the WB, the United Nations and the European Union estimated recovery needs at approximately US$100 million. Most of these needs were in the transport, agriculture and housing sectors which were significantly impacted by the flooding (**Figure 9**). The Nabeul disaster flagged Tunisia's exposure to the growing risks of climate change.

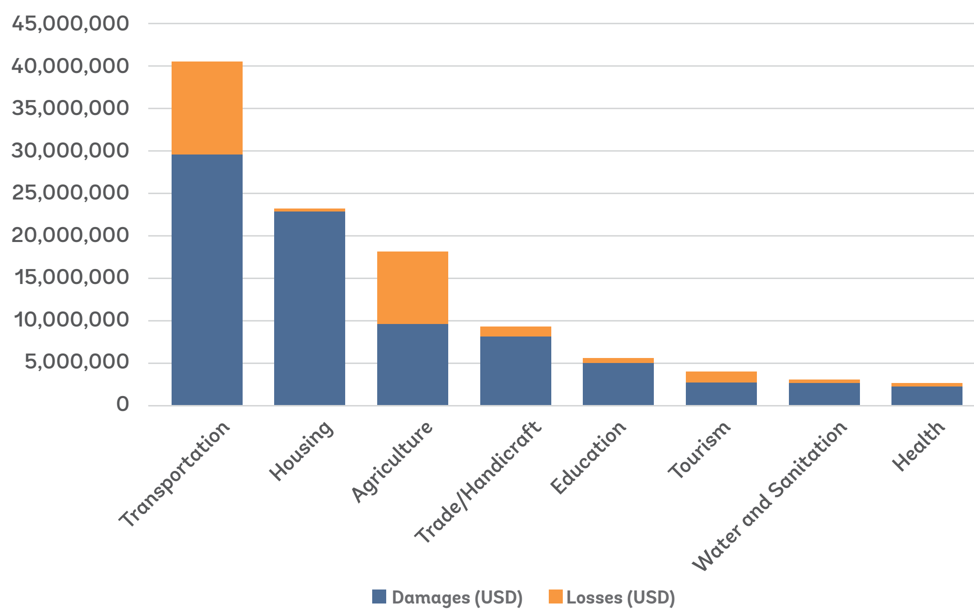
FIGURE 8. Projected Evolution of Urban Risks in Tunis

Urban Risks	**Tunis**	
Horizon	Current	2030
Seismicity/ground/installation	Medium	High
Tsunami/Marine Submersion	Medium	High
Coastal Erosion	High	Very High
Flooding	High	Very High
Water Scarcity	Low	Medium

Very High · High · Medium · Low

Source: World Bank and CMI 2011

FIGURE 9. Nabeul Disaster – Damages and Losses by Sector (in US$)



Source: RNA conducted by the Government of Tunisia in partnership with the World Bank, the United Nations and the European Union in 2018

4 NEEDS ASSESSMENT FOR WEATHER, CLIMATE, AND HYDROLOGICAL INFORMATION AND SERVICES

National Meteorological and Hydrological Services (NMHSs) are public agencies mandated to provide public meteorological (weather and climate) and hydrological information and warning services, although some may also provide commercial services, such as the case of INM in Tunisia.

The provision of weather-, climate-, and hydrological-related forecasting, warning and information services should be shaped by user needs, and in preparing the road map for Tunisia's service providers, the main stakeholders were consulted regarding their use and requirements for products and services. Stakeholders included the National Civil Protection Office (ONPC); Ministry of Agriculture, Water Resources, and Fisheries (MARHP) and its Directorates; the Ministry of Equipment and its Directorates; and the Ministry of the Environment (ME). It is recognized that there are many other stakeholders that would benefit from meteorological and hydrological information and services.

In discussions with officials from these agencies it became clear that stakeholders require a range of services—e.g. weather forecasts, climate change projections, flood forecasts, hydromet-related early warnings, drought prediction, and landslide forecasts. In addition to hazard forecasts, stakeholders also require information on the impacts of these hazards in order to better inform and alert the public. They require information at various temporal resolutions, ranging from nowcasting (0–6 hours) in the case of flash floods to seasonal and longer-range forecasts for planning and preparedness activities, particularly in the water resources management and agriculture sectors. In addition, locality-specific warnings are required.

The ONPC and ME recognize the need for hydromet information to mitigate natural disasters. The ONPC needs to combine data and information from many different ministries, and data exchange protocols (national standards) are essential. For example, a national standard would make it possible to unify geographic information system (GIS) data from different sources. Current risk-estimation tools should be supported by real-time data from several services, and an automatic link for data access with meteorological and hydrological service providers is required. Other needs identified by ONPC and ME include:

a) Automation of meteorological and hydrological information exchange between agencies and shared information between national and local (municipal) levels;
b) Training of ONPC staff to interpret this information, and capacity building/staff training at the ONPC school;
c) Implementation of a national early warning system (EWS) at ONPC to bring together the contributions of different institutions in a single platform;
d) Dissemination of information to users and awareness-raising (public outreach);
e) Land use and urban planning and development considering hydrometeorological information and climate change.

At this stage, there is no operations center at ONPC for integrated disaster risk management; and the associated legal framework will need to be revised.

MARHP requires exchange of critical meteorological observation data (mostly rainfall) and of model outputs/forecasts (global, regional or locally run, and at different timescales), especially for flood forecasting and water resource management.

Even though other socioeconomic sectors in Tunisia were not consulted, **Table 1** gives user requirements by sector for Tunisia.

TABLE 1. User Requirements by Sector

Sector	Rainfall/Snow	Temperature	Wind (spd/dir)	Humidity	Cloud Cover	Visibility	Storm	Wave height	Water level	Discharge	Flood/ Inundation
Disaster management	√	√	√				√	√	√	√	√
Transport	√	√	√	√	√	√	√				
Agriculture and food production	√	√		√			√				
Water resource management	√		√	√			√		√	√	√
Energy	√	√	√				√	√	√	√	
Fisheries	√	√	√			√	√	√	√		
Forestry	√	√	√	√							
Health	√	√					√				√
Media	√	√					√				√
Tourism	√	√	√		√		√	√			√

Data needs vary per user sector, and **Table 2** provides an overview of sectoral data frequency requirements.

TABLE 2. Data Frequency Needs Per User Sector

Sector	Real time	Hourly	Daily	Weekly	Monthly	Seasonal	Longer
Disaster management	√	√	√	√	√	√	
Transport	√	√	√	√			
Agriculture and food production			√	√	√	√	√
Water resource management	√	√	√	√	√	√	√
Energy		√	√	√	√	√	√
Fisheries		√	√	√			
Forestry	√	√	√	√	√	√	√
Health			√	√	√	√	
Media	√	√	√	√	√	√	√
Tourism	√	√	√	√			

5 INSTITUTIONAL AND ORGANIZATIONAL ANALYSIS OF METEOROLOGICAL AND HYDROLOGICAL SERVICE PROVIDERS

While meteorological services in Tunisia are provided by the National Meteorological Institute (INM), hydrological and climatological services are fragmented. Many activities related to water resources management are the responsibility of the Ministry of Agriculture, Water Resources and Fisheries (MARHP) and its Directorates/Institutions. However, all environment-related aspects, including urban sanitation, fall under the Ministry of the Environment. The Ministry of Public Health is responsible for water quality control in general and The Ministry of Equipment for urban flood management.

In this section, we focus on meteorological (weather and climate) and hydrological service providers; therefore, the detailed institutional and organizational analysis pertains primarily to INM, and Directorates within the MARHP, namely the General Directorate of Water Resources (DGRE), the General Directorate of Dams and Hydraulic Works Department (DGBGTH). Other Directorates and Bureaus have observation stations as part of pilot Early Warning Systems (EWS) in vulnerable areas, and/or specific projects, and these were established with the above-mentioned Directorates. This is particularly the case for monitoring of certain hill lakes and the development of a territorial observatory by the General Directorate of Development and Conservation of Agricultural Lands (DGACTA).

5.1 National Meteorological Institute (INM)

5.1.1 Brief History and Current Institutional Status

The first Meteorological Service in Tunisia was created in 1885 in Tunis-Manoubia and meteorological activities began in 1873. Law No. 2009-10 of 16 February 2009 established the INM as a public institution under the Ministry of Transport, and since its inception it has gone through various reforms and changes of status.

The INM's mission and organization are described in Article 2 of the Decree No. 2009-10 of 16 February 2009, as follows:

a) Satisfy the meteorological, geophysical and climate information needs of various sectors of the economy including meteorological services to air navigation, shipping, agriculture, and tourism;
b) Design programs and policies to develop meteorology, geophysics, and climatology through technological and scientific progress;
c) Contribute to sustainable development through programs for environmental protection, conservation of natural resources and quality of life;
d) Protect life and property from natural and industrial disasters; and mitigate their effects with the agencies concerned;
e) Coordinate technical aspects related to meteorology (weather and climate) and geophysics;
f) Manage and maintain meteorological and geophysical databases;
g) Prepare technical and economic studies relevant to its mandate;
h) Carry out basic and applied research to develop meteorology (weather and climate) and geophysics;
i) Implement international agreements subscribed to by Tunisia in meteorology and geophysics;
j) Provide services for which a fee is charged, as part of its mission; the list of services and related rates are set by the Minister of Transport.

Since then, the INM has adopted a commercial policy, offers multiple products and services in the fields of weather, climate, and seismology, and pursues its mission in two major fields:

i) Meteorology, which is the backbone of INM's activity, and for which it has many facilities for:
   a. Observation, storage, exchange and processing of meteorological data;
   b. Weather forecasting;
   c. Climatology, and applied meteorology and research;
ii) Geophysics and astronomy, which has been added to the INM's brief, and which covers:
   a. Measurement and monitoring of seismic activity, and applied geophysical studies;
   b. Observation of the lunar crescent and preparation of the lunar calendar for religious purposes;
   c. Setting lunar and solar eclipse dates and drawing up ephemeris;
   d. Measurement and processing of different types of solar radiation.

The current organizational chart of the INM is provided in **Figure 10**. The INM is headed by a General Management supported by a Council. There are four operational and technical departments; three departments for administration, human and financial resources, planning, international relations, communications and marketing; and six regional sub-divisions – Tunis, Jendouba, Sousse, Sfax, Touzer, and Medenine – to: (a) implement the directives of the central administration; (b) provide meteorological assistance for air and maritime navigation; (c) study meteorological factors which impact on regional economic development; and (d) manage meteorological stations . The INM is currently re-organizing to improve service delivery and its new organizational chart and justification note have been submitted to the Ministry of Transport.

FIGURE 10. Organizational Chart of the National Meteorological Institute (INM)

Source: INM

The INM has a strategic plan for 2015–2020, and is preparing a 2021–2025 update to help it contribute more effectively to the following eight strategic pillars of its mission:

1. Ensure the best possible air navigation service and anticipate regulatory changes.
2. Contribute to the safety of life and property in the face of natural and industrial disasters.
3. Strengthen expertise and upgrade technical resources in core business areas.
4. Develop managerial culture, modernize management (administrative, financial, HR) and adapt the organization, in particular through a better presence in the regions.
5. Develop capacity for innovation by strengthening R&D.
6. Develop institutional cooperation and international projects, and proactively mobilize resources.
7. Improve customer orientation and services, and develop commercial products comparable to those of other national meteorological agencies.
8. Increase the visibility of the INM and facilitate access to services.

5.1.2 Human Resources

As of December 2019, INM had a workforce of 314 (244 male and 70 female), of whom 61 were Engineers (MSc and PhD holders), 184 senior technicians (MSc and Bachelor's degree), 4 computer scientists (Bachelor's degree), 24 managers/accountants (Bachelor's degree and MSc), and 41 technicians holding a high school certificate; staff numbers have declined recently. A list of personnel for 2016–2019 is given in **Table 3**.

TABLE 3. INM Personnel

Grade	Education level	2016		2017		2018		2019	
Engineers	MSc and PhD	47	25	46	24	45	22	40	21
Senior Technicians	Bachelor's degree and MSc	149	30	158	28	152	26	156	28
Computer scientists	Bachelor's degree	4	6	3	4	2	3	2	2
Managers/ Accountants	Bachelor's degree and MSc	9	16	8	16	10	14	10	14
Technicians	High school certificate	50	9	45	8	38	7	36	5
TOTAL (Male/Female)		**259**	**86**	**260**	**80**	**247**	**72**	**244**	**70**
GRAND TOTAL		**345**		**340**		**319**		**314**	
Employee/Management Ratio		**42 percent**		**42 percent**		**43 percent**		**43 percent**	

Source: INM

The average salaries of INM personnel are given in **Table 4**. The need for more capacity has been identified by INM in the following areas for existing staff: research and development in meteorology, management, production (weather forecasting and climate services), observations and ICT, marketing, geophysics and astronomy. A list of training topics, indicating staff numbers and priorities, is provided in **Annex I**.

TABLE 4. List of Average Salaries of INM Personnel (in Tunisian dinars)

Grade	Monthly salary	Annual salary
Meteorologist	2 607	38 326
Computer scientist	2 607	38 326
Analyst (informatics)	2 422	35 612
Technician	1 844	27 701

Source: INM

5.1.3 Budget

INM's main sources of funding are: the government, commercial activities, and cost recovery (e.g. from meteorological services for air navigation). The budget of INM in 2019 was 20 585 000 Tunisian dinars (approximately US$7,2 million). Revenue from charges has provided approximately 77 percent of the annual budget of INM, with most income coming from services to aviation. A breakdown of the INM budget for 2016–2019 is given in **Table 5**. Data indicate that INM's budget is increasing while government funding for salaries has been decreasing. The capital budget from government increased significantly in 2019 by 1,4 million Tunisian dinars (US$490 000).

TABLE 5. Income of INM for 2016–2019 (in Tunisian dinars)

Source of funding	2016	2017	2018	2019
Government funding (for salaries)	3 000 000	1 920 000	2 800 000	2 400 000
Revenue from services provided to aviation	5 745 544	10 000 492	13 074 376	14 650 000
Revenue from weather and climate services provided to non-aviation sectors	712 846	702 000	766 319	784 000
Other (miscellaneous) revenues	52 261	189 000	349 600	442 000
Capital budget from the Government	1 350 000	650 000	900 000	2 309 000
TOTAL	**10 860 651**	**13 461 492**	**17 890 295**	**20 585 000**

Source: INM

INM's budget allocation from government is below international benchmarks. For instance, in most developed countries, government allocations to national meteorological agencies are above 0.01 percent of GDP for salaries, operations and maintenance (O&M) and capital investment, a figure which Tunisia falls far below. For Tunisia, under the 2019 GDP, this would equate to an allocation from the government of US$4.0 million (approximately 11,4 million Tunisian dinars) for meteorology alone, while the actual allocation from the government in 2019 was 4,7 million Tunisian dinars. In addition, the INM's dependency on revenue from services to aviation exceeds that of comparable agencies, and this income may fall following membership of the Single European Sky in 2017, flagging the need for up-to-date Quality Management Systems (QMS) and ISO Certification of these products. Given that most of the socioeconomic sectors contributing to Tunisia's GDP are weather and climate related, the government budget for INM should be higher under current levels of GDP.

A breakdown of INM expenditure for 2016–2019 is given in **Table 6**. Expenditures have increased over the last four years, especially in 2019 due to increases in salaries and investments.

TABLE 6. INM Expenditure for 2016–2019 (in Tunisian dinars)

Type of expenditure	2016	2017	2018	2019
Salaries	6 500 000	8 369 000	8 750 000	10 572 000
Operating expenditures	2 786 258	2 647 656	2 672 727	2 466 000
Maintenance/replacement expenses	84 933	309 214	350 000	298 000
Investments	1 089 000	381 600	625 000	2 156 000
TOTAL	**10 460 191**	**11 707 470**	**12 397 727**	**15 492 000**

Source: INM

5.1.4 National and International Agreements, Conventions and Memoranda of Understanding

Tunisia has been a member of the World Meteorological Organization (WMO) since 1957; the INM Director General serves as the Permanent Representative of Tunisia with WMO, participates in World Meteorological Congresses, the Regional Association I (Africa) sessions, the Intergovernmental Board on Climate Services (IBCS), and African Ministerial Conference on Meteorology (AMCOMET). INM staff are active members of WMO Technical Commissions and Mediterranean Climate Outlook Forums (MedCOF), and also work with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the Arab Permanent Committee on Meteorology (APCM) and its sub-groups.

The INM has established a number of international cooperation programs, conventions, and memoranda of understanding, as listed in **Table 7**. Within the framework of the twinning projects supported by the European Commission, an institutional program to strengthen the technical capacities of INM was established in 2015 between Tunisia and France. This program focused on technical collaboration in the fields of observations, information systems and production; training, and development of commercial services for aviation.

TABLE 7. International Cooperation Programs, Conventions and Memoranda of Understanding

Cooperation program/ convention/ Memorandum of understanding	Area of cooperation	Effective date	Nature of the agreement
Framework partnership agreement between Météo-France and INM	Scientific and technical cooperation in meteorology (weather and climate)	January 2009	Framework Agreement
Consortium ACCORD (A Consortium for Convection-scale modeling Research and Development)	Multilateral cooperation	2020	Convention
Météo-Maroc	Scientific and technical cooperation in meteorology (weather and climate)	October 2017	Memorandum of Understanding
Mauritania	Scientific and technical cooperation in meteorology (weather and climate)	June 2012	Convention
Jordan	Scientific and technical cooperation in meteorology (weather and climate)	July 2019	Memorandum of Understanding

Source: INM

At the national level, conventions and memoranda of understanding with partners are listed in **Table 8**.

TABLE 8. National Conventions and Memoranda of Understanding

Institution	Nature of services/ conventions	Area of activity	Effective date
Office of the Civil Aviation and Airports	Meteorological services to air navigation	Air Transport	17 June 2003
TV National Channel	TV Bulletins	Communication and Information	27 June 2002; updated on 26 August 2009
National Radio	Radio Bulletins	Communication and Information	27 June 2002; updated on 11 April 2012
Radio IFM	Radio Bulletins	Communication and Information	15 November 2016
Radio Mosaïque FM	Radio Bulletins	Communication and Information	1 February 2012
TPS (Tyna Petroleum Service) Company	Meteorological Assistance	Energy	30 May 2009

Institution	Nature of services/ conventions	Area of activity	Effective date
SEREPT (Petroleum Research and Exploitation Company in Tunisia) Company	Meteorological Assistance	Energy	10 August 1979; updated on 15 December 2009
ENI Tunisia BV	Meteorological Assistance	Energy	1 January 2015
Tunisia Telecom	Meteorological Bulletins	Communication and Information	7 March 2019
GETWIRELESS Company	Meteorological Bulletins	Communication and Information	5 June 2005
Carthage Cement Company	Seismic Surveys	Safety	1 July 2017
INGC (National Institute of Field Crops)	Meteorological forecasts and climate data	Agriculture	20 May 2010
DGRE (General Directorate of Water Resources)	Rainfall data	Hydrology	2018
MARHP (Ministry of Agriculture, Water Resources and Fisheries)	Meteorological forecasts and climate data	Agriculture, Hydrology, Fisheries, and Research	February 2020

Source: INM

5.2 Ministry of Agriculture, Water Resources and Fisheries (MARHP)

The MARHP is mainly responsible for public domain management, mobilization and development of water resources, water management projects and agricultural withdrawals, and provides water for domestic and other uses. The organizational structure of the Ministry of Agriculture, Hydraulic Resources and Fishing was established by Decree No. 2001–419 of 13 February 2001, developed for the General Directorates by Decree No. 2001–420 of 19 February 2001, and modified by Decree No. 2011-1560 of September 5, 2011. The MARHP departments with roles in water resources management and hydromet are:

- General Directorate of Water Resources (DGRE);
- General Directorate of Dams and Hydraulic Works Department (DGBGTH);
- Bureau of Water Planning and Hydraulic Equilibriums (BPEH);

and for other related aspects:

- General Directorate for Development and Conservation of Agricultural Land (DGACTA); General Directorate of Rural Engineering and Water Exploitation (DGGREE);
- National Society for Exploitation and Water Distribution (SONEDE); National Society for the Exploitation of the Northern Water Canal and Adductions (SECADENORD).

The MARHP is represented at regional level by the Agricultural Development Regional Offices (CRDA) in the country's 24 governorates. In addition to the MARHP and its subordinates, governance of the water sector is shared by different ministries and agencies such as the National Water Exploitation and Distribution Company (SONEDE), responsible for drinking water, and the National Office for Sanitation (ONAS) (WGS 2016).

This sectoral and national/regional organization plays a major role in the management of disasters, in particular floods, according to the inter-ministerial transversal framework provided by:

- Law 91-39 of 8 June 1991 related to disaster prevention and relief;
- Decree 93-942 of 26 April 26, 1993, fixing the modalities to apply Law 91-39 of 8 June 1991, regionally and nationally;
- legal texts, in particular in the Code of Land Use and Town Planning, the Water Code and the Forest Code.

5.2.1 Office of Planning and Hydraulic Balance (BPEH)

BPEH is the General Directorate attached to the Ministerial Cabinet which coordinates players in the water system, mobilizes water resources, allocates water, and monitors the water system's functioning. The BPEH reports to the Minister of Agriculture and is accountable for (OECD 2014):

- Planning the mobilization of conventional water resources and development of non-conventional water resources to meet medium and long term demands, and increasing water demand in the different sectors;
- Scheduling of annual water allocations so as to meet demand;
- Managing risk and providing emergency plans to deploy resources during droughts or floods, or failures in production and distribution of water;
- Coordinating between service providers and water users in different sectors.

BPEH is organized in three cells (Decree No 2011-1560):

- Water-related planning;
- Annual hydraulic scheduling;
- Monitoring management of the hydraulic sector.

The BPEH is developing the 'Water Strategy 2050'. The Government of Tunisia received a €1 million grant to develop a national water vision and strategy for water resources up to 2050, and to increase water security. The purpose of this 3-year project is to support socio-economic development by providing water efficiently, equitably, and sustainably by 2050 through a structured, integrated and participatory vision and strategy. To achieve this, the project will follow the following intermediate steps:

a) Define a long-term vision (horizon 2050) based on diagnosis of the water sector and sub-sectoral prospective studies.
b) Use the vision to develop a strategy.
c) Translate the strategy into objectives and activities.

The main components of the 'Water Strategy 2050' project are:

- Its operational framework
- Its vision and strategy
- Its terms of reference for master and action plans
- Project management. This project will help the government make informed and guided decisions about water investments and projects across the country (ADBG 2022).

5.2.2 General Directorate of Water Resources (DGRE)

The DGRE is responsible for:

- Developing methods to manage water resources, balancing supply and demand;
- Developing plans to exploit surface and ground water in rural and urban Tunisia;
- Promoting research on conventional and nonconventional water resources;
- Managing and growing the observation network to monitor water quantity and quality in rivers and aquifers;
- Developing research capacity to assess water resource balances.

The DGRE works at the intersection of intra- and inter-ministerial management of resources and of water-related disasters in natural environment and rural areas.

5.2.3 General Directorate of Dams and Hydraulic Works Department (DGBGTH)

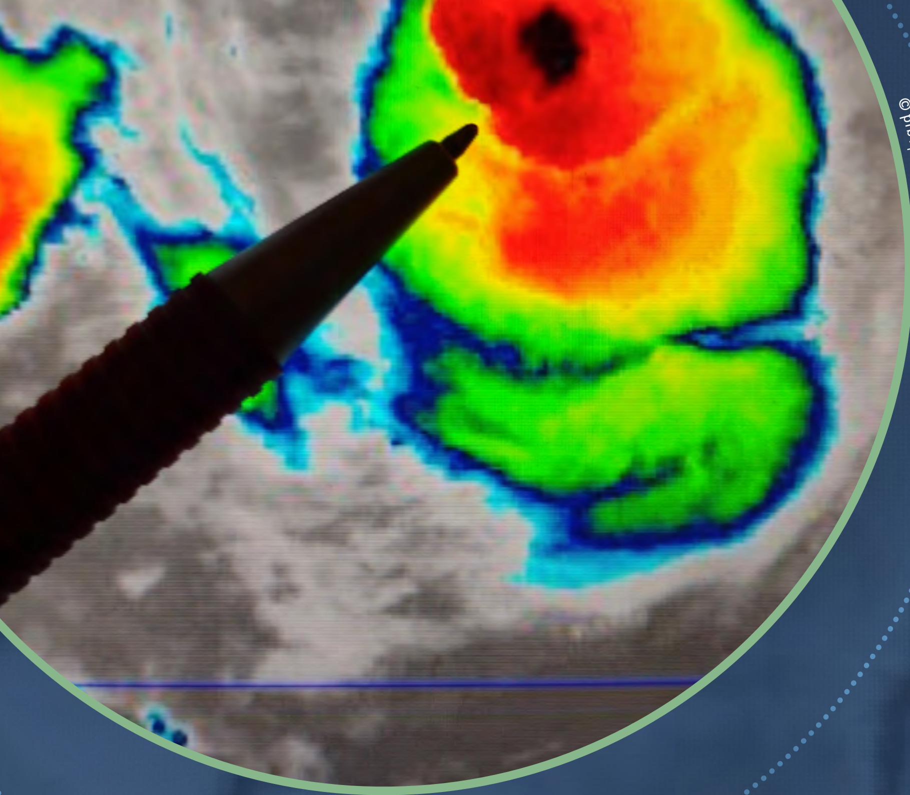
The DGBGTH is responsible for:

- Hydraulic studies;
- Master plans for surface waters;
- Studies and plans for water mobilization;
- Studies of large hydraulic structures (e.g. large dams, hill dams, canals) and supervising their construction;
- Monitoring and maintaining dams;
- Drainage, hydraulic exploitation, transfter and protection of rural and agricultural areas.

5.3 Transboundary Aspects

These aspects concern the upper Medjerda basin, where a joint Algeria-Tunisia technical committee, led by the two Prime Ministers, has met since 1985, and is supported by a monitoring committee established in 1991. In 2006, Algeria, Libya and Tunisia agreed to manage and share the Aquifer System of the Northern Sahara (NWSAS). As a Maghreb State, Tunisia is a member of the Sahara and Sahel Observatory (OSS), an international intergovernmental organization to encourage partnerships to manage shared water resources[6], based in Tunis since 2000.

[6] Observatoire du Sahara et du Sahel (Sahara and Sahel Observatory) - see http://www.oss-online.org/en



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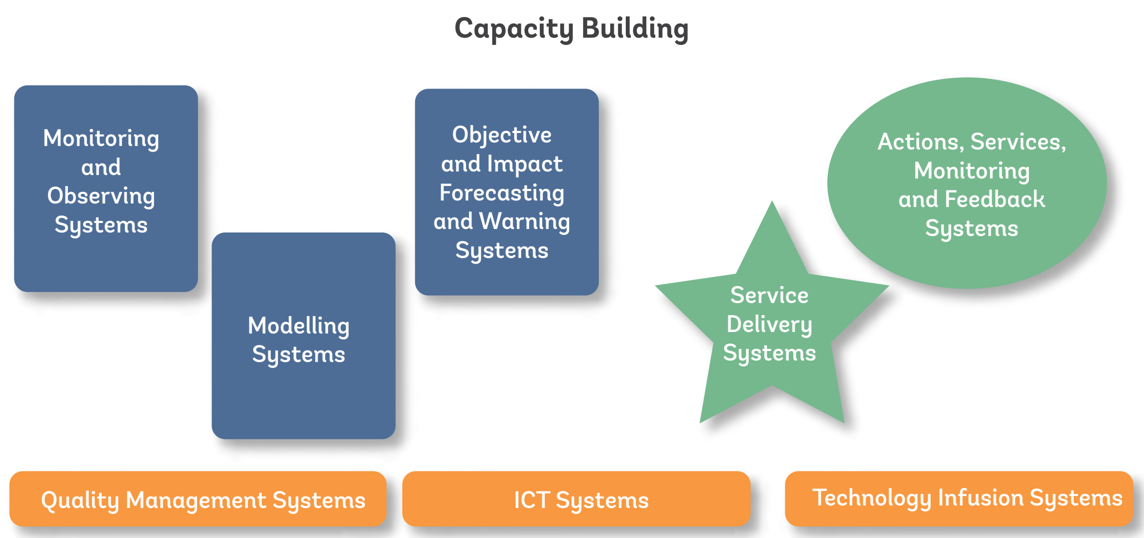
6 TECHNICAL ASSESSMENT OF METEOROLOGICAL AND HYDROLOGICAL SERVICE PROVIDERS: *CURRENT STATUS*

6.1 Methodology

Modernizing meteorological and hydrological service providers is complex and costly. Therefore, such an endeavor should follow a structured, long-term plan based on a sound strategy reflecting the needs of the stakeholders and the end user community.

A typical National Meteorological and Hydrological Service (NMHS) is a system-of-systems grouped in three categories: delivery systems, production systems and supporting systems – all supported by capacity building (**Figure 11**). This is also referred to as the "hydromet value chain" (GFDRR 2020; WMO et all 2015). This generic conception of a weather, climate or hydrological system-of-systems can be used to analyze an NMHS and to identify investment needs, component-by-component, in each system to achieve a particular level of improvement. The complexity of each system and its sub-systems varies with the size, level of development, and resources of the NMHS, but the building blocks are inter-dependent. In Tunisia, the division of responsibilities (i.e. INM is responsible for weather and climate services, and the MARHP [DGRE, DGBGTH, DGACTA, and BPEH] for water-related services) compounds the complexity.

FIGURE 11. The NMHS System-of-Systems



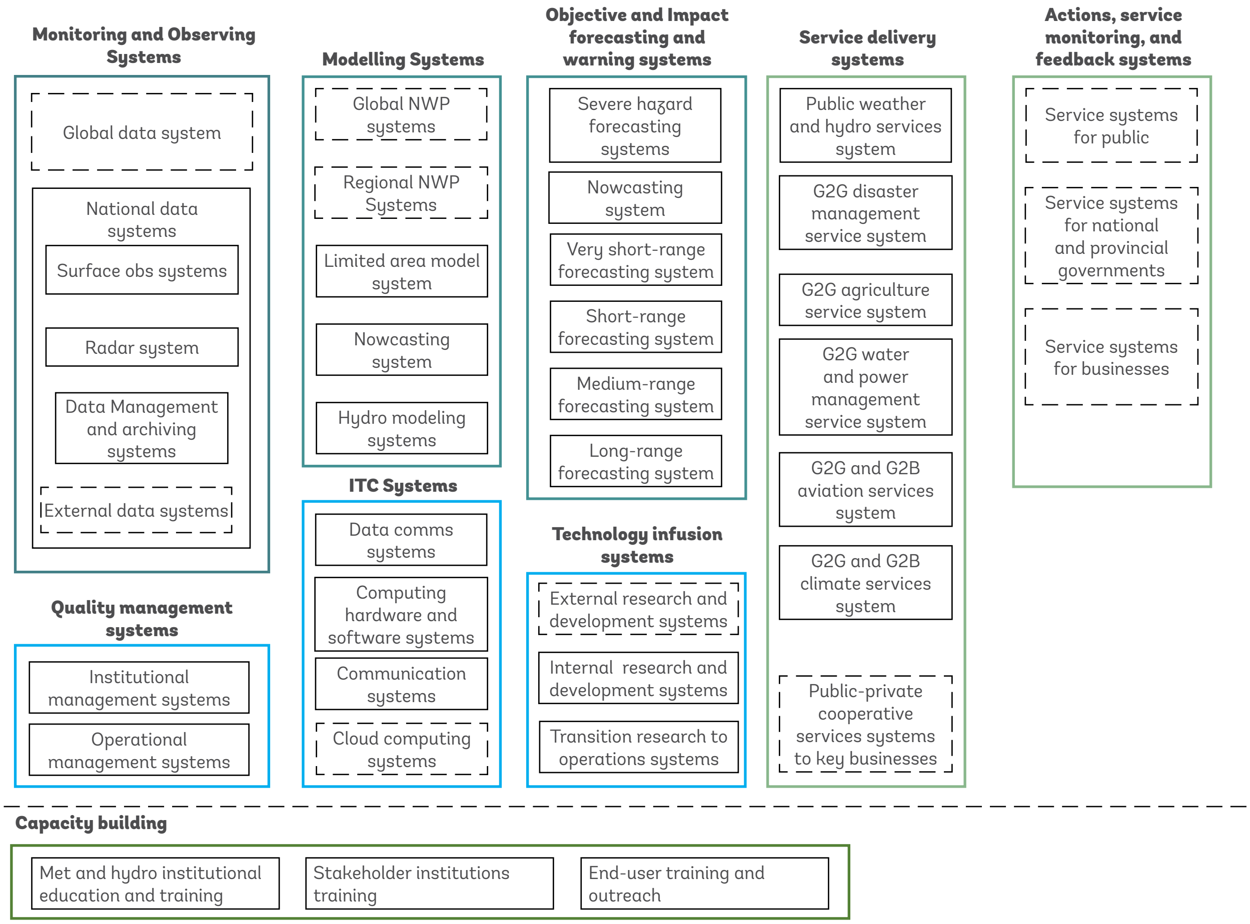
Source: Rogers *et al.* 2019 ***[green – delivery systems; blue – production systems; brown – supporting systems; light brown – capacity building].***

To modernize hydromet services, the first step is to analyze the structure of the institutions to which changes will be made. **Figures 12 and 13** present the typical system-of-systems for a National Meteorological or Hydromet Service (such as the INM) and the operational system of a National Hydrological Service (NHS) for the production of flood forecasts; in which production and delivery systems need to be supported by quality management, ICT, and capacity building systems. The "system-of- systems" in **Figure 13** is run/operated by General Directorates within the MARHP. The solid lines in the boxes indicate typical internal subsystems, while the broken lines indicate either external or mixed internal and external subsystems.

Single agency service providers such as the NMHS are better able to coordinate their inputs to avoid breaks in the hydromet value chain (see Chapter 7). In most countries, (and in Tunisia) these services are provided by different organizations, and thus, the exchange of data and modelling outputs (global, regional or locally run) is critical, especially for flood forecasting. These differences are illustrated in **Figures 12 and 13** by the solid or broken lines for various subsystems. In some countries, meteorological and hydrological service providers collaborate to produce flood forecasts and warnings, and in these cases, cross-training of meteorologists and hydrologists is needed. These aspects, in relation to data exchange arrangements in Tunisia, are discussed under item 6.3 below; and in the context of modernizing hydromet services in Chapter 7.

The first requirement for hydromet services is staff with the capacity to understand and operate a particular system. This Road Map employs a system-of-systems approach in the remainder of this chapter to describe the status of meteorological and hydrological service providers, and to arrive at three phases required to modernize them.

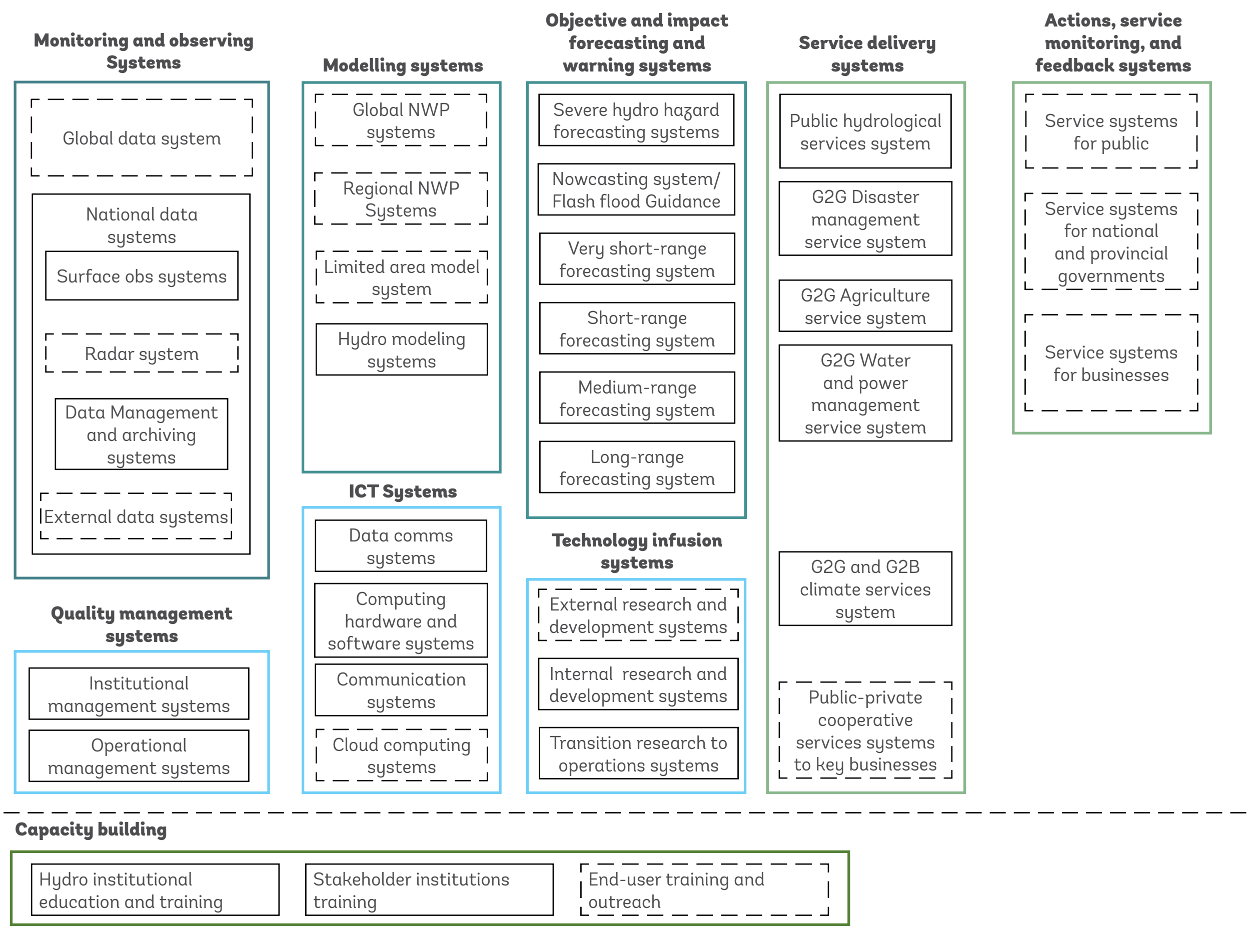
FIGURE 12. Generic System-of-Systems for an NMHS



Source: Rogers et al. 2019

[green – delivery systems; dark teal – production systems; cyan – supporting systems; dark green – capacity building].

FIGURE 13. System-of-Systems Concept of Operational Flood Forecasting by a National Hydrological Service



Source: Rogers et al. 2019
Note: G2G = government-to-government; G2B = government-to-business. ***[green – delivery systems; dark teal – production systems; cyan – supporting systems; dark green – capacity building].***

6.2 Delivery Systems

NMHSs must compete for scarce public resources, and need to demonstrate their value by offering affordable, useful products and services (WMO 2014). Policy makers and the public continually assess the value of NMHSs based on their ability to meet the service delivery standards of client countries. Even the best forecast, issued on time, will have little effect if it does not generate the desired response from those at risk. This means that the utility of weather-, climate-, and water-related information depends on the degree to which it has a beneficial effect on societal and economic outcomes (WMO 2015). When available information is underutilized, value can be increased by improving the forecast, enhancing communication, and refining the decision-making process.

Thus, an effective service provides products which have utility to users. It is essential to understand the users' value chain in order to gain knowledge about users, the decisions they must make, and how weather-, climate-, and water-related information is applied to minimize risk and provide benefits, not only for specific user groups but also for society as a whole. With this knowledge, service providers are able to offer products which are useful, relevant, and responsive. NMHSs should be able to measure the value of their information to society and continually evaluate and improve it. Adopting a more collaborative approach provides everyone in the service delivery process—providers, users, and partners—with a clear understanding of service needs. In this section, a detailed description of the services offered by INM and MARHP (DGRE, DGBGTH, DGACTA and BPEH) is provided.

6.2.1 Public Weather Services Systems

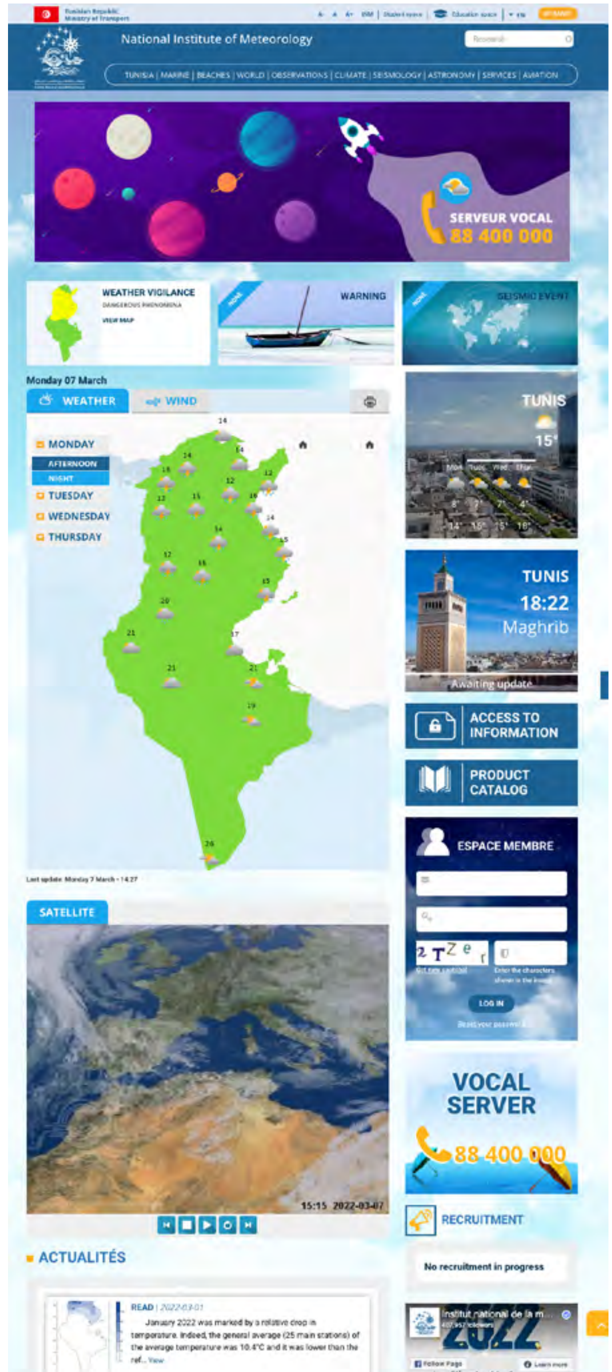
The INM Forecast Office runs 24/7/365, with three shifts of five forecasters: the daytime shifts of 6 hours each, and the night shift of 12 hours. For other tasks (mostly management related), there are two additional daytime staff.

Public weather services (PWS) are issued by INM in French, Arabic and English. At least twice a day (at 7:00 and 17:00 local time), INM produces weather forecasts (significant weather, cloudiness, precipitation, maximum and minimum temperature, and wind) for the territory of Tunisia for the actual day D (with detailed forecasts for the morning, afternoon and night) plus three days ahead (for D+1, also with detailed forecasts for the morning, afternoon and night; while for D+2 and D+3 the forecasts are for 24 hours). INM also issues medium-range forecasts for D+3 to D+6. These forecasts are posted on the INM's new website (https://www.meteo.tn/) which was launched in French and English on 4 May 2020 (**Figure 14**). INM has a strong presence in the media (TV and Radio; with whom INM has a long-standing relationship through formal Memoranda of Understanding/Conventions – see Chapter 5), the internet, and on Facebook and Twitter which are the most widely used sources of PWS information.

The INM website also provides three-day weather and wind forecasts for a number of cities, and severe weather warnings; alongside other specialized forecasts (marine, climate, aviation, etc. – described in related sections). A weather application is operational on Android just one month following the launch of the website. The INM Facebook page contains some weather information and also provides feedback from users on the weather forecasts from time to time. INM operates an automatic telephone answering system for weather information, and the public can also reach forecasters by phone; and during severe weather, forecasters receive many enquiries from the public. SMS messages are sent by the INM Sub-Directorate of Information Systems and Communications to subscribers in government, private companies and the public. In addition to regular services to the media, state and private television reporters often interview INM forecasters for their respective outlets during severe weather.

INM conducts outreach and public education, but while it receives user feedback via social media, it has no formal mechanisms to evaluate user satisfaction. INM interprets

FIGURE 14. Screenshot of the New INM Website Homepage



Source: INM website

and/or translates its forecast to help users make daily decisions, and offers information on the possible impacts of hazards (see item 6.2.3).

In addition to meteorological (weather and climate) monitoring and forecasting, INM has been working on air quality, including sandstorm forecasts for Tunisia. Other public forecasts e.g. marine, aeronautical, etc. are described in the sections below.

INM subscribes to the WMO competency guidelines specifying the requirements for education and training of personnel in meteorology, including public weather services.

6.2.2 Water Resource Management and Flood Forecasting Services Systems

A National Hydrological Service (NHS) is an institution which informs decision makers about the water (or hydrological) cycle and the status and trends of a country's water resources. Typically, it assesses water resources, including drought monitoring and outlooks, and flood forecasts and warnings. In most countries, including Tunisia, NHS functions are dispersed among related water agencies. In Tunisia, as described in Chapter 5, many such functions fall under MARHP and the Directorates/ Institutions under its authority (primarily the DGRE and the DGBGTH), while flood management in urban areas falls under the Ministry of Equipment – Directorate of Urban Hydraulics (DHU).

DGRE and the DGBGTH are responsible for monitoring, modeling, forecasting, research, and developing hydrological methodologies to produce information for a variety of purposes. This information is published daily by the DGBGTH on the two onagri platforms (onagri.nat.tn & agridata.tn) and sent daily by email directly to the decision-makers and partners concerned.

Hydrological forecasts are provided by (a) the DGBGTH for dam control management and inundation risk systems, based on established hydrological and hydraulic modeling initiatives supported by development partners (JICA, Korea International Cooperation Agency (KOIKA), and KFW) – see 6.3.2 for details of current hydrological modeling capabilities, and 7.2 for development partner initiatives; and (b) the DGRE for flood forecasting in pilot basins and catchments, based on experiments – further information on modeling capabilities is provided in 6.3.2. While DGRE has qualified and experienced staff, they are unable to reliably run models and issue real time forecasts; additionally, hydrological information, observations and modeling are insufficient upstream of certain dams to meet management needs (in particular the strategic dams of Sidi Salem, Bouheurtma, Mellègue, Barbara, Sidi Barrak and Sejnene).

In the AGIRE program supported by GIZ, a SYstem for COllecting Hydrological Data in Real-time and Flood Alert (SYCOHTRAC) and the corresponding platform has been initiated over the last two years; the program prioritizes visualization of time series and geographic features, exchange formats, automatic updating procedures and management of rights.

A pilot telemetry system for the 6 strategic dams (Sidi Salem, Bouheurtma, Mellègue, Barbara, Sidi Barrak and Sejnene) has been set up within the framework of the same project (AGIRE) with the GIZ, it is currently in its final test phase. This system is composed of equipment and materials for the collection, acquisition and transmission of hydrological data, materials and equipment for analysis and processing, and a web platform for viewing and publishing daily reports on the hydraulic situation of dams.

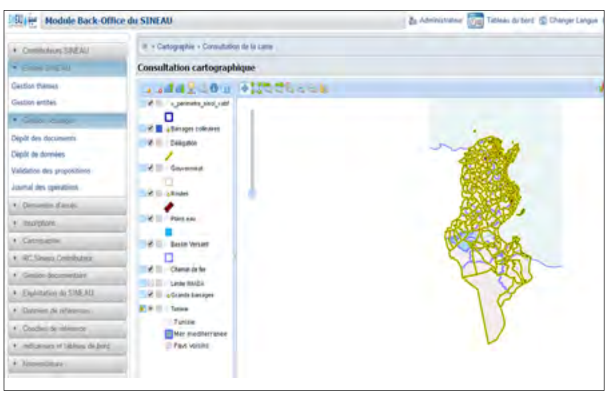
With the support of development partners (GIZ, KfW and AdB), the National Information Systems for Water Resources (SINEAU) has been developed to automate data processing in order to better manage water resources, both in terms of quantity and quality. The SINEAU Portal elaborates on the SYGREAU and SYCOHTRAC water resources management systems of the DGRE and and the telemetry system managed by the DGBGTH, and receives inputs from Directorates within the MARHP, the general ministerial ONAGRI portal, and from INM (rainfall data). **Figure 15** provides a screenshot of the SINEAU website homepage, **Figure 16** shows examples of the products and services managed by the DGRE and **Figure 17** shows the daily situation of the dams managed by the DGBGTH, which are provided under the Portal. For floods, see hydrological vigilance under 6.2.3.

Each year, BPEH, with the support of DGRE, DGBGTH, and other Directorates, prepares the national water sector report, and studies on floods and droughts.

FIGURE 15. Screenshot of the SINEAU Website Homepage

Source: SINEAU website

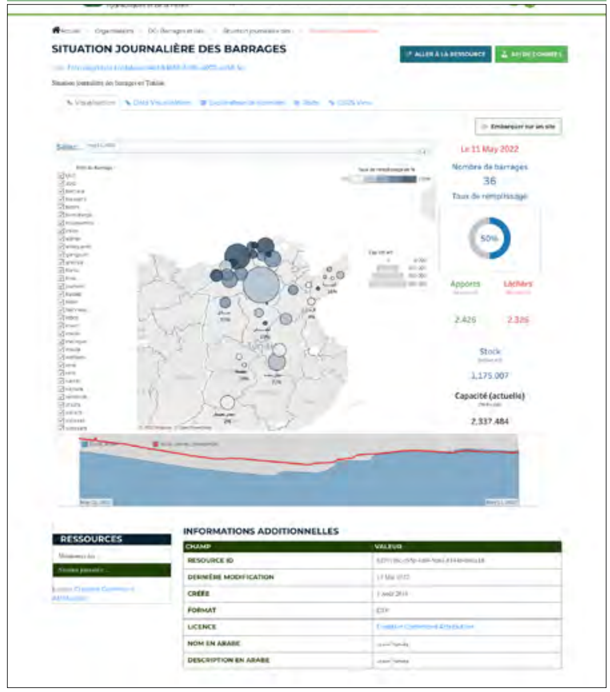
Figure 16. Example of the products and services managed by the DGRE



6.2.3 Disaster Management Services Systems

The INM, with the National Civil Protection Office (ONPC), BPEH, DGBGTH and the Ministry of the Environment (ME), has been working on a meteorological vigilance maps tool ("*Carte de Vigilance*") designed to inform people and public authorities of hazardous weather (i.e. strong winds, rainfall, thunderstorms, heat/cold waves, snow, fog, and sandstorms) in Tunisia, highlighting possible impacts/damages and self-protection measures (behavior). Vigilance is also designed for Civil Security services and health care authorities, who can use it to direct intervention teams and health professionals.

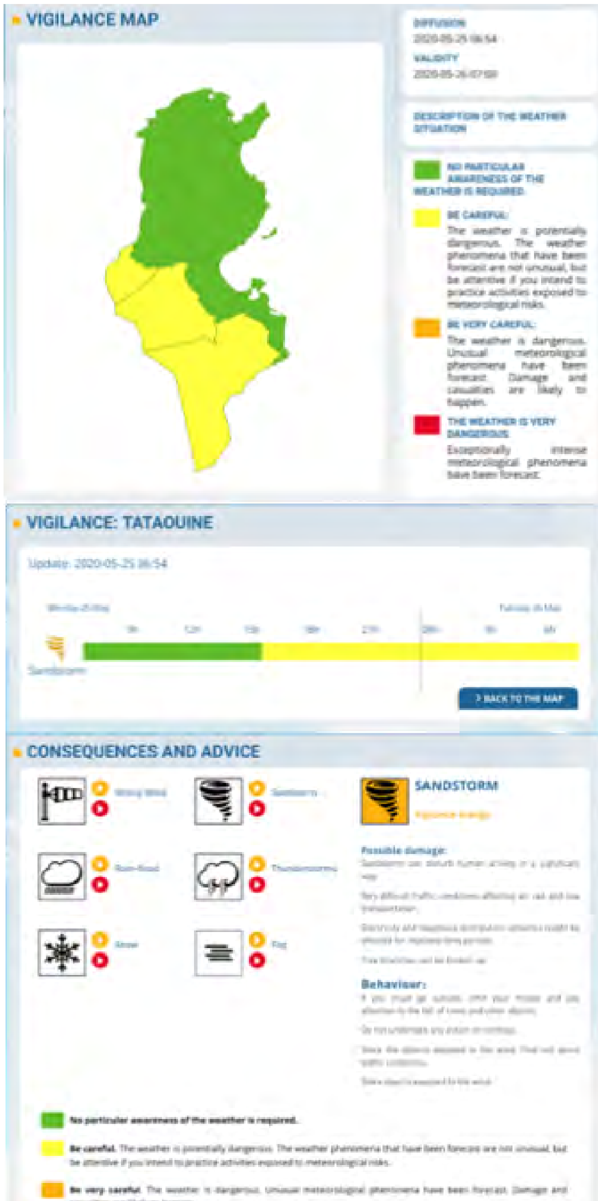
Figure 17. Example of the daily situation of the dams managed by the DGBGTH



The Vigilance map is updated at least twice a day at 7:00 and 17:00 local time, and notes hazards to governorates over the following 24 hours. Four colors correspond to four levels of vigilance, based on well-established thresholds for warnings. Each governorate is colored in green, yellow, orange or red, depending on the meteorological situation and the required level of vigilance. The map can be updated in real time, with colors changing to reflect increasing intensity of the hazardous phenomenon. The maps are available on the INM website at https://www.meteo.tn/en/vigilance-meterologique. **Figure 18** gives an example of a meteorological vigilance map, the information for a specific governorate, and related consequences and advice. INM is working with DGRE and for the expansion of the Vigilance system to include floods and develop *"Vigilance Crues"*[7] – *VigiCrues*, also relying on the ongoing development of SYCOHTRAC.

[7] *Crues* mean floods.

FIGURE 18. Example of a Meteorological Vigilance Map and Associated Information



Source: INM website

Current hydrological vigilance is based on the DGRE's telemetry system in which warning and overflow levels are set on the basis of feedback. Once water levels trigger an alert level, an SMS automatically informs authorities who initiate flood responses. Also, the volume of inflow for each dam, under flood conditions, is estimated by the DGBGTH. Each dam site calculates the outflow separately, based on the information provided by the DGBGTH.

DHU of the Ministry of Equipment is responsible for city flood protection studies. With support from the World Bank, terms of reference have been developed for an urban flood risk reduction strategy. Important elements include land-use planning based on hydromet and climate change data, observation systems for urban flooding, and increased lead times for alerts. Currently, the DHU has no capacity to monitor water levels in cities. The DHU has not participated in testing the Vigilance Map, but could benefit from the project, and its participation is therefore recommended.

ME, with the support of UNDP, KfW and Expertise France, is setting up early warning systems (EWS) with ONPC in three municipalities (Ain Draham, Jendouba-Bou Salem and Tataouine), with three different climates (sub-humid mountainous forested north west, upstream Medjerda wadi basin, and arid South). Risk management centers and meteorological stations are being established with the support of the INM, who will also manage them.

In particular, the Bou Salem EWS focuses on flooding in the Medjerda wadi and its major tributaries, and expects to improve anticipation times for flood arrival at the Sidi Salem dam/Medjerda-Mellègue drainage system and the Tessa sub-basin. Its scope covers: data collection, transmission, and management for 46 rainfall and 15 hydrometric stations; remote sensing reception and assimilation; hydromet modelling (of the MIKE type) to account for geometric and hydraulic changes after the recent construction of flood protection infrastructure; capacity support for a DGRE-DGBGTH flood forecasting center; an Inundation Crisis Management Center in Bou Salem or Jendouba; a mobile command post with data and mapping visualization facilities, and a comprehensive alert and information mechanism up to the last mile. Beyond its focus on the upper Medjerda basin upstream of Sidi Salem dam, this hydromet-focused EWS will have generic value for the country, and enhance adaptation to different contexts across Tunisia's north-south gradient.

ONPC has been working with the INM on the Vigilance Map project. At this stage, there is no operations center at ONPC (national level) to support integrated disaster risk management; and the associated legal framework will need to be revised. While a number of EWS components are being planned, there is no national platform to host the contributions of different institutions.

While noting collaboration between ONPC, INM, DGRE, DGBGTH, and DHU, there are no formal standard operating procedures to exchange information between agencies and national and local (municipal) levels. In addition, capacity building has been identified as a core need at the ONPC school.

Tunisia has implemented a Common Alerting Protocol (CAP), which allows INM (formal entity registered for weather, seismic and tsunami hazards) and DGRE (formal entity registered for floods) to issue alerts, via a compatible format, through the disaster management authorities, thus overcoming some of the challenges in disseminating such information to the population at large.

6.2.4 Aeronautical Meteorological Services Systems

Meteorological services contribute to the safety, regularity, and efficiency of international air navigation by supplying users (i.e. operators, flight crew, air traffic services, search and rescue units, and airport managers) with the meteorological information they need to perform their functions.

In Tunisia, this service is provided for in the following regulations:

- Decision of the Minister of Transport No. 9 of 18 January 2019 designating a meteorological authority to provide meteorological services for international air navigation in the TUNIS flight information region.
- Decision of the Minister of Transport No. 67 of 11 February 2017 on meteorological services for air navigation. INM is the designated meteorological service provider in Tunisia.
- The Letter of Agreement between the INM and the Civil Aviation and Airports Office (CAAO), including its annexes.

The regulations above were established pursuant to the provisions of the WMO Technical Regulation (WMO-No. 49) and those of Annex 3 of the Chicago Convention on International Civil Aviation Organization (ICAO), and are effected by the organizations described in **Figure 19**.

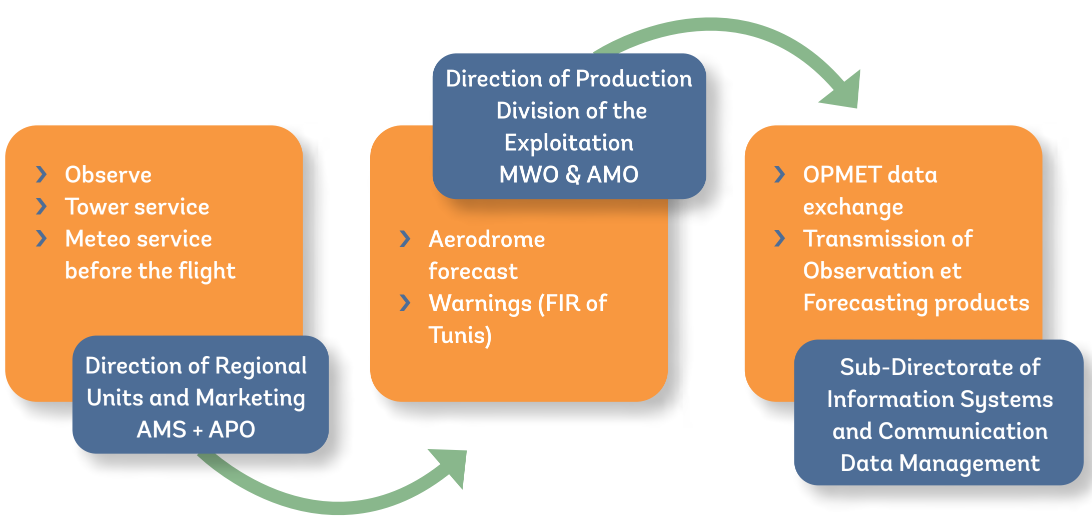
Meteorological services for air navigation in Tunisia fall under the following organizations:

1. Meteorological watch office (MWO).
2. Central aerodrome meteorological office (AMO), supported by aeronautical protection offices (APO) at airports.
3. Aeronautical meteorological stations (AMS).

In Tunisia, a single MWO is attached to the only flight information region (FIR) i.e. Tunis. Its functions are governed by the Aeronautical Forecasting Service of the Division of Operation, which is part of the INM Directorate of Production.

In Tunisia, aerodromes do not have AMOs on site; they have APOs which are attached to a single AMO which provides meteorological services for international air navigation at each airport. This office holds the International Civil Aviation Organization (ICAO) code for the Tunis Carthage airport "DTTA" and is housed in the aeronautical forecast-

FIGURE 19. Functional Organizations Responsible for Meteorological Services for Air Navigation



Source: INM

ing service. The AMO and the APO share responsibilities for user needs. At each aerodrome, the INM has an APO which is under the authority of the regional unit to which it belongs and which works closely with the home AMO.

INM has a number of aeronautical weather stations which make hourly or semi-hourly observations. At AMSs at aerodromes, these routine observations are supplemented by special observations made when specified changes occur in respect of surface wind, visibility, runway visual range, present weather, clouds.

INM's aviation reports include Operation Resolute Support (ORS) for the Meteorological Terminal Air Report (METAR), Aviation Special Weather Report (SPECI), Terminal Aerodrome Forecast (TAF) and Significant Meteorological Information (SIGMET), all of which meet international standards.

INM receives Operational Meteorological data (OPMET) and World Area Forecast System (WAFS) products, and uses MESSIR-Aero, supported by Corobor to brief pilots; however, it requires a script for automatic editing and correction of aeronautical bulletins, as errors prevent their issuance.

INM effects cost-recovery for aeronautical meteorological services – see details of the revenues from these services under Chapter 5; and uses an internationally certified quality management system meeting international standards. Air Navigation is certified by the International Organization for Standardization (ISO) and carries an ISO-9001: 2015 certification – further information is provided in 6.4.2.

6.2.5 Agricultural Services Systems

INM provides agrometeorological data, information, forecasts and warnings to assist (a) agriculture and farming; (b) irrigation planning and management; and (c) disease and natural disaster management (e.g. drought, frost, hail, forest fire, etc.). Weather bulletins with alerts are issued to MARHP and the agriculture sector when needed, and INM provides services which include:

- Regular weather bulletins - these are decadal agrometeorological bulletins with monthly summaries of parameters (26) such as evaporation, humidity, cumulative rainfall, tem- perature, evapotranspiration and water balance.
- Decadal rainfall bulletin that contains: (a) monthly, annual and decadal rainfall totals, and precipitation records from 42 stations (b) the number of rainy days; (c) the monthly normals; and (d) ratios to normals. At the end of the month, a monthly summary is attached to this bulletin.
- Daily agrometeorological bulletin that contains: (a) the changing meteorological situation for the present and following day; and (b) the maximum and minimum predicted temperatures, precipitation, and humidity for the following day (for 26 regions).

INM issues weather bulletins on request for clients needing specific meteorological data.

DGACTA monitors water balance at sites chosen for their hydrometeorological, soil, and cropping characteristics; and water storage dynamics using rainfall and limnometric measurements at hill dams in the Dorsal ridge to support local irrigation. DGACTA, with support from GIZ, plans to develop a territorial observatory to study drivers of agricultural dynamics (climate, environment, socio-economy, etc.) to support stakeholder cooperation and decision-making.[8]

Droughts can arise from a range of hydrometeorological processes that suppress precipitation and/or reduce surface and/or groundwater. While meteorological dry spells and droughts are monitored and forecasted by INM, hydrological droughts are monitored by DGRE, and agricultural impacts are managed by General Directorates in charge of crops. Drought indicators and indices allow DGRE to state the severity, location, duration, onset, and cessation of such conditions, and DGRE uses these metrics to prepare drought maps.

6.2.6 Marine Meteorological Services Systems

INM operates a MFWAM model and offers standardized marine meteorological products and services as follows:

- **High seas marine bulletins (Figure 20a):**
  - Contents of the morning bulletin (07:00 UTC)
    - Strong wind or storm warnings
    - General evolution of the situation
    - Day and night forecast
    - Overview for the next 24 hours
  - Contents of the afternoon bulletin (16:00 UTC)
    - Strong wind or storm warnings
    - General evolution of the situation
    - Day and night forecast
    - Overview for the next 24 hours
- **Maritime bulletin for the coasts (Figure 20b):**
  - Contents of the morning bulletin (04:30 UTC)

[8] Elaboration d'un projet d'observatoire territorial de GRN en Tunisie, Notes conceptuelles.

- Notice of extreme cold, strong wind or storm
- General evolution of the situation
- Day and night forecast
- Overview for the next 24 hours

» Contents of the evening bulletin (16:00 UTC as well as the bulletin for the coasts at 04:00 UTC (the bulletin for the coasts is produced 3 times a day))

- Notice of extreme cold, strong wind or storm
- General evolution of the situation
- Day and night forecast
- Overview for the next 24 hours

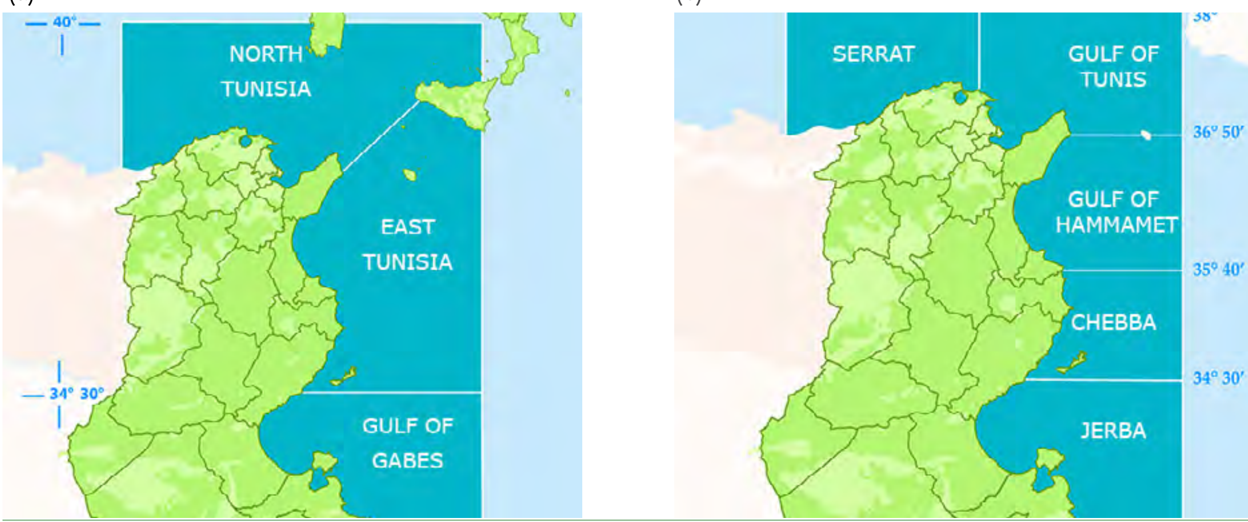
» Special weather statement – an alert for worsening weather.

- Fog warning when visibility is less than 1000 meters.
- Beach weather and wind forecasts for days D and D+1.

INM has an observation network at the coast, but does not have meteo-oceanographic buoys to monitor weather and sea conditions, and verify and improve forecasts. The Agency for the Protection and Development of Coast Areas (APAL) has installed wave buoys with the support of UNDP, and INM would benefit their data. The Ministry of Defense, including the CNCT, also has potentially useful information for monitoring coastal conditions.

FIGURE 20. (a) High Seas Areas: North Tunisia - East Tunisia - Gulf of Gabes; and (b) Coastal Areas: Serrat - Gulf of Tunis - Gulf of Hammamet - Chebba – Jerba

(a) (b)



Source: INM

Under the Tunisian-Italian program for the protection of the environment, and climate change adaptation, and with funding from the EU, a 30-month project is monitoring and forecasting marine pollution, and modelling oil drift at sea.

6.2.7 Climate Services Systems

Tunisia's topography produces large spatial variations in temperature and precipitation. These underscore the need for comprehensive climate information which is required for planning in many sectors— including agriculture, water resources management, and disaster management—and to assess climate variation and change. All observational data since 1950 has been digitized, but the historical data gathered from 1873 to 1950 mostly are in paper form. Some studies on climate change have been carried out using the last 50 years of data, and reports have been produced.

Climate normals are three-decade averages of climate variables such as temperature (mean, minimum, and maximum) and precipitation, and are produced by INM once every 10 years, with data starting in 1950. The most recent normals (1981–2010) for temperature and precipitation were calculated and made available on the INM website. A Climate Atlas provides information on the geography of Tunisia, including: maps of annual, seasonal and monthly means for climate parameters; frequency histograms for various climate parameters; inter-annual and monthly variations; daily rate charts; table of extremes with corresponding dates. DGRE is also preparing an Atlas for the hydrological aspects, and in the context of hydromet services for climate change monitoring and adaptation, it makes sense to combine these efforts, especially as the INM atlas needs to be updated.

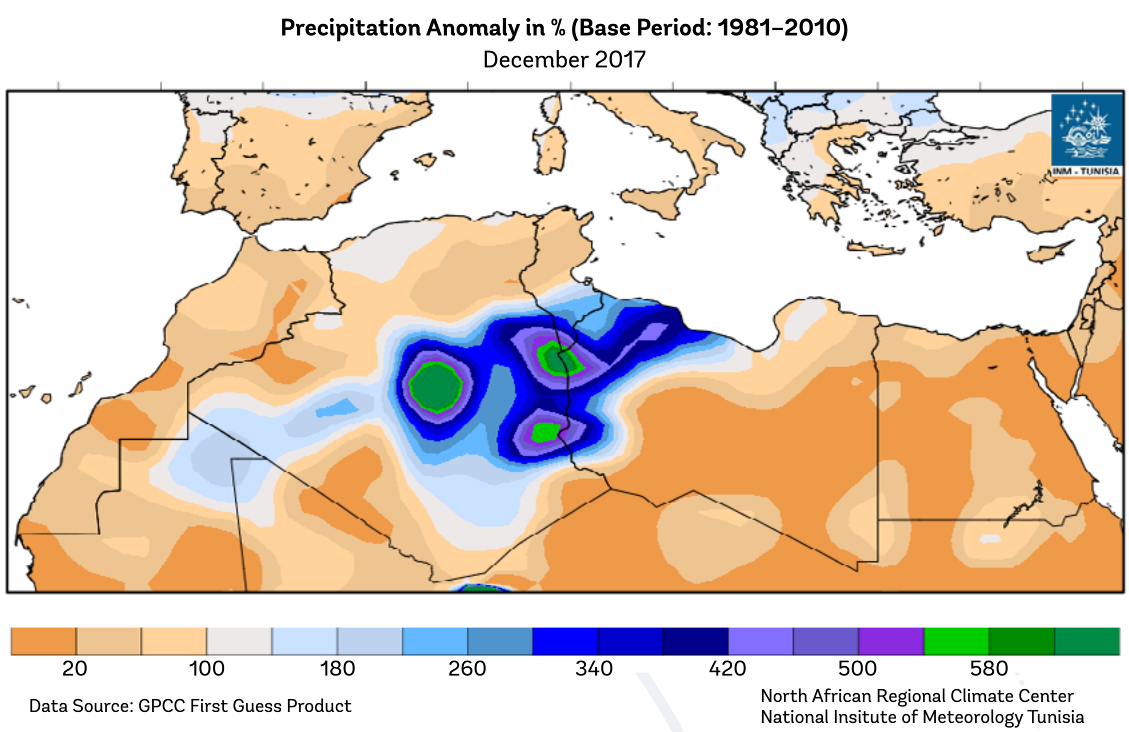
Seasonal forecasts provide major trends based on a few meteorological parameters (temperature and precipitation) for the next months (warmer or colder, drier or wetter than the usual climate). To produce these forecasts, INM downscales to national level the outputs of global and regional numerical models. In addition, INM participates in the *Mediterranean Climate Outlook Forum* (*MedCOF*). MedCOF produces consensus-based, user-relevant climate outlook products (generally probabilistic predictions of seasonal mean rainfall, surface air temperature, and other weather parameters, as well as the likely evolution of key drivers of seasonal climate variability relevant to the region) in real time in order to reduce climate-related risks and support sustainable development for the coming season in sectors of critical socioeconomic significance for the region in consideration.

The members of the Regional Climate Center for the North Africa region (RCC-NA) are: Morocco, Algeria, Tunisia, Libya and Egypt. This center assists its members to deliver better climate services and products, and to strengthen their capacity to meet national climate information needs. RCC-NA assumed a network structure in which each country leads in a specific function/s for the region, and INM leads the climate monitoring function. **Figure 21** gives an example of a product produced by INM in its regional role.

INM contributes effectively and directly to the study of climate change and helps decision-making to limit its impacts. As part of its mandate, INM is interested in the production of high-resolution climate projections of cumulative rainfall, temperature and indicators of extreme climatic phenomena over Tunisia at different horizons (2030, 2050 and 2100). Aware of the central role that climate services and access to data play in the success of adaptation policies, INM has produced high-resolution climate projections using EUROCORDEX models. This climate database is a crucial source of information and offers multiple application perspectives to support public and private action in the field of adaptation.

These projections are based on the reports of the Intergovernmental Panel on Climate Change (IPCC Panel), on the basis of major scientific advances in dynamic climate modelling. INM, after developing the projections, and with the support of the AFD, developed a web portal for the provision of climate data to various stakeholders and potential users of the information. The objective was to facilitate the direct access of users to the climate data

FIGURE 21. Example of a Regional INM Climate Product



Source: INM

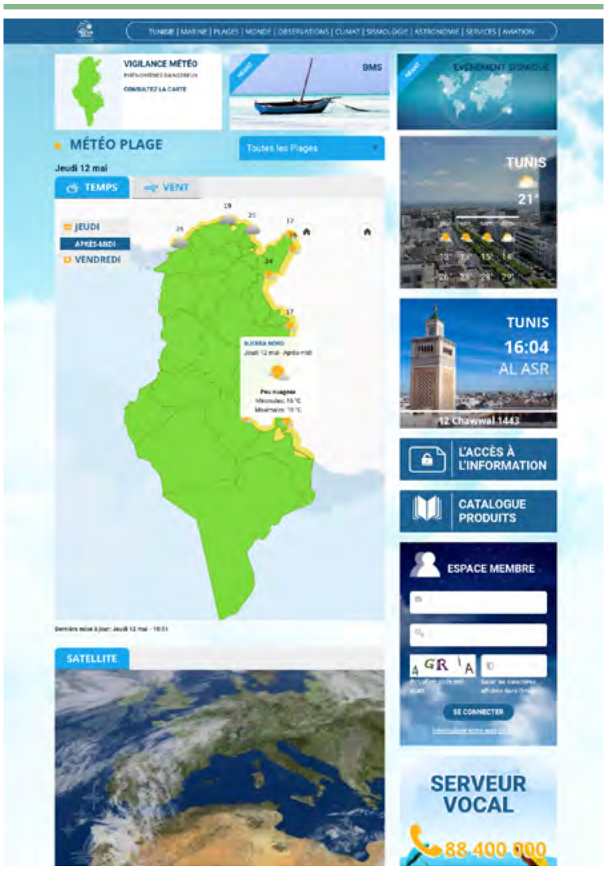
produced to strengthen the position of INM on climate services and to increase the visibility of INM's products on a national and international scale (http://www.climat-c.tn).

6.2.8 Meteorological Services Systems for the Tourism Sector

INM offers a number of products and services to the tourism sector; these are predefined or adjustable, depending on client/user needs, and standard products and services include:

- Weather bulletin for tourism (regular) – reports on weather of the day in Tunisia and other cities, providing**:** (a) the dominant phenomenon; (b) air temperature; (c) wind; and (d) other specific observations. There is also the beach weather forecast for the most frequented beaches in Tunisia (**Figure 22**).
- Special weather bulletin (on request) - weather assistance for special occasions (evening party, competition, outing, etc.). Its content is established in agreement with the customer.
- Meteorological data on request.

FIGURE 22. Screenshot of the beach weather forecast



6.2.9 Meteorological Services Systems for the Energy Sector

INM provides the industrial sector (professionals and the public) with a variety of meteorological products and services, predefined or adjustable, depending on the needs of the client/user. Standard products include:

- Weather bulletins for energy (regular) – this bulletin contains: (a) forecasts for the day, night, and following day; and (b) quantitative forecasts for 13 weather locations about: (i) the lowest temperature expected for the following 24 hours (09:00 to 09:00); (ii) the maximum temperature expected for the current day; (iii) the maximum temperature for the following day; the sky condition for the current day, expressed in octas (i.e. 0 for clear sky; 1 to 2 for partly cloudy sky; 3 to 4 for cloudy sky; 5 to 6 for mostly cloudy sky; 7 to 8 for cloud-covered sky; and Ø for invisible sky) – the attributed value is an average for the given day; and the maximum wind speed and direction, for the next 24 hours, from 09:00 of day D to 09:00 of Day D+1.
- Special weather bulletin (on request) **–** for a particular meteorological service as agreed with a customer.
- Meteorological data (as required).

6.2.10 Meteorological Services Systems for the Health Sector

Under the Tunisian-Italian cooperation program for the protection of the environment, and climate change adaptation, and with funding from the EU, INM's NETTUNIT project is developing a platform for meteorological alerts, and air/marine pollution alerts for Civil Protection, local health, and other Italian and Tunisian intervention services.

This project will respond in particular to the growing threat of atmospheric and marine pollution, which will require innovative science and multidisciplinary collaboration.

6.2.11 Commercial Services Systems

INM provides commercial services to specific users/clients; these products and services are available at https://www.meteo.tn/en/catalog-website. Decree No. 2011-89 of 11 January 2011 establishes the prices for these products and services.

6.3 Production Systems

6.3.1 Monitoring and Observation Systems

Meteorological and hydrological observations are the first step in producing weather and flood forecasts with proper lead time, and provide baseline data for water resources management, drought monitoring and forecasting, and determination of a long-term climate trends. Depending on their purpose, observing stations record temperature, precipitation, pressure, humidity, evaporation, wind speed, and solar radiation; they also record hydrological information (water levels, discharges, and reservoir storage) and agrometeorological data (soil temperature and soil moisture). Monitoring and observation systems consist of observation stations and data management systems (data transmission, telecommunication networks, and data processing and storage).

6.3.1.1 Global Data System

INM acquires global observational data through the Global Telecommunication System (GTS) and satellite data via the EUMETCast system of EUMETSAT (European Organization for the Exploitation of Meteorological Satellites).

6.3.1.2 National Surface Data System

Surface Meteorological Observation Network

Meteorological observation is the core business of INM, and the basis for all general, marine, aeronautical, climatological and numerical weather prediction. It has a countrywide network of observation stations to gather data such as air temperature, humidity, wind (direction and speed), pressure, visibility, and cloud base height.

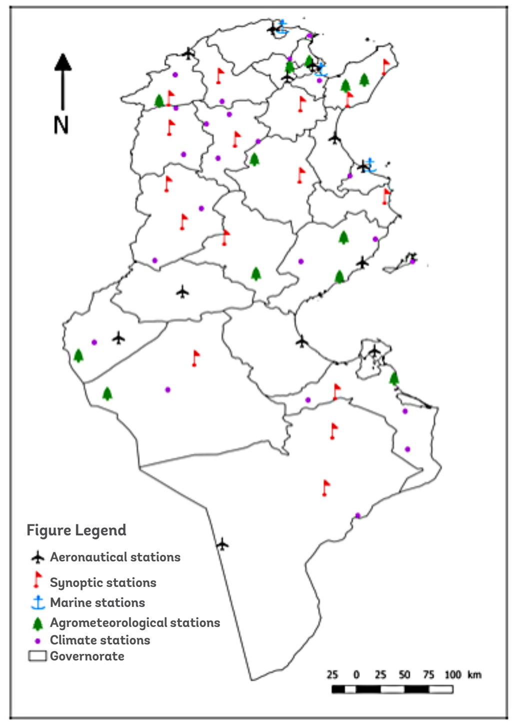
Rainfall records go back more than a century. The Mannoubia-Tunis station is the oldest, being established in 1873; and since then, the observations were done manually. In 1997/1998, the INM began to automate its observation network, and currently operates 66 automatic stations (**Figure 23**), distributed as follows:

- Synoptic network composed of 28 synoptic stations (12 aeronautical and 16 non-aeronautical), reporting every minute;
- Agrometeorological network composed of 12 agrometeorological stations, reporting every hour;
- Climatological network composed of 24 climatological stations, reporting every hour;
- 2 Port Stations.

These stations have a lifespan of 15 years, and require increasingly costly maintenance; their upgrading is now urgent, and INM has secured government funds to begin this work.

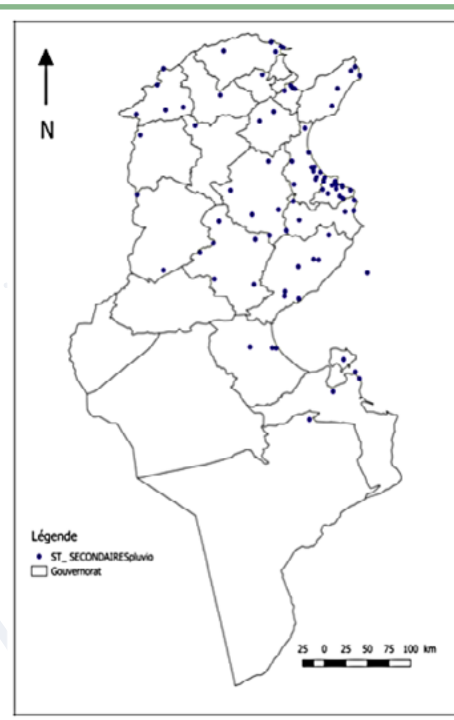
In addition, INM manages a network of volunteers who gather data from 90 rain gauges throughout Tunisia and report once a day at 7:00 local time (**Figure 24**).

FIGURE 23. INM Surface Meteorological Observation Network



Source: INM

FIGURE 24. INM Rain Gauge Stations



Source: INM

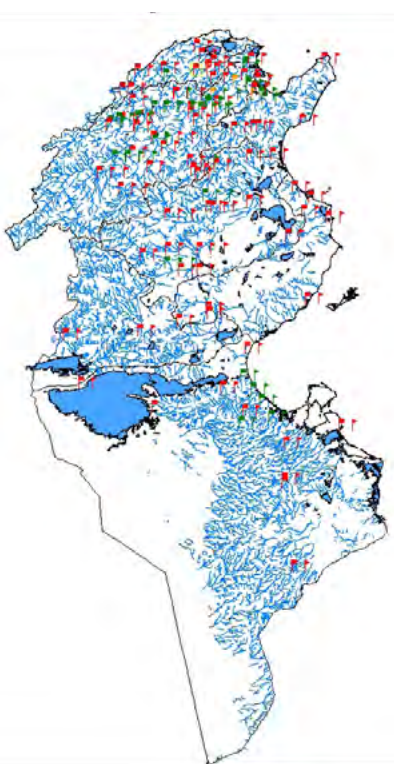
INM data conform to WMO international standard formats, and are shared from 28 stations on the WMO Global Telecommunication System (GTS). Given this network architecture, metadata are critical to the homogeneity of the time series used for climatological studies, and INM needs to improve its metadata formats and to establish a metadata catalogue.

INM's calibration laboratory needs to be upgraded so that its measuring equipment and sensors comply with international standards.

Surface Hydrological Observations Network
The rainfall network of DGRE is currently made up of 64 automatic and 712 manual daily stations located throughout the country, and Tunisia has 53 hydrometric stations developed over the last three decades.

Groundwater is monitored with 3,015 monitoring devices located at 2,209 surface wells, 712 piezometers, and 94 drilled sites; and the overall network has 874 observation points, 578 surface wells and 296 drilled wells.

FIGURE 25. DGRE Rain Gauge Stations



Source: DGRE

The DGBGTH has 6 remote telemetry stations and 37 hydrological stations (measuring evaporation, rainfall, water level for inflow, and other parameters) at its network of dams. The measuring stations are mainly made up of gauge piezometers, which are particularly vulnerable to floods and post-flood sedimentation.

All rainfall, hydrologic and hydrogeologic data have made it possible to take stock of the country's water resources, providing precious information for local, regional and national water resource planning.

Exchange of Rainfall Data
Every day, INM and DGRE exchange rainfall data from the six regional meteorological subdivisions of INM with the Regional Offices for Agricultural Development (CRDAs) of the regions concerned. These include:

- The 26 main synoptic stations in the INM meteorological network.
- Approximately 200 DGRE rainfall stations throughout Tunisia.

At the level of the Medjerda valley, this exchange concerns:

- The four main synoptic stations in the INM meteorological network (Jendouba, Béja, le Kef and Siliana).
- Approximately 100 rainfall stations in the CRDAs of Jendouba, le Kef, Béja and Siliana.

Following this exchange, each institution draws up a daily rainfall map for its needs. However, DGRE data are not in the WMO international standard format, are of limited use to INM, and urgently need to be standardized.

Exchange of data with Algeria for hydromet monitoring and EWS is highly recommended.

6.3.1.3 Upper-air System
Upper-air observations provide the most important land-based data for forecasting, and Tunisia has upper-air stations in Tunis-Carthage and Touzer. According to WMO, NMHSs should operate a set of upper air stations to record temperature, humidity and horizontal wind profiles, with a vertical resolution of 100 m or higher, twice a day or more frequently, with a horizontal resolution of 500 km or higher-resolution. Noting the absence of upper-air stations in Libya and Algeria, it would be beneficial to establish one in Remade.

6.3.1.4 Lightning System
INM does not have a lightning system, but is evaluating its benefits for airports.

6.3.1.5 Lidar System

INM does not have a lidar system (for measuring wind shear), but understands its benefits for airports.

6.3.1.6 GAW System

INM does not have a GAW system to monitor air quality.

6.3.1.7 AMDAR Program

INM does not have an AMDAR program for an observation system at airplanes.

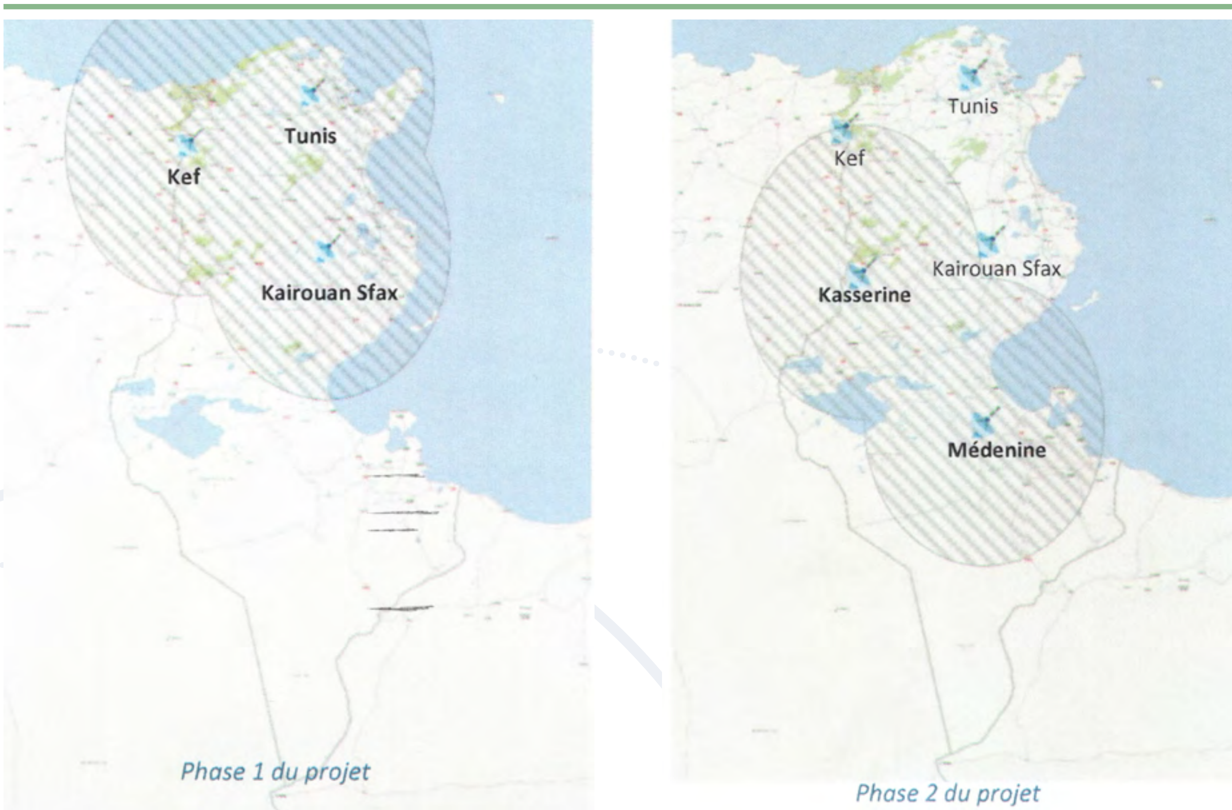
6.3.1.8 Radar System

Over the past 50 years, weather radar has advanced, and has roles in many weather, climate, and water applications. It can detect hazards such as hail, high winds, and rainfall from local storms, and thus improves aviation safety and operational efficiency for air transport, and provides agriculture alerts and flood warnings. Radar also advances understanding of the atmosphere, and supports weather forecasts over a number of temporal and spatial scales. These advances come from improved radar hardware, signal processing, automated weather-based algorithms, and displays. Radar is also used for recreational planning and other weather-impacted activities.

In recent years, improvements in short-range forecasting and nowcasting have emerged from integrated observing systems which blend data from weather radar and other instruments to produce a more complete picture of atmospheric conditions.

In Tunisia, the first meteorological radar was installed in 1992 at INM headquarters in Tunis. In 1998, it was moved to Sidi Zid (50 kms from Tunis and 740 m above sea level). Currently, this radar is no longer in service, as it is obsolete (the radar life cycle is approximately 20 years if proper upgrades and O&M are in place). In 2008–2011, INM prepared a feasibility study with the support of RHEA-CONCEPT Group for the installation of a network of S-band radars; and more recently (in 2019), another study was prepared based on multiple visits to the sites. The latter proposes a 2-phases project to set up a network of five C-band radars covering the entire country: 3 radars installed in the first phase (2020–2022) covering the northern part of the country and parts of central Tunisia (sites: Tunis, Kef and Kairouan) and two radars in the second phase (2023–2025) covering the remaining part of the country i.e. west and southeast (sites: Kasserine and Médenine) – **Figure 26**.

FIGURE 26. Proposed INM C-band Radar Network



Source: INM

There are three electromagnetic wavelengths commonly used for weather radar applications i.e. S band (10cm), C band (5cm) and X band (3cm). Shorter wavelengths can detect smaller particles (e.g. drizzle) but this type of electromagnetic signal is also more readily absorbed (or attenuated) by the water in the atmosphere. For X-band, attenuation is very severe and it is therefore only used for short distance purposes. C-band radar can also be attenuated by severe storms, although this happens less frequently at C-band than at X-band. At S-band, the electromagnetic signal is not affected by attenuation and therefore this wavelength is commonly the preferred option to follow intense storms.

Under the framework of the HTBM project "for Hydrometeorology in Tunisia: the Medjerda river basin", the government of France donated an X-band weather radar to Tunisia to measure rainfall with the objective of water management and hydrological risk assessment. The location of this radar has been chosen and the radar has been installed in the Nebeur area (a few km from the Mellegue dam). The location of this radar has been chosen and the radar has been installed in the Nebeur area (a few km from the Mellegue dam). The radar is currently in the test phase of exploiting its data, but from the meteorological point of view, this radar will have limited use.

6.3.1.9 Remote-sensing

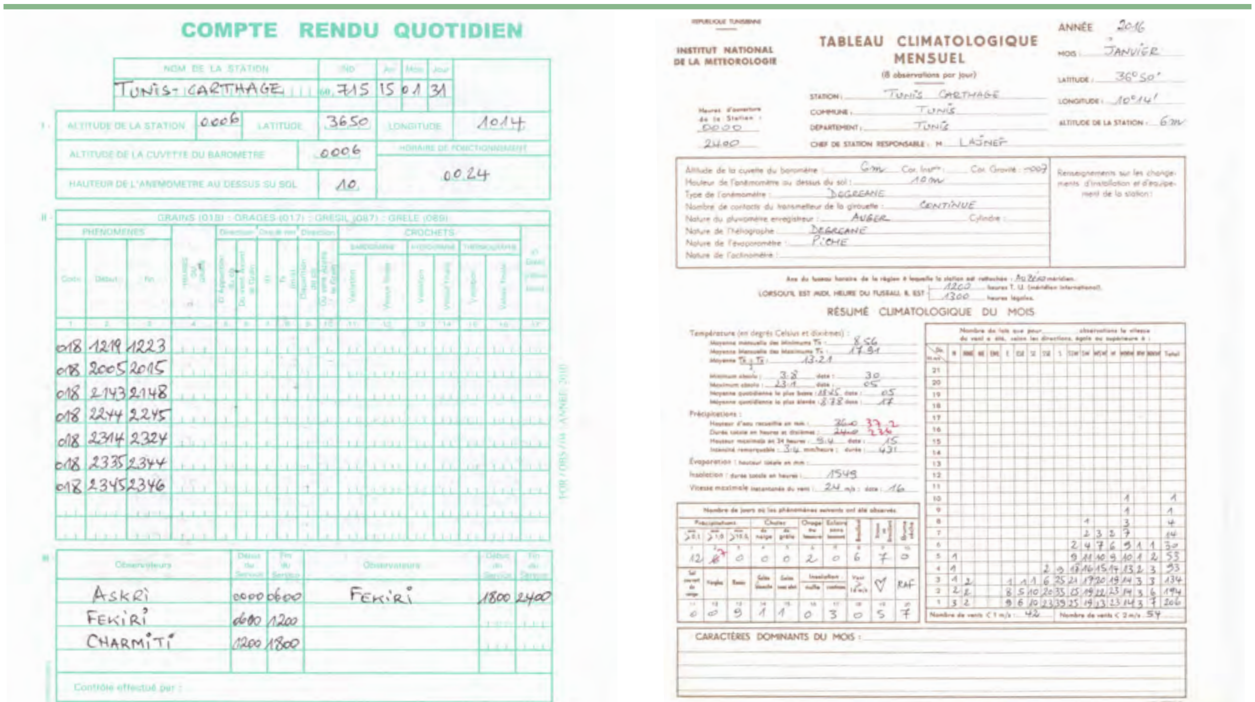
INM has a receiving station for Meteosat Second Generation (MSG) satellite remote sensing products. The images and data received by the station (in 12 channels and every fifteen minutes) provide information on the atmosphere; cloud, land and sea surface temperatures. With a resolution of one kilometer, the High Resolution Visible (HRV) channel helps forecasters to detect and anticipate hazardous weather. Following the EUMETSAT recommendations, this MSG receiving station needs to be upgraded to third generation.

6.3.1.10 Data Management and Archiving Systems: Data Collection System, Quality System, Storage and Archiving, and Data Exchange

Meteorological Systems

For the storage of the data into the climatological database, and in the absence of the real time data collection, transmission, storage and archiving of observational data into the climate database and for ingestion in the forecasters' workstation (called Synergie, supported by Météo-France International (MFI)), Observers at synoptic stations manually fill in the observation logs and the daily reports that contain hourly data and the monthly climate table containing daily data (every 3 hours) as well as monthly totals and averages (**Figure 27**). Quality Assurance and Quality Control (QA/QC) of data from these

FIGURE 27. Monthly and Daily Reports



Source: INM

stations is also done manually at the INM headquarters. These issues create significant delays in the transmission of the data, and therefore, there is urgency in addressing the upgrade of the observation network, alongside with the transmission of the data in 3G-GPRS.

INM has climate observations that date back to 1873. After collection and validation (QA/QC), the data is processed and stored. All data from 1950 onward are available on magnetic support. In the past, INM used to use an ORACLE SQL Plus database; and it has been migrating the data to a recently acquired MESSIR-Clim database (2018 version, supported by Corobor). Currently, data from 27 automatic weather stations (AWSs) go directly and automatically to the MESSIR-Clim database, where QA/QC is also performed. However, there are still difficulties with the migration of the data from the previous database into MESSIR-Clim, due to a script error.

Hydrological Systems

The DGRE's hydrological network is dense, and data are regularly collected in situ, or remotely acquired, in real time, via the GSM DATA network, and processed with HYDRAS3 (OTT software).

There are 37 DGBGTH stations that are not automated or remote tele-transmitted. The data are transmitted manually, and are up-loaded daily to the ONAGRI platform (www.agridata.tn and onagri.nat.tn). The DGBGTH also has 6 telemetric stations for Sidi Salem,Bouheurtma, Mellègue, Barabara, Sidi Barrak and Sejnene dams, and will use a database specific to the DGBGTH. Format compatibility is needed for DGRE to integrate its data with the SINEAU and SYCOHTRAC databases.

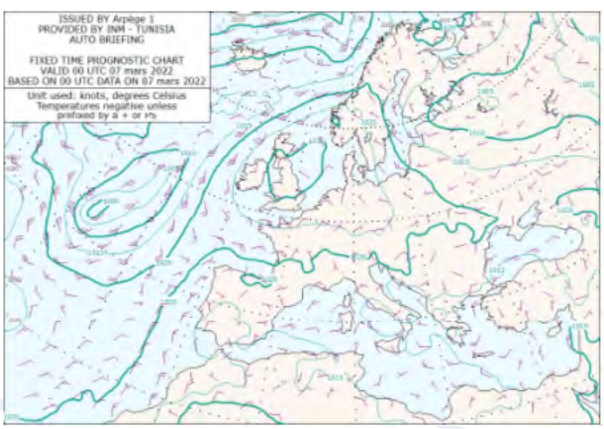
6.3.2 Modelling Systems

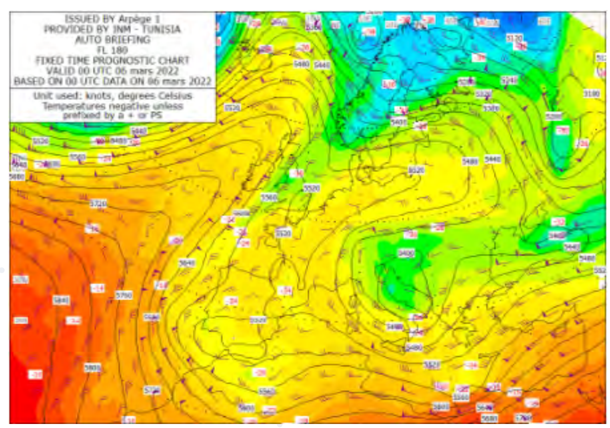
6.3.2.1 Meteorological Models

Global and Regional NWP Systems

INM's main global weather forecasting models are the French ARPEGE-France model (**Figure 28**) at 0.5° and 0.1° horizontal resolution received via MESSIR-Comm (supported by Corobor) and displayed in the Synergie (2008) visualization system (also supported by MFI), which is outdated. Through password-protected website, INM has access to graphical products from the ECMWF IFS (Integrated Forecast System, 9km deterministic and 18km probabilistic), and may acquire full access to ECMWF digital data through a license agreement or a membership as a cooperating State. For severe weather forecasting, INM uses primarily the ECMWF Ensemble Prediction System (EPS), including the extreme forecast index.

FIGURE 28. Example of Output from the French ARPEGE-France Model





Source: INM

Limited Area Meteorological Models

INM joined the ALADIN Consortium in 2001. A first pre-operational version of Tunisia-adapted ALADIN Model was installed on Météo-France computers in Toulouse in September 2001, and an extract by domain was daily sent to Tunis via the Internet. An objective model output verification process has been established at INM to help its forecasters in understanding the model strengths and weaknesses over Tunisia, and statistical adaptation has been implemented to calibrate the models over Tunisia.

In 2002, INM purchased the first High Performance Computer (HPC) to locally run the ALADIN-Tunisia. For many years, INM has able to run the model at 7.5km horizontal resolution and

70 vertical levels. Experiments have been done with the assistance of Météo-France to run the AROME model at 2.5km horizontal resolution and 60 vertical levels; and in the future the plans are to run AROME at 1.3km. A new HPC (24 nodes) has recently been procured and delivered at INM in August 2019. Since then, the HPC has been configured, and the migration of the models have been done. ALADIN-Tunisia and AROME have been running in the new HPC since February 2020. Next steps include data assimilation.

For seasonal forecasting, an atmospheric dynamic model is operated at the INM to produce monthly temperature and precipitation forecasts for the next three months. The atmospheric model, "ARPEGE-CLIMAT", is coupled to an oceanographic model, "NEMO", and they are fed with observation and re-analysis data from the ECMWF and the laboratory MERCATOR.

INM, as an institution responsible of the study of the climate, has elaborated an evaluation of future climate on the basis of the scenarios of the EURO-CORDEX Project. A selection of 14 Regional Climate Models was retained for two parameters, the temperature and precipitation. The time horizons are:

- 2050: the period considered is 2021-2050
- 2100: the period considered is 2070-2099

Temperature and total precipitation projections have been developed for two emission scenarios (the medium scenario RCP4.5 and the pessimistic scenario RCP8.5). The spatial resolution of the models is 12.5Km.

6.3.2.2 Hydrological Models

Some modelling has been done by academics/resource persons with development partners (KfW and JICA), mostly on flood control and basin management of the Medjerda River, with implementation by DGBGTH. In particular, under the framework of (a) the flood control in the Medjerda River – upstream area (supported by KfW; and implemented by DGBGTH); and (b) the integrated basin management focusing on flood control in the Mejerda River – downstream area (supported by JICA; and implemented by DGBGTH).

The JICA project supported the use of the GESRESISL software, a hydrological model to simulate floods in Sidi Salem in delayed time. It includes 45 sub-watersheds, 16 dams (including programmed dams) and 47 diversion bays. It uses three standard modules: (i) an hydrological module that deals with the rain-flow transformation over a watershed distribution; (ii) a propagation module that deals with the propagation and combination of flows resulting from rainfall-runoff transformation in the river system; and (iii) a reservoir management module that integrates dam reservoirs, with their height-area-volume law, spillways and management instructions.

The KfW is supporting modeling efforts by DGBGTH and training activities using MIKE-flood model.

Within the framework of the LDAS (Land Data Assimilation System) project completed in 2015, whose objective was to estimate the flow upstream of Sidi Salem, the National Centre for Cartography and Remote Sensing (CNCT) in collaboration with its partners, notably those of the Ministry of Agriculture, has planned to install the CREST model (Coupled Routing and Express STorage) at the DGRE in order to forecast floods in real time. This model could be fed by data available free of charge on the web through the LANDSAT 8 satellite, however, for use with an acceptable resolution at the operational level, the satellite data necessary for its initialization would be costly. In a future step it will be possible to create a synergy between the CREST and AROME models, the outputs of the latter could be used for the initialization of the hydrological model.

More recently, DGRE has been using MIKE for flood forecasting.

6.3.2.3 Forecasting and Warning Systems

Very Short- to Short-range Weather Forecasting Systems

To produce meteorological forecasts, INM accesses data via the MFI Synergie system (the main tool) and uses ECMWF products available on its password-protected website. A plain-language three-day weather forecast are issued twice daily, and it is the output of INM's short-range forecasting system. The daily forecasting routine includes the examination of EUMETSAT imagery; analysis of the data received from the GTS (plotted by the Synergie system); the global and locally run model outputs available. Verification and statistic adaptation of model outputs over Tunisia is performed daily.

Although not a member of EUMETSAT, Tunisia is a cooperating state and so has access to EUMETSAT products. Nowcasting products of the EUMETSAT Satellite Application Facility for Nowcasting (NWC SAF) are used, but this has not been customized for Tunisia, so global data is used.

Medium- and Long-range Weather Forecasting Systems

INM provides medium-range forecasts for D+3 to D+6, based on the outputs from global and regional models.

The development of the seasonal forecast bulletin is based on the products of the model operated at the INM in addition to the products of other international climate prediction centers such as: IRI (International Research Institute for Climate and Society), NCEP (National Center for Environmental Prediction) and ECMWF (The European Centre for Medium-Range Weather Forecasts).

Hydrological Forecasting Systems

Reliable hydrological forecasts require meteorological data in the form of quantified estimates of observed and forecast precipitation and temperature, dew point, wind speed and direction, and solar radiation, as well as river levels, and river discharge. In addition, weather forecasts on various time scales are required. Too often these data and products are provided to hydrological forecasters as inputs for hydrologic modeling as an afterthought, without consideration of required data formats, timeliness, and delivery methods. This is the situation in Tunisia.

Under flood conditions, a forecast hydrograph is developed in collaboration between the DGRE and the DGBGTH. They forecast the inflows into each dam on the basis of discharges at stations located in the upstream course of the wadi. These two services of the MARHP, both at the central and regional levels, have the scientific knowledge and a know-how resulting from several feedbacks, which is translated into a set of rules for flood anticipation and management, including the critical warning and flood levels; the mean propagation times of the flood wave between two points; and empirical forecasting hydrograph estimating, in particular, the input flows in each roadblock. Based on investments by development partners (JICA and KfW), modeling capacity and capability at DGBGTH for dam management has improved throughout the recent years, while it is still at pilot stage for the Medjerda basin by DGRE.

6.4 Supporting Systems

6.4.1 ICT Systems: Telecommunication Systems (Data-Exchange and Distribution System, Transmission)

Meteorological systems

Until now, the INM system for collecting observation data in real time has been limited to synoptic observation messages. The scoping study for the optimization of the observation network of INM highlighted several constraints recorded in the modes of data collection and transmission currently in use. Indeed, the current observation network is based on data collection methods that have become obsolete and outdated by technology.

According to the study, the diagnosis of the state of the surface observation network showed that the transmission of hourly and/or three-hourly data in the form of (METAR, SYNOP, SPECI,...) constitutes 42% (only 28 stations out of a total of 66 stations) of the entire observation network. This transmission mode covers the majority of synoptic stations classified as aeronautical and/or synoptic.

The rest of the network about 58% uses very outdated data collection and concentration technologies as follows:

- 8% represents the rate of stations using the telephone network and PSTN lines (CATRA) to ensure remote data acquisition and transfer to INM. It should be noted that CATRA network modems are no longer marketed.
- 50% represents the rate of stations that require on-site travel to collect data on PCMCIA magnetic cards for the purpose of collecting climatological data for the database. It should be noted that such cards are not available on the market today.

The connection with the WMO Global Telecommunication System (GTS) (MESSIR-Comm, supported by Corobor), is outdated (2003 version) and therefore requires upgrade.

Hydrological systems

The DGRE's hydrological data have been regularly collected by direct in situ or remote acquisition in real time via the GSM DATA network. The collection has recently evolved towards GPRS. Noting that the collected data will have to be sent back to the other users, there is a need for the implementation of a backup transmission system.

Except for the 6 telemetric stations, DGBGTH stations are not automated or remote-transmitted. Data transfer from these stations to Tunis is done by an operator, by telephone, daily in the morning during normal periods, and on demand during flood periods. Since these stations are not automated, it will therefore be necessary to install sensors and a real-time operational data transmission system. The specifications will have to be compatible with what exists at the DGRE, for facilitating the integration of all data into the SYGREAU database and SYCOHTRAC.

6.4.2 Quality Management Systems

A quality management system (QMS) is defined as the organizational structures, procedures, processes, and resources needed to develop and successfully manage an organization's delivery of products and services (WMO 2013).

In Tunisia, QMS principles have been adopted by INM to provide services to the aviation sector, and to comply with ICAO, and INM is ISO 9001:2015 certified to provide meteorological assistance to air navigation (**Figure 29**). All processes within INM are documented. This needs to be kept up-to-date and INM would benefit from extending QMS to other types of services.

FIGURE 29. ISO Certificate for INM


REPUBLIQUE TUNISIENNE
MINISTERE DE L'INDUSTRIE ET DES PETITES ET MOYENNES ENTREPRISES
INSTITUT NATIONAL DE LA NORMALISATION ET DE LA PROPRIETE INDUSTRIELLE

INNORPI
ISO 9001

Certificat de conformité
N° : CSQ 431/2019 R3
Certificate of conformity

L'INNORPI certifie que l'entreprise :
INNORPI certifies that the company :

Institut National de la Météorologie

a établi et entretient un Système de Management de la Qualité conforme à la norme
has established and maintains a Quality Management System in compliance with

NT – ISO 9001 (Version 2015)

sur les sites suivants :
at the following locations :

Siège : Avenue Mohamed Ali Akid, Cité Olympique, B.P. 156 Tunis-Carthage

- Station d'observation et Centre météorologique d'aérodrome de Tunis Carthage : Aéroport de Tunis-carthage
- Station d'observation et Centre météorologique d'aérodrome de Monastir : Aéroport de Monastir
- Station d'observation et Centre météorologique d'aérodrome d'Enfidha : Aéroport d'Enfidha
- Station d'observation et Centre météorologique d'aérodrome de Gafsa : Aéroport de Gafsa
- Station d'observation et Centre météorologique d'aérodrome de Sfax : Aéroport de Sfax
- Station d'observation et Centre météorologique d'aérodrome de Tozeur : Aéroport de Tozeur
- Station d'observation et Centre météorologique d'aérodrome de Gabes : Aéroport de Gabes
- Station d'observation et Centre météorologique d'aérodrome de Jerba : Aéroport de Jerba
- Station d'observation et Centre météorologique d'aérodrome de Tabarka : Aéroport de Tabarka

pour les activités suivantes :
for the following activities :

Assistance météorologique à la navigation aérienne

Meteorological services for air navigation

Ce certificat est émis le
This certificate is issued on
07 Mai 2019

et valable jusqu'au
and is valid until
06 Mai 2022

Direction de la Certification
Certification Direction
Nehla RACHICO

INNORPI D.C

Le Directeur Général
Director General
Riadh SOUSSI

IAF

8, Rue de l'Assistance par la rue Alain Savary, BP 57 – Cité El Khadra – 1003 Tunis – TUNISIE
Tél. : 216 71 806 758 – Télefax : 216 71 807 071
Site web : www.innorpi.tn

Source: INM

6.4.3 Technology Infusion Systems

INM has an R&D department to support operations and develop new methodologies to address country-specific weather and climate issues. Aspects addressed are, *inter alia*:

- Improving numerical weather prediction (NWP) with data assimilation;
- Seasonal forecasting and climate change projections;
- Ocean-atmosphere interactions;
- Collaboration with DGRE in hydrometeorological modeling.

6.5 Capacity Building

6.5.1 Capacity-Building Activities

Building capacity through training and cooperation with other WMO members is needed to modernize hydromet services. For meteorological and hydrological service providers to be effective, continued capacity development and access to new skills for new and existing staff are essential. Capacity building is the foundation of any NMHS.

Educating stakeholders and partner organizations to apply hydromet products in decision making is essential. Educating the general public to better understand warnings and probability forecasts is also important, especially for flooding, which is a major risk in Tunisia. User education could be undertaken through diverse means such as social media, workshops, flyers, publications, public service videos, and posting of educational materials on the website, and would increase awareness of, and help people to prepare for floods and other hazards.

Currently, INM works with the media and engages in public outreach and school visits.

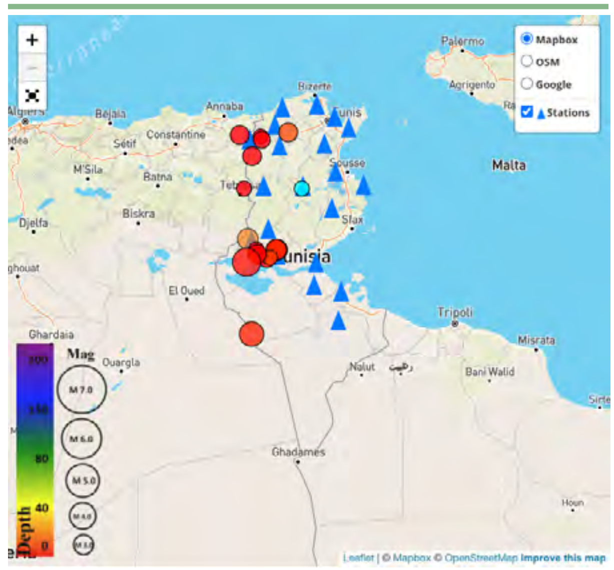
6.5.2 Collaboration with Academia

Universities can foster hydromet skills, and meteorological and hydrological research takes place at several academic institutions; INM has MoUs with some universities, with research outputs used by INM and MARHP. In view of the support academe can offer to INM and MARHP, closer collaboration is recommended to promote the exchange of ideas and information, and the application of research findings.

6.6 Seismology

Since 2008, INM has managed a network of 16 government-funded seismic stations and three stations supported by development partners (**Figure 30**). There is a need to install stations at Sea.

FIGURE 30. Tunisia's Seismic Network



Source: INM

INM and the Ministry of Equipment are preparing technical specifications for equipment to monitor the effects of seismic activity on housing.

While the likelihood of a tsunami is low, impacts would be severe, and thus, there is a need for tsunami monitoring and modeling at INM.

6.7 Summary of the Current Status of the Hydromet System

Figure 11 in this road map presents the system-of-systems concept in the structure and functioning of a modern NMHS, while **Figures 12 and 13** show the subsystems. For the existing system, progress models have been used to estimate approximate capabilities for major components such as meteorological service delivery (WMO 2014), modeling and forecasting, observation and telecommunication, and hydrological services. The progress models use a scale of 1 to 5 (Undeveloped, Development Initiated, Development in Progress, Developed, Advanced).[9]

INM's current **meteorological service delivery** is assessed to be between Level 3 (Development in progress) and Level 4 (Developed), and to meet users' needs it needs to achieve Level 5 (Advanced) by the end of the Phase III intervention (see Chapter 7). This would make Tunisia comparable to many European countries that have developed a strong hydromet and EWS culture.

INM's current **meteorological modeling and forecasting** capability falls under Level 3 (Development in Progress), but Level 4 (Developed) is required to meet the standards of Phase III, which would be comparable to most European countries.

Current **observation and telecommunication** capability is at Level 2 (Development Initiated) but Phase III requires progress to Level 5 (Advanced). This goal does not require expansion of the observation network, but rather, improved data quality, accessibility, sustainability, and use, including technical and financial capacity for operation and maintenance. Such an improvement would put Tunisia at a level similar to most European countries.

Current **hydrological services** capability is assessed to be between Level 2 (Development initiated) and Level 3 (Development in Progress) but Phase III requires Level 4 (Developed); again, this improvement may not require an expanded observation network, but rather improved data quality, accessibility, sustainability, use (including technical and financial capacity for operation and maintenance) and modelling capabilities. Such an improvement would put Tunisia at a level similar to most European countries.

9 More detail on the models is in Annexes 3–7.

7 MODERNIZATION OF METEOROLOGICAL AND HYDROLOGICAL SERVICES AND EWS

7.1 The Hydromet Value Chain (institutional mapping)

NMHS should play a key role in EWS, primarily by issuing warnings which help people to mitigate weather-related risk. To this end NMHSs increasingly collaborate with governments to provide impact-based forecasts based on vulnerability and exposure data. These services should go hand-in-hand with an educated population and trained emergency management authorities, who, respectively, understand the risks posed by weather, and are able to respond to them.

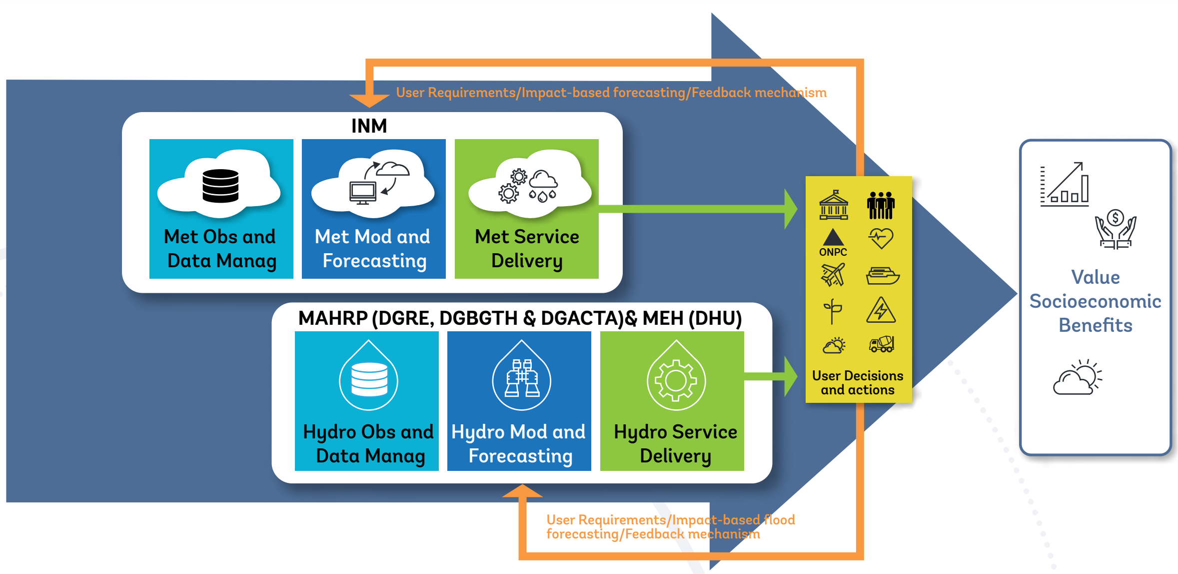
Modernizing an NMHS is a complex, time-consuming, and costly task in any country. To cite two examples: the modernization of the US National Weather Service and Japan's Meteorological Agency both took many years and cost hundreds of millions of dollars (Rogers and Tsirkunov 2013; WB 2017). The modernization of the hydromet services in Slovenia, a country one-eighth the size of Tunisia, and with a slightly higher GDP, was completed in 2015 and cost €33 million (SEA 2015). Thus before proposing modernization activities for Tunisia, it is instructive to describe the main elements of a well-functioning NMHS.

The operation of an NMHS in any country is based on observations and data collection; data processing; telecommunications; preparation of forecasts, warnings, and climate advisories; and dissemination of forecasts and other specialized information through the media and other channels, to users. These functions are carried out through a combination of many networks, centers, and hubs at different scales—global, regional, and national—that form the intricately interconnected world of global hydrometeorology (WB, 2018).

The value of NMHSs' products and services is manifested in the way they are used by recipients. The generation of meteorological and hydrological value can be depicted in a hydromet value chain linking the production and delivery of services to users' decisions and the outcomes and values resulting from those decisions (WMO et al. 2015). Potential value is added at each link of the chain as services are received by users and inform their decisions. Value-adding involves tailoring services to more specialized applications and decisions (i.e. making the information more specifically relevant) or expanding the reach of information to larger audiences (e.g. public, decision makers, and clients). In a modern, well-functioning NMHS, every link in this value chain is strong, and helps to deliver value to the users at the end of the chain. A broken link in the value chain leads to suboptimal value for the society (WB, 2018).

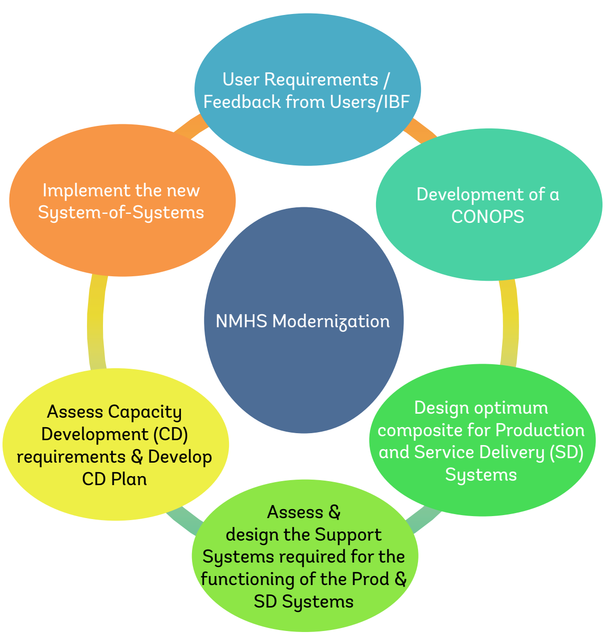
In Tunisia, meteorological and hydrological services are not provided by a single institution, and there is thus a strong need for collaboration among services providers. **Figure 31** displays the hydromet services value chain as a mix of the meteorological and hydrological value chains, shows the interdependencies between the two chains, and maps the institutions involved. In particular, it reveals the imperative to share data among organizations responsible for forecasting, and for local, regional and global models for flood forecasts. Therefore, in addition to MoUs between institutions, data exchange protocols and standard operating procedures are needed to acquire and exchange data timeously, and in a standardized and useful manner. Also, cross-training of meteorologists and hydrologists should be encouraged.

FIGURE 31. Hydromet Services Value Chain (mapping Tunisian meteorological and hydrological service providers)



Modernizing NMHSs is best achieved through a phased approach over a number of years which considers the level of improvement needed for all components of each system (see item 5.1 and **Figure 10**). A Concept of Operations (CONOPS)[10] is a document that describes the existing system, the scope and characteristics of the proposed (modernized) system, and how, from different stakeholder viewpoints, the new system will function. CONOPS can be used to maximize benefits through optimum use of funds and resources, and to inform the design, procurement, implementation, operation, maintenance, and replacement of that system. CONOPS supports the evolution of a fully integrated, modernized NMHS which meets the needs of users and stakeholders, including new technologies for observation and data recording, data validation, archiving, and tools for modelling, forecasting, dissemination, and communication of products and services (WB, 2018) – the Production Systems. Improved Support Systems (including ICT) are needed for Production and Service Delivery (SD) Systems to function. While technology plays a large role, human capacity remains key, and Capacity Development Plans underpin a modernized system-of-systems. **Figure 32** gives a schematic overview of the steps in a modernization process.

FIGURE 32. Schematic of Steps in NMHS Modernization



Design of an observation network, modeling, forecasting and service delivery should reflect changing user needs, and as new observer stations replace old ones, metadata catalogues are needed to homogenize datasets. Selecting technologies for data transmission is complex because of multiple vendors and products; and reliability, reporting accuracy, costs, operation and maintenance requirements, durability, and site specifications need to be factored into decisions. Data management should achieve storing, analyzing, and reporting of data, and secure its validity through compliance with QMS (WB, 2018).

The socioeconomic benefits of modernization manifest in improved risk management and decision making for both weather-related disasters and economic development, and especially during floods and droughts, which have big impacts on vulnerable populations. Improved forecasting and early warnings supports resilience in communities and sectors at risk (WB, 2018) – see also Chapter 8.

7.2 Development and Cooperation Partners and Donors

Alongside government capital investment, donors and development partners have initiated numerous projects to strengthen EWS and hydromet services (or achieve related goals) in Tunisia. **Annex II** lists 18 such projects, based on information provided by these donors and development partners. Twelve of these are ongoing, and the rest have been accomplished. These projects address primarily hydrological aspects, and hydromet early warning systems.

Assuming that the project objectives were achieved, some improvement of capacity was provided to the stated beneficiaries. However, in the absence of a national strategy to improve EWS and hydromet services, insufficient coordination among donors and recipient agencies has led to a piecemeal approach and a disjointed system with limited connection between components. To avoid this situation, it is important that future initiatives build upon the activities and achievements of ongoing projects that fit within an overall national plan. New projects to modernize meteorological and hydrological services should align with previous projects and coordinate their proposed activities with ongoing initiatives.

[10] A proposed outline for a CONOPS is provided in Rogers et al (2019).

7.3 Proposed Roadmap to Modernize Weather, Climate and Hydrological Services and Early Warning Systems

7.3.1 The 3 Pillars of Modernization

Recognizing that cultural change in institutions takes time (Rogers and Tsirkunov 2013), this road map presents a phased approach to the long-term goal of hydromet modernization. The project needs to lay a strong foundation that can be developed over time, and in which government authorities understand the role that meteorological and hydrological service providers can play in many development contexts in Tunisia.

Recent experiences in WB projects to strengthen NMHSs in client countries have shown the value of three principal interventions: (i) institutional strengthening and capacity building; (ii) modernization of observation, ICT and forecasting infrastructure; and (iii) enhancement of service delivery systems (Rogers and Tsirkunov 2013). This approach is favored by clients, and is reflected in the actions proposed in the following sections.

7.3.2 Roadmap Phases

The roadmap considers several questions:

- Is the long-term strategy of the various institutions aligned with the expectations of the government and people of Tunisia?
- What future needs for data and information will users have?
- Will the institutions concerned have the tools to meet the expectations of the government and people of Tunisia?
- How to design a business plan which optimizes investments in modernization to provide adequate public and commercial services throughout Tunisia?

The above considerations have shaped the roadmap's development phases, each of which builds on the previous one to contribute to the overall goal i.e. Phase II assumes the accomplishment of objectives in Phase I and builds on them; and Phase III assumes the accomplishment of objectives in Phases I and II and builds on those.

This phased approach progresses towards a system which can produce and deliver (i) timely warnings of extreme and hazardous weather events and their potential impacts; and (ii) forecasts for operations and planning in weather and climate-sensitive economic sectors, particularly DRM, transport, agriculture, water resources management, climate change and environment, health, tourism, energy and education. Within each phase, minimum, good and ideal scenarios are given, and each completed phase indicates achievement of an ideal scenario in the preceding phase/s. In addition, priorities have been identified for each Phase to indicate timelines to achieve the objectives (1–3 with 1 = highest priority).

Phase I: immediate to short-term activities. This phase invests in high-priority areas to improve basic public services through affordable new technologies and staff training in the institutions concerned (immediate to short term: two- to three-years duration).

Phase II: medium-term activities. This phase invests in modest improvements to weather, climate and hydrological services to the most important users, including disaster management, transport, agriculture, and water resources management (medium term: two-years duration on top of Phase I).

Phase III: long-term activities. Phase III investments support service providers to deliver data, forecasts, and warning services for public safety, and to aid development in important socioeconomic sectors (long term: two-year duration on top of Phases I and II).

The first two phases build the capacity of institutions to serve their clients while the third phase consolidates this capacity so that they can offer specialized services, either alone or in partnership with other institutions.

The phases are based on discussions with INM, MARHP (BPEH, DGRE, DGBGTH and DGACTA), DHU, ME, ONPC, development partners and donors. The discussions revealed the difficulties faced by the abovementioned organizations in meeting user needs, and the proposed phases are designed to help them meet these challenges, and strengthen their links with ONPC.

The institutions concerned should clearly demonstrate to the government authorities the importance of access to essential modern tools and technologies—for observation, data processing and forecasting infrastructure, and delivery of services and advisory guidance to users. It should also rigorously argue the case for the expected social and economic benefits of the services they could provide (by reducing losses from floods and other hazards) given adequate government support for its operations.

To compete for and optimally use scarce public resources, the institutions concerned must justify the need for improving its operations and thus the investment of public funds to support their basic infrastructure and suite of services. To demonstrate the benefits to users, however, the institutions concerned must first be able to provide fit-for-purpose services to the satisfaction of those users, which they cannot perform without upgrading of their own forecasting and ICT infrastructure and their services capability, as well as coupling meteorological and hydrological monitoring and forecast modeling.

This roadmap and the phased approach it presents offer the institutions concerned a systematic basis for setting strategic and forward-looking priorities to improve their service delivery capability, given available (and potential future) financial and human resources. Future challenges may include the impacts of climate change with resulting increases in the frequency and intensity of natural hazards as well as the emergence of new technologies and economic evolution in the country.

Based on users' requirements, the modernization of the institutions concerned should be guided by three main pillars: (i) enhancement of service delivery; (ii) modernization of observation infrastructure, data management systems, and forecasting; and (iii) institutional strengthening and capacity building.

The three phases of modernization are presented below.

7.3.2.1 Phase I: short-term actions (2-3 years)

Priority interventions for improved weather, climate, and hydrological services (monitoring, forecasting, ICT, service delivery) and public products, achieved by new technologies and infrastructure upgrades. 2–3 years.

Strengthening institutional capacity can be achieved through these means:

1. Developing a Concept of Operations (CONOPS) document to guide the design of an optimum composite national hydromet observation network, modelling, forecasting and service delivery processes.
2. Establishing protocols and standard operating procedures for data-exchange between relevant water-institutions (initially over Medjerda as the EWS pilot, but with the intention to scale it up to national level), and with APAL for marine meteorological aspects.
3. Keeping up-to-date the implementation of Quality Management Systems (QMS) and ISO certification.
4. Developing and initiating the implementation of a capacity development and training program covering all NMHS aspects (i.e. institutional management, observations, modelling, forecasting, ICT and O&M, and service delivery, including early warning systems), and training of stakeholders; exploring "twinning" arrangements from other selected NMHSs; and collaborating with universities for fellowships and internships.
5. Developing a business plan to capitalize the investment in the modernization of the institutions concerned to provide sustained, high-quality, value-for-money public and fee-based services throughout Tunisia.

Modernization of weather-, climate- and water-related monitoring, modelling and forecasting systems can be achieved through these means:

1. Collaborative approach to monitoring, modeling, forecasting, and service provision to government stakeholders; and streamlining the forecasting processes, procedures, and functions involving all institutions concerned.
2. Convert all data into a standard, WMO-compliant format to support an integrated national system covering the needs of meteorological and hydrological institutions, and the requirements for data exchange between them.
3. Introducing near-real-time QA/QC for meteorological and hydrological observations.
4. Upgrading meteorological and hydrological observation networks (including topographical survey of existing stations) and related telecommunications, and establishing optimized national networks with associated metadata.
5. Acquire and install three Band-C weather radars.
6. InstallBand-X hydrometeorological radar offered by France.
7. Access and use numerical weather prediction / ensemble prediction systems (NWP/EPS) data and products from advanced centers; purchasing license (e.g. ECMWF).
8. Complete transfer of existing meteorological models to the new High Performance Computer (HPC).
9. Carry out objective verification of NWP/EPS data and products against their own observations, and post-process and calibrate forecasts countrywide.
10. Explore data assimilation techniques in NWP to improve weather forecasting, and conduct research to improve microphysics parameterizations in locally run models.
11. Enhance use of remote sensing for nowcasting and short-range weather forecasting, and hydrological services, by upgrading the satellite receiving station and introducing new tools.
12. Implement a nowcasting and flash flood guidance system.

13. Implement climate data rescue and migrate historical and real-time data into the climate database.
14. Promote existing climate studies.
15. Develop hydrological modeling, initially in the Medjerda basin.
16. Procure software (including meteorological and hydrological model licenses, and upgrade of tools for visualization and manipulation of data and products by forecasters), computing and communication (ICT) equipment.

Strengthening service delivery can be achieved through these means:

1. Develop and implement a national strategy for service delivery based on the WMO Strategy for Service Delivery and Its Implementation Plan (WMO 2014), and a National Framework for Climate Service (NFCS), following the WMO guidelines.[11] The WMO strategy and framework provides a process for NMHSs to develop and deliver services in collaboration with users, including DRM, transport, agriculture, water resources management, climate change and environment, health, tourism, energy and education.
2. Collaborate via protocols and standard operating procedures (SOPs) between INM, MARHP (DGRE, DGBGTH, DGACTA, and BPEH), MEH (DHU) and ONPC to improve data and information exchange; conduct joint exercises and provide mirror computer and video conferencing to display weather and hydrological information as seen by the forecaster; attach meteorologist and hydrologist to the disaster management office at the ONPC during severe hydromet events for improved EWS.
3. Apply the national strategy for service delivery and CONOPS to develop initial SOPs for operating critical existing and new equipment, to review needs for improved forecasting, and to review service delivery for meteorological and hydrological functions.
4. Establish a multi-stakeholder hydrometeorological technical group to develop and enhance services, improve coordination among service providers, and improve interaction with and response to users.
5. Continue to develop Web sites and Portals, making further use of social media, and increasing dissemination channels to enhance weather, climate and hydrological services.
6. Further develop the "*Carte de Vigilance*" and the "Système de collecte des données hydrologiques en temps réel et d'annonce de crues" (SYCOHTRAC), and establish synergies between the two, as a first step towards *VigiCrue*.

The estimated costs for Phase I activities, executing institutions and indication of scenarios (minimum, optimum, ideal), are shown in **Table 9**.

[11] https://gfcs.wmo.int//

TABLE 9. Phase I: Activities, Estimated Costs, Executing Institutions, and Scenarios

Phase I Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Strengthening institutional capacity					
Advisory services to (a) assess existing systems and design an optimum composite national observation network, forecasting and service delivery processes (systems integration); (b) develop CONOPS at national level; (c) support activities under Phase I, including technical specifications and supervision of installations; and (d) improve legal and regulatory framework for operations, inter-departmental coordination and planning, including development of SOPs, and data exchange protocols	1,000	INM, MARHP (BPEH, DGRE, DGBGTH), MEH (DHU), ONPC, APAL	Minimum	1	
Advisory services to establish new Strategic Plans 2021–2025 for the individual institutions	200	INM, MARHP (BPEH, DGRE, DGBGTH & DGACTA), MEH (DHU), ONPC	Minimum	1	Institutions concerned should align their Strategic Plans with the national strategic approach presented in this roadmap. This activity should be supported by their individual government budgets
Advisory services to keep QMS and ISO Certification at INM current	50	INM	Minimum	1	
Advisory services, including training to develop and implement capacity building and training program for Phase I	1,000	INM, MARHP (DGRE & DGBGTH), MEH (DHU), ONPC	Minimum	1	The amount allocated to each institution must be aligned with the importance of and activities in this phase
Procure equipment to improve inter-DGs and ONPC operational relations (video conferencing, etc.)	500	INM, MARHP (DGRE & DGBGTH), DHU, ONPC	Good	2	
Advisory services to develop Service Delivery Strategy (SDS) and National Framework for Climate Services (NFCS)	150	INM	Good	2	

TABLE 9. Phase I: Activities, Estimated Costs, Executing Institutions, and Scenarios (cont.)

Phase I Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Advisory services to evaluate opportunities to introduce new sustainable business models, including public-private engagement	100	INM	Good	2	
Sub-total	**3,000**				
Modernization of weather and flood monitoring, modelling and forecasting systems					
Procure equipment, including related services and training, to expand and upgrade the surface meteorological network and related telecommunication systems, and create a climate reference network, including metadata	1,000	INM	Minimum	1	This activity has already been initiated for stations not located at airports. This is supported by government funds. For O&M, including this network in the GBON / SOFF could be explored
Advisory services to (a) implement real-time QA/QC for meteorological data and conversion of all meteorological data into standard format (WMO compliant) required for an integrated system; and (b) automation of operational processes	200	INM, MARHP (DGRE & DGBGTH for rainfall data)	Minimum	1	
Procure equipment, including related services and training, for the topographic survey; expand and upgrade the hydrological network (including in urban areas) and related telecommunication systems	1,000	MARHP (DGRE), MEH (DHU)	Minimum	1	
Advisory services to implement real-time QA/QC for hydrological data and convert all hydrological data into standard format (WMO compliant) required for functioning of an integrated system	100	MARHP (DGRE & DGBGTH), MEH (DHU)	Minimum	1	
Procure equipment, including related services, to upgrade satellite receiving station and migrate to 3rd generation of European satellites Meteosat from EUMETSAT (MTG)	500	INM	Minimum	1	

TABLE 9. Phase I: Activities, Estimated Costs, Executing Institutions, and Scenarios (cont.)

Phase I Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Procure equipment and related services to upgrade data collection and transmission (including WIS/GTS upgrade, transmission 3G/GPRS), and data exchange/transmission between INM and MARHP & ME (dedicated lines)	700	INM, MARHP (DGRE & DGBGTH), MEH (DHU)	Minimum	2	For INM, this activity has been initiated in association with the stations upgrade. This is supported by government funds
Procure communication and computer equipment for acquisition, storage (real time and archiving), processing and visualization of data (servers and workstations); editorial tool; equipment for data rescue, including digitization, archiving and data storage; forecaster workstations	1,000	INM, MARHP (DGRE & DGBGTH)	Minimum	1	
Advisory services to migrate all data into the climate database	100	INM	Minimum	3	
Purchase of the ECMWF license for 3 years	150	INM	Minimum	1	
Advisory services to use NWP/EPS from ECMWF in operational forecasting	150	INM	Minimum	2	
Advisory services to downscale AROME; increase resolution, data assimilation and improve microphysics	500	INM	Minimum	1	
Advisory services for nowcasting and flash flood guidance systems	200	INM	Minimum	1	
Advisory services for hydrological modeling capability (initial focus on Medjerda)	400	MARHP (DGRE & DGBGTH)	Minimum	1	
Procure equipment, related services and training to install 3 C-band radars	6,000	INM	Minimum	1	
Procure equipment and related services to upgrade HPC (resources to be shared with MARHP (DGRE) for flood forecasting)	1,500	INM	Good	2	
Advisory services and training to reinforce capacity in seismology	200	INM	Good	1	
Sub-total	**13,700**				

TABLE 9. Phase I: Activities, Estimated Costs, Executing Institutions, and Scenarios (cont.)

Phase I Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Strengthening service delivery					
Procuring equipment, related services and training to develop a Common Alerting Protocol (CAP), and improve dissemination to communities (last mile) via mobile apps (for warnings, agromet/food security), FM radios, SMS and web-based services (establishing partnerships with mobile service providers)	800	INM, MARHP (DGRE), MEH (DHU), ONPC	Minimum	1	
Advisory services to further develop Web sites and Portals such as the "*Carte de Vigilance*" and SYCOHTRAC, and establishing synergies between the two, as a first step towards *VigiCrue*	500	INM, MARHP (DGRE)	Minimum	2	
Advisory services to further develop a drought monitoring and forecast system	400	INM, MARHP (DGRE)	Minimum	1	
Advisory services to evaluate forecast utility and user satisfaction ("user satisfaction index")	300	INM, MARHP (DGRE), ONPC	Minimum	2	
Advisory services to implement an EWS platform	1,000	ONPC	Minimum	1	
Advisory services to implement SDS and NFCS	300	INM	Good	1	
Sub-total	**3,300**				
Grand-total	**20,000**				

To fully realize the benefits of this Phase, an increase in staff is recommended, as shown in **Table 10**. With an estimated average remuneration cost per month per person (as per the information in Chapter 5), and the required addition of 14 persons to the staff of meteorological and hydrological service providers, the additional staff cost for this phase is US$511,728. The source of the additional staff is currently unclear; while some specialists will come from universities, some staff may come from government agencies or the private sector.

The activities proposed in this Phase will strengthen the capabilities of meteorological and hydrological service providers to discharge their basic public functions.

The cost of activities under Phase I is approximately US$20.5 million. The biggest impact under this phase is expected to be strengthened institutional and staff capacity, enhanced delivery of weather and hydrological services, and improved observations, forecasting and ICT capabilities. Using the progress models for various components of meteorological and hydrological service providers, the **meteorological service delivery** capability is expected to rise to Level 4 (Developed); the **meteorological modeling and forecasting** capability is expected to rise to Level 3 (Development in Progress); the **meteorological observing and telecommunications** capability is expected to reach Level 3 (Development in Progress); and the **hydrological services** is expected to reach Level 3 (Development in Progress).

TABLE 10. Additional Staff and Staff Costs for Phase I

Position	Phase I	Number of additional staff	Personnel costs (US$/year)	Total costs (US$) for 3 years
1	Meteorologists	4	13,232	158,784
2	Computer scientists (for Met)	2	13,232	79,392
3	Meteorological technicians	2	9,564	57,384
4	Hydrologists	3	13,232	119,088
5	Computer scientists (for Hydro)	1	13,232	39,696
6	Hydrological technicians	2	9,564	57,384
	Total	**14**		**511,728**

7.3.2.2 Phase II: medium-term actions (2 years on top of Phase I)

This intermediate investment phase aims to improve capabilities to provide weather, climate, and hydrological services to meet the needs of the most important public service users (such as disaster management, transport, agriculture, and water resources management) and users in the private sector. As explained earlier in this chapter, the phase builds on Phase I, and cannot be implemented as a stand-alone phase.

The activities under this phase will result in significant improvements in each particular component of the hydromet system (monitoring, forecasting, ICT, service delivery, etc.). The implementation of this phase should be completed within two years.

Strengthening institutional capacity can be achieved through these means:

1. Continue to implement a capacity development and training program covering all NMHS aspects (i.e. institutional management, observations, modelling, forecasting, ICT and O&M, and service delivery, including early warning systems), and training of stakeholders; exploring twinning arrangements with other NMHSs and collaborating with universities for fellowships and internships.

Modernization of weather-, climate- and water-related monitoring, modelling and forecasting systems can be achieved through these means:

1. Upgrade the surface observation network at airports.
2. Expand the agrometeorological network.
3. Acquire and install two additional weather radars.
4. Continue to access and use NWP/EPS data and products from advanced centers; purchasing license (e.g. ECMWF).
5. Couple meteorological and hydrological models for flood forecasting (initially for the Medjerda basin).
6. Run air quality forecast and marine models locally.
7. Continue R&D in NWP, and explore running an EPS locally, and develop site-specific forecasts.
8. Keeping up-to-date the implementation of the SYGREAU service.
9. Procure ICT equipment for a centralized system.
10. Establish a calibration laboratory.

Strengthening service delivery can be achieved through these means:

1. Develop impact-based forecasts and risk-based warnings.
2. Develop hazard maps.
3. Establish a Joint Operations Room, with a platform to access all information from the EWS.
4. Develop tailored products for key socioeconomic sectors.
5. Implement ACAS.
6. Expand "*Carte de Vigilance*" to *VigiCrue*.
7. Upgrade the Climate Atlas (meteorological and hydrological aspects).

The estimated costs of Phase II activities, associated executing institutions and scenarios (minimum, good, ideal) are shown in **Table 11**.

TABLE 11. Phase II: Activities, Estimated Costs, Executing Institutions, and Scenarios

Phase II Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Strengthening institutional capacity					
Advisory services and training for capacity development and training program for Phase II	1,000	INM, MARHP (DGRE & DGBGTH), MEH (DHU), ONPC	Minimum	1	The amount allocated to each institution must align with the importance of and activities in this phase.
Sub-total	**1,000**				
Modernization of weather and flood monitoring, modelling and forecasting systems					
Procure equipment, services and training to upgrade the surface observation network and related telecommunication systems at airports, including metadata	1,500	INM	Minimum	1	Including this network as part of the WMO GBON / SOFF should be explored
Procure equipment, services and training to expand and upgrade the agrometeorological network and related telecommunication systems, including metadata	500	INM & MARHP (DGACTA)	Minimum	1	
Procure equipment, services and training to acquire 2 C-band radar	4,000	INM	Minimum	2	
Procure equipment, services, and advisory services to establish centralized and automated data management systems (including servers, software, etc.)	1,500	INM, MARHP (DGRE)	Minimum	2	
Purchase ECMWF license for 2 years	100	INM	Minimum	1	
Procure equipment, services and training to establish a calibration laboratory	300	INM	Minimum	1	
Advisory services to keep up-to-date the SYGREAU service	200	MARHP (DGRE)	Minimum	1	
Advisory services to couple meteorological and hydrological modeling for flood forecasting (initial focus on Medjerda)	500	INM, MARHP (DGRE & DGBGTH)	Minimum	1	
Procure equipment, services and training for LIDAR network and related telecommunication systems and metadata	1,000	INM	Good	3	
Procure equipment and related services and training for a GAW network and related telecommunication systems including metadata	500	INM	Good	3	

TABLE 11. Phase II: Activities, Estimated Costs, Executing Institutions, and Scenarios (cont.)

Phase II Activities	Estimated cost (KUSD)	Institutions	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Procure equipment, services and training for AMDAR program	300	INM	Good	2	
Advisory services for R&D in the NWP, and running an EPS locally, and development of site-specific forecasts	500	INM	Good	3	
Advisory services to run air quality forecast and marine models locally	300	INM	Good	3	
Advisory services to run seismic and tsunami models	300	INM	Good	2	
Sub-total	**11,500**				
Strengthening service delivery					
Advisory services to develop impact-based forecasting and risk-based warnings	1,000	INM, MARHP (DGRE), ONPC	Minimum	2	
Advisory services to develop hazard maps	300	INM, MARHP (DGRE)	Minimum	2	
Advisory services to develop tailored products for key socioeconomic sectors	500	INM	Minimum	2	
Advisory services for ACAS	400	INM, MARHP (DGRE)	Minimum	2	
Advisory services to expand the “Carte de Vigilance” to VigiCrue	700	INM, MARHP (DGRE)	Minimum	3	
Advisory services to upgrade the Climate Atlas	200	INM, MARHP (DGRE)	Minimum	2	
Procure equipment, services and training for Joint Operations Room	750	INM, MARHP (DGRE), MEH (DHU), ONPC	Good	3	
Sub-total	**3,850**				
Grand-total	**16,350**				

To fully realize the benefits of this Phase, an increase in staff is recommended, as shown in **Table 12**. With an estimated average remuneration cost per month per person, and the required addition of 11 persons to the current staff of the meteorological and hydrological service providers, the additional staff cost for this phase is US$269,096. The source of the additional staff remains unclear; while some specialists will come from universities, other staff may come from government agencies or from the private sector.

The activities proposed in this Phase will strengthen the capabilities of meteorological and hydrological service providers to discharge their basic public functions.

TABLE 12. Additional Staff and Staff Costs for Phase II

Position	Phase I	Number of additional staff	Personnel costs (US$/year)	Total costs (US$) for 2 years
1	Meteorologists	3	13,232	79,392
2	Computer scientists (for Met)	2	13,232	52,928
3	Meteorological technicians	2	9,564	38,256
4	Hydrologists	2	13,232	52,928
5	Computer scientists (for Hydro)	1	13,232	26,464
6	Hydrological technicians	1	9,564	19,128
	Total	**11**		**269,096**

The cost of Phase II is approximately US$16.65 million; and the total for Phases I and II is approximately US$37.15 million. The biggest impact under this phase is expected to be strengthened institutional and staff capacity, enhanced delivery of weather and hydrological services, and improved observations, forecasting and ICT capabilities. Using the progress models for various components of meteorological and hydrological service providers, the **meteorological service delivery** capability is expected to be between Level 4 (Developed) and Level 5 (Advanced); **meteorological modeling and forecasting** capability is expected to be between Level 3 (Development in Progress) and Level 4 (Developed); **meteorological observing and telecommunication** capability is expected to reach Level 4 (Developed); and **hydrological services** is expected to be between Level 3 (Development in Progress) and Level 4 (Developed).

7.3.2.3 Phase III: long-term actions (2 years on top of Phases I and II)

This advanced investment phase aims to improve capabilities to provide weather, climate, and hydrological services; it will build on Phases I and II, and cannot be implemented as a stand-alone phase.

Phase 3 will improve each component of the hydromet system (monitoring, forecasting, ICT, service delivery, etc.) and should be completed within two years.

Strengthening institutional capacity can be achieved through these means:

1. Continue to implement a capacity development and training program covering all NMHS aspects (i.e. institutional management, observations, modelling, forecasting, ICT and O&M, and service delivery, including early warning systems), and training of stakeholders; exploring twinning arrangements with other NMHSs; and collaborating with universities for fellowships and internships.

Modernization of weather-, climate- and water-related monitoring, modelling and forecasting systems can be achieved through these means:

1. Acquire and install a lightning network.
2. Continue to access and use NWP/EPS data and products from advanced centers; purchasing license (e.g. ECMWF).
3. Continue R&D in NWP/EPS.
4. Couple meteorological and hydrological models for flood forecasting (for other catchment areas).

Strengthening service delivery can be achieved through these means:

1. Develop risk maps.
2. Develop tailored products for socioeconomic sectors.
3. Expand "*Carte de Vigilance"* to *VigiMarine*.
4. Develop outreach materials.

The estimated costs of Phase III activities, executing institutions and scenarios (minimum, good, ideal) are shown in **Table 13**.

TABLE 13. Phase III: Activities, Estimated Costs, Executing Institutions and Scenarios

Phase III Activities	Estimated cost (KUSD)	Institution	Scenario (Minimum, Good, Ideal)	Priorities (1 to 3, 1 = highest)	Comments
Strengthening institutional capacity					
Advisory services and training for capacity development and training program for Phase III	1,000	INM, MARHP (DGRE & DGBGTH), MEH (DHU), ONPC	Minimum	1	The amount allocated to each institution must align with the importance of and activities in this phase.
Sub-total	**1,000**				
Modernization of weather and flood monitoring, modelling and forecasting systems					
Procuring equipment and related services and training to install lightning network and related telecommunication systems, and metadata	800	INM	Minimum	3	
Purchase of ECMWF license for 2 years	100	INM	Minimum	1	
Advisory services to couple meteorological and hydrological modeling for flood forecasting (other catchment areas)	1,000	MARHP (DGRE & DGBGTH)	Minimum	1	
Advisory services for research and development in the NWP/EPS	500	INM	Good	3	
Sub-total	**2,400**				
Strengthening service delivery					
Advisory services to develop risk maps	300	INM, MARHP (DGRE)	Minimum	1	
Advisory services for tailored products for socioeconomic sectors	500	INM	Minimum	2	
Advisory services to expand the "Carte de Vigilance" to VigiMarine	700	INM, MARHP (DGRE)	Minimum	1	
Advisory services to develop outreach materials	300	INM, MARHP (DGRE), MEH (DHU), ONPC	Good	2	
Sub-total	**1,800**				
Grand-total	**5,200**				

To realize the benefits of this Phase, an increase in staff is recommended, as shown in **Table 14**. With an estimated average remuneration cost per month per person and the required addition of 6 persons to the current staff of the meteorological and hydrological service providers, the additional staff cost for this phase is US$158,784. The source of these staff remains unclear; some specialists will come from universities and some staff may come from government agencies or the private sector.

The activities proposed in this Phase will strengthen the capabilities of meteorological and hydrological service providers to discharge their basic public functions.

TABLE 14. Additional Staff and Staff Costs for Phase III

Position	Phase I	Number of additional staff	Personnel costs (US$/year)	Total costs (US$) for 2 years
1	Meteorologists	2	13,232	52,928
2	Computer scientists (for Met)	1	13,232	26,464
3	Meteorological technicians	-	9,564	-
4	Hydrologists	2	13,232	52,928
5	Computer scientists (for Hydro)	1	13,232	26,464
6	Hydrological technicians	-	9,564	-
	Total	**6**		**158,784**

The cost of activities under Phase III is approximately US$5,4 million; and the total for Phases I, II and III is approximately US$42,55 million. The biggest impact under this phase is expected to be strengthened institutional and staff capacity, enhanced delivery of weather and hydrological services, and improved observations, forecasting and ICT capabilities. Using the progress models for various components of meteorological and hydrological service providers, the **meteorological service delivery** capability is expected to reach Level 5 (Advanced); the **meteorological modeling and forecasting** capability is expected to reach Level 4 (Developed); the **meteorological observing and telecommunication** capability is expected to reach Level 5 (Advanced); and the **hydrological services** is expected to reach Level 4 (Developed).

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8 SOCIO-ECONOMIC BENEFITS OF IMPROVED HYDROMETEOROLOGICAL SERVICES AND EARLY WARNING SYSTEMS

For a potential public investment to be justified, the socio-economic benefits it will foster should be compared to the costs involved. The application of cost-benefit analysis to modernizing hydrometeorological services was explored in WMO et al. (2015), which also outlined different methodologies (and challenges) for quantifying benefits and costs related to weather, climate, and water-related information and services. This global study found that in general, investing US$1 in hydrometeorological services and EWS results in at least US$3 in socioeconomic benefits (defined as a 3:1 benefit/cost ratio), and often far more. Cost-benefit analysis for Tunisia indicates that all three proposed investment phases are economically efficient, meaning they will produce socioeconomic benefits greater than their costs at a 5.5:1 ratio.

8.1 Conservative Approach

Cost-benefit analyses for disaster and climate risk management are often limited by a lack of data and information. In addition, complexities and uncertainties inherent in quantifying disaster risk management are compounded by climate change (IPCC 2012). Cost-benefit analyses are not equipped to account for intangibles and—of particular importance for extreme events—in discounting future impacts (WB, 2018). Therefore, building a robust cost-benefit analysis of hydrometeorological services requires a transparent and conservative approach (Kull, Mechler, and Hochrainer 2013). All assumptions and their supporting analyses are described below. Where a range of inputs is generated, the most "conservative" values are taken, meaning that for a range of potential benefits the lowest value is used. This approach results in net present values and benefit/cost ratios for the lowest threshold of expected economic effectiveness; thus, realized economic efficiencies will be greater than those reported here.

The three key conservative assumptions adopted in this study are:

1. The analysis does not consider future population growth and development gains that will follow from this investment; the economy at risk is considered the same as that of the most recent World Bank data on GDP (2019).
2. Only reductions in the short-term direct impacts of weather and climate-related hazards are considered; long-term indirect impacts (such as in health) are not included.
3. Disaster risk is based on past experience and therefore does not consider the potential impacts of climate change.

As indicated above, these assumptions give a conservative estimate of the investment's economic effectiveness.

8.2 Benefits from Avoided Disaster Losses

Considering the stochastic nature of disasters, a common practice for cost-benefit analyses of disaster risk management is to determine the average annual losses due to disasters (Kull, Mechler, and Hochrainer 2013). This approach averages all potential losses over time to quantify the expected economic burden per year. When sufficient data are available, the average annual loss is calculated as the area under a loss frequency curve, which is a common metric indicating the probability of exceeding the full potential range of losses per year (for example from the yearly flood to the 100- or 200-year flood).

Tunisia is a lower-middle-income country with a population of 11.6 million and a GDP of US$39.87 billion (2018). According to preliminary findings of a national disaster risk profile conducted by the World Bank (WB), it is estimated that floods have an average annual loss (AAL)[12] of US$42.3 million (or 0.11 percent of Tunisia's 2018 GDP).

8.3 Benefit Analysis

8.3.1 Benefits from Reduced Disaster Losses

According to Subbiah, Bildan, and Narasimhan (2009), damage reduction from early warning ranges from 5 percent to 90 percent, depending on the items at risk and the lead times provided. While a 20 percent reduction, for instance, is often assumed as an average reduction in economic losses attributable to early warning, contextual experience indicates that a more conservative range of 5–10 percent is more appropriate; for example, 5 percent in Georgia (World Bank 2018), 8.5 percent in Russia (World Bank 2005) and 10 percent for floods in southeastern Europe (World Bank 2008). In line with the conservative approach adopted for this analysis, the lower end of the range of global experience (5 percent) is applied. Out of total annual flood damages of US$42.3 million, improved forecasting and early warning can potentially eliminate some US$2.12 million.

Considering limited data availability, a benchmarking method based on a country's GDP is used to verify the results, following Hallegatte (2012). Hallegatte (2012) found that on average, well-functioning, modern EWS reduced disaster-related asset damages by 0.003–0.017 percent of GDP. The study concluded that the potential benefit of an investment in EWS is the difference between the protection provided by the country's existing systems and the potential reduction in asset damages that would be gained if the system were modernized.

Under this benchmarking approach, Tunisia is considered a lower-middle-income country[13] with a relatively modest system and an assumed capture of only 20 percent of the potential damage reduction benefits of hydromet early warnings. Potential benefits would thus be calculated as

[12] Average Annual Loss (AAL) represents the expected loss per year, averaged over many years.
[13] https://data.worldbank.org/country/tunisia

the difference between the potential reduced losses—between 0.003 percent and 0.017 percent of GDP, assuming Tunisia corresponds to the global benchmark—and the actual reduced losses, which in this case would be 20 percent of that value. The results for Tunisia are as high as US$1.4 million in average annual reduced losses.

The benchmarking indicates that estimates of annual benefits from reduced flood losses are of a similar order of magnitude as the lower value. Because Tunisia's exposure to hydrometeorological hazards is less than the global average, a sensitivity analysis was carried out to describe the impact of reduced benefits on the overall economic assessment.

8.3.2 Benefits from Increased Production

In addition to reducing disaster losses, modernized hydromet systems can significantly enhance economic productivity. Because information is lacking, a benchmarking approach is used to estimate potential benefits to economic productivity from modernized hydromet services in Tunisia.

Hallegatte (2012) found that about 25 percent of global GDP is generated in weather- and climate-sensitive sectors i.e. agriculture, mining and energy, construction, and transport. Modernized hydromet and warning systems can benefit these sectors in many ways, ranging from immediate warnings and seasonal advisories to infrastructure design and spatial planning. A conservative global benchmark is that modern forecasts add value of 0.1 percent to 1 percent in weather- and climate-sensitive sectors, translating into gains of approximately 0.025 percent and 0.25 percent of global GDP.

In Tunisia, weather- and climate-sensitive sectors account for about 50 percent of the economy for agriculture, transport, energy, construction and tourism; but this may be even higher as there are other sectors that are also weather- and climate-sensitive, but for which data are not available. Applying the Hallegatte (2012) benchmarking approach results in annual benefits in production of US$20–200 million per year. To avoid double-counting, and adopting a conservative approach, the lower end of the range (i.e. US$20) is used in this analysis. However, considering the frequency of droughts and floods in Tunisia, this is conservative.

8.3.3 Total Annual Benefits

Table 15 summarizes the benefits attributed to improved hydrometeorological services for this analysis, including the bounds of values used for sensitivity analysis. Maximum value for reduced disaster losses due to floods assumes 20 percent reduction of annual losses.

TABLE 15. Annual Benefits Attributed to Modernized Hydrometeorological Services (US$)

Benefit	Minimum value	"Realistic" value	Maximum value
Reduced disaster losses due to floods	0.93 million	2.12 million	8.5 million
Increased productivity	20 million	20 million	80 million
Total	20.93 million	22.12 million	88.5 million

8.4 Cost-Benefit Analysis

The three investment phases described in Chapter 7 will not only incur different costs but will also bring the meteorological and hydrological service providers to different levels. It is assumed that only full modernization will deliver the 5 percent loss reduction possible with early warning. It must again be noted that this is already a conservative estimate. It is assumed that smaller project investments will deliver less than the 5 percent associated with full modernization, resulting in 4,4 percent loss reduction for partial modernization (Phase II) and 2.4 percent for the modernization of the priority activities (Phase I) (**Table 16**). Benefits of reduced disaster damages and increased production are assumed to increase linearly after the first project year, reaching full benefits the year after program completion.

TABLE 16. Assessment of the Three Phases of Modernization

Phases	Total Cost (accumulated) (US$ million)	Duration (Years)	Period of Impact (Years)	Loss Reduction (percent)
I	20.50	3	20	2.4
II	37.15	5	20	4,4
III	42,55	7	20	5

Comparing the costs and benefits of the program over time can show the relative value of the planned investments. While cost-benefit analysis provides an instructive process and metrics to inform investments, it should not be the only factor considered.

While the implementation phases range from three to seven years, this analysis assumes a project impact of 20 years, based on the average life cycle of the infrastructure (meteorological and hydrological equipment). Investment disbursements are assumed to occur equally across each phase. Additional O&M costs of modernized assets thus increase linearly as project investments are made, reaching a constant maximum the year after Phase III investments are completed. Benefits in terms of reduced disaster damages and increased production are also assumed to increase linearly, starting to be realized from the second year and reaching a constant maximum the year after Phase III investments are completed.

Cost-benefit analysis uses a discount rate to represent societal preference for consuming in the present as opposed to saving and consuming in the future. A discount rate of 0 percent indicates no preference for present or future, while a discount rate of 15 percent represents a high preference for spending now. In this analysis a discount rate of 5 percent is applied, based on the understanding that future costs and benefits are important when compared to the current situation (in keeping with concerns regarding climate change). However, 0 percent to 15 percent discount rates are also applied for sensitivity analysis. **Tables 17–19** show the results of the analysis for the following cost-benefit metrics:

- **Net present value:** Present benefits minus present costs. If the net present value is greater than 0, then the investment is considered economically effective.
- **Benefit/cost ratio:** Present benefits divided by present costs. If the benefit/cost ratio is greater than 1, then the investment is considered economically effective.

TABLE 17. Cost-benefit Analysis for Phase I

Discount rate	Net present value (US$ million)				Benefit/cost ratio			
	0%	*5%*	*10%*	*15%*	*0%*	*5%*	*10%*	*15%*
Minimum benefits	162	96	62	43	5.2	4.2	3.6	3.1
"Realistic" benefits	173	103	66	46	5.5	4.5	3.8	3.3
Maximum benefits	811	500	338	246	21.8	18	15.1	13

TABLE 18. Cost-benefit Analysis for Phase II

Discount rate	Net present value (US$ million)				Benefit/cost ratio			
	0%	*5%*	*10%*	*15%*	*0%*	*5%*	*10%*	*15%*
Minimum benefits	262	147	89	57	4.8	3.9	3.3	2.8
"Realistic" benefits	281	158	96	62	5.1	4.2	3.5	3
Maximum benefits	1330	781	501	346	20.4	16.6	13.8	11.8

TABLE 19. Cost-benefit Analysis for Phase III

Discount rate	Net present value (US$ million)				Benefit/cost ratio			
	0%	*5%*	*10%*	*15%*	*0%*	*5%*	*10%*	*15%*
Minimum benefits	287	158	95	60	4.7	3.8	3.2	2.7
"Realistic" benefits	308	171	102	66	5	4.1	3.4	2.9
Maximum benefits	1464	850	538	367	19.9	16.2	13.5	11.6

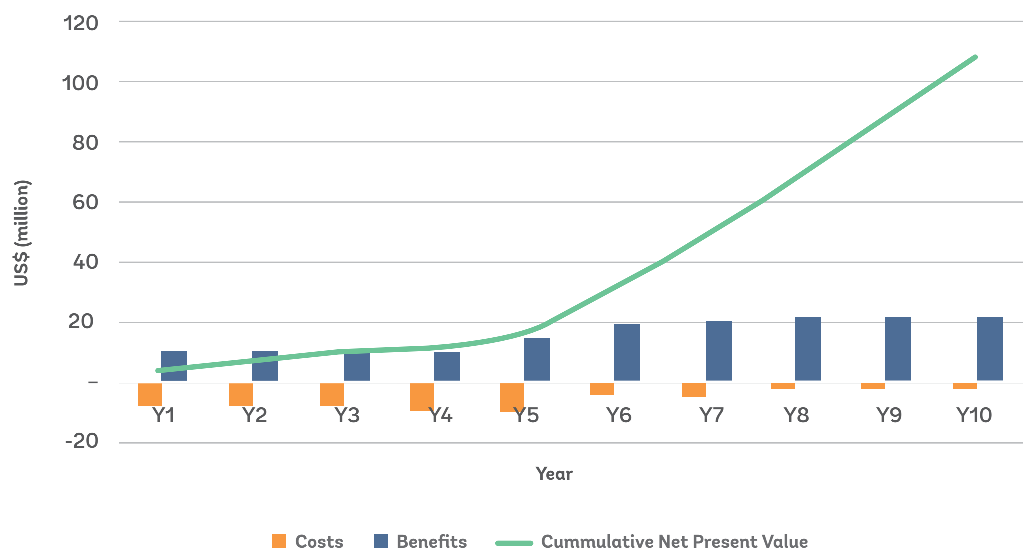
To further test the sensitivity of the analysis, the realistic benefit assumption for all three Phases is analyzed using an assumption that the costs are 30 percent higher than estimated. The results are shown in **Table 20**.

TABLE 20. Cost-benefit Analysis: Realistic Benefits and 30 Percent Cost Overruns

	Net present value (US$ million)				Benefit/cost ratio			
Discount rate	*0%*	*5%*	*10%*	*15%*	*0%*	*5%*	*10%*	*15%*
Phase I	162	94	59	40	4.2	3.5	2.9	2.5
Phase II	261	143	84	53	3.9	3.2	2.7	2.3
Phase III	285	154	89	55	3.8	3.1	2.6	2.2

The importance of reliable long-term budgets is given in **Figure 33**, which shows the first 10 years of financial and economic flows for Phase III, assuming "realistic" benefits and a discount rate of 5 percent. The first year of investments result in a nearly constant reduced net present value, but as more investments come online (from year 5 onwards), the net present value appreciates, despite increased O&M costs. Once the program is completed (in year 7), the annual costs and benefits remain constant, with the cumulative net present value significantly increasing year-on-year. The relatively small O&M costs leverage the Phase III investment to deliver significant benefits into the future.

FIGURE 33. Annual Financial and Economic Flows of Phase III Investment with "Realistic" Benefits and 5 Percent Assumed Discount Rate



8.5 Summary of the SEB Analysis

The cost-benefit analysis indicates that all three investment Phases are economically efficient, meaning they will produce socioeconomic benefits greater than their costs. In all cases the benefits are significantly greater than the costs; for example, in the worst-case scenario with realistic assumed benefits and 30 percent cost overruns the benefit/cost ratios for all investment Phases are over 2.2. For what are considered the most realistic assumptions, the benefit/cost ratios for all Phases range between 2.9 and 5.5.

Considering the very conservative approach and assumptions applied throughout the analysis, the results are considered robust. Hallegatte et al. (2017) found that global use of EWS would almost double the benefits of reduced asset losses by also reducing "well-being" losses. These less tangible well-being benefits—for example, contributions to poverty reduction—are not considered in this analysis, further suggesting that the analysis is underestimating the benefits of the proposed investments. Neither does the analysis consider the saving of lives, which is a primary benefit of EWS that is omitted due to the moral implications and sensitivities of assigning economic values to human lives, even with "neutral" approaches such as value of a statistical life (VSOL). This omission further asserts the conservative nature of the analysis.

As weather and climate impacts increase, the net present values and benefit/cost ratios of the proposed investments will also increase. This is because early warning provides benefits that are not limited by thresholds; whether a flood is a 25-year or a 50-year event, early warning reduces impacts similarly (as opposed for example to levees or other structural measures, whose design thresholds are at some point exceeded).

As Tunisia's population and economy grow, EWS will continue to provide benefits. New developments and investments benefit from EWS, as opposed to structural flood controls which may need to be built to protect new developments. The fact that these two factors (climate change and population/economic growth) were not incorporated in the analysis again points to an underestimation of program benefits.

While all three investment Phases are economically efficient (i.e. net present value greater than 0 and benefit/cost ratio greater than 1), the analysis shows that Phase III is more efficient than Phase II, which itself is more efficient than Phase I. At the same time, Phases II and III deliver significantly higher absolute benefits to Tunisia. Given that these higher-level investments are relatively low in cost, are economically efficient, protect lives and property, and contribute to economic development and resilience, they should be considered for priority financing.

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9 CONCLUSIONS AND A WAY FORWARD

The strategic steps needed to modernize hydrometeorological products and services in Tunisia are primarily driven by the needs of the user community. Extensive discussions with the management and technical staff of INM, MARHP/DGRE, DGBGTH (the primary hydromet service providers) and key stakeholders (i.e. the MARHP/BPEH, DHU, ME, ONPC, and development partners and donors) dealing with the country's most pressing issues have revealed that these needs are not being fully met. Due to a lack of resources, Meteorological and Hydrological Service Providers in Tunisia no longer use current technologies and tools to monitor weather and climate, produce forecasts, or efficiently deliver services.

There is clearly a demand for a modernized EWS service in Tunisia. This requires building up-to-date observation and monitoring systems, and data management systems; a forecasting system offering forecasts on all time scales (from nowcasting and very short-range to long-range/ seasonal forecasts), and impact-based forecasts; hydrological services and flood forecasting; an ICT system capable of transmitting, processing, and storing data from all the different components of the observing networks in a harmonized and efficient manner; and effective service delivery systems.

There is a potential mutual benefit in closer collaboration between INM and MARHP/DGRE, DGBGTH, and DHU. In view of the factors cited above, the assessment and modernization of Meteorological and Hydrological Service Providers has been the main focus of this road map. Modernization is proposed in three phases, (each phase building on the previous one) with support for the ONPC for improved EWS, and the level of complexity and resources is different for each phase, as shown below.

Phase I: immediate to short-term activities. Invests in high-priority activities to improve basic public services through new technologies, staff training and capacity building (immediate to short term: two- to three-years duration). Implementation requires an additional 14 staff. The investment cost is estimated at US$20.5 million, and the annual operating cost is US$1.03 million.

Phase II: medium-term activities. Investments to modestly improve weather, climate and hydrological services that meet the public service needs of the most important user communities, including disaster management, transport, agriculture, and water resources management (medium term: two-years duration on top of Phase I). Implementation is expected to follow Phase I and will cost US$16.65 million; it requires an additional 11 staff and has an operating cost of US$1.86 million per year (after the implementation of Phases I and II).

Phase III: long-term activities. Investments in data, forecasts, and warning services for the safety of the public, and support to develop the most important socioeconomic sectors (long term: two-year duration on top of Phases I and II). Implementation is expected to follow Phases I and II and will cost US$5.4 million. Implementation requires an additional 6 staff and has an operating cost of US$2.13 per year (after the implementation of Phases I, II and III).

Cost-benefit analysis for Tunisia indicates that all three proposed investment phases are economically efficient, meaning they will produce socioeconomic benefits greater than their costs (5.5:1). In all cases, benefits in the longer-term are greater than costs.

To achieve the expected results of Phase III, two main conditions will need to be met: (i) the government must direct resources from to modernize observation, ICT, and forecasting infrastructure, and improve service delivery; and (ii) the government must recruit 31 specialists and technicians.

Developing a Concept of Operations is essential for detailed planning and implementation of each phase.

ANNEX 1. AREAS OF TRAINING IDENTIFIED BY METEOROLOGICAL AND HYDROLOGICAL SERVICE PROVIDERS

Capacity Building / Training topics for INM (High priority)

Direction	Training topic	Objective	Audience	Number of participants
Research and Development in Meteorology	Atmospheric pollution	Reinforcement of capacities in atmospheric dispersion modeling within the framework of the NETTUNIT project	Engineers of the NETTUNIT project	3
	Marine pollution	Reinforcement of capacities in oil spill modeling within the framework of the NETTUNIT project	Engineers of the NETTUNIT project	3
	Numerical Weather Prediction: Data assimilation	Reinforcement of capacities in data assimilation of EUMETSAT data and use of algorithm. Data assimilation at INM to improve weather forecasts	NWP Engineers	2
	Utilization of satellite data and products	Estimates from satellite data e.g. precipitation, humidity and evapotranspiration in order to respond to agriculture and other needs	Engineers of the hydro-agro service, general forecasting and NWP	3
Planning, Quality and International Relations	Strategy for the development of INM	Elaboration of a new strategy for development of INM 2021-2025 and new strategic plan for INM	Personnel responsible for Planning	2
	Steering Panel	Put in place a Global Steering Panel for INM taking into account its technical, scientific and administrative specificities	Directors	7

Capacity Building / Training topics for INM (High priority) (cont.)

Direction	Training topic	Objective	Audience	Number of participants
Production	Marine forecasting	Use of Altimeter and Scatterometer data for marine forecasting	Framework of the Marine Forecast Service	
		Use of satellite imagery in Marine Meteorology		
		Tide effects and storm surge		
	Monitoring submersion waves	Process for monitoring submersion waves		
	ECMWF products	Introduction of ECMWF products: Ensemble Prediction Systems (EPS) and Probabilistic Forecasts	Framework of the General Forecasting Service	
	Monitoring	Monitoring and EWS using ECMWF products		
	Deep convection	Forecasting deep convection		
	Forecasting severe phenomena	Forecasting severe phenomena such as heavy precipitation at mid-latitudes		
	Communication and crisis management	Communication and management of meteorological hazards (Formation and organization of crisis cells)		
	Aeronautic	Dangerous phenomena in aviation	Framework of the Aeronautical Forecasting Service	
	Data rescue	Data rescue	Personnel responsible for Database management	
	Statistical adaptation	Statistical adaptation methods, auto-adaptative methods of weather forecasts	Adaptation and control of forecasts	

Capacity Building / Training topics for INM (High priority) (cont.)

Direction	Training topic	Objective	Audience	Number of participants
Technologies of Information and Observations	Managing Observation Systems	Management of the observation network and database (development of tools and methods)	Personnel managing Observation Systems	3
		Put in place performance indicators for the observation network (measure effectiveness)		
		Development of observation products and services within the framework of an EWS focused on floods and droughts	Personnel managing Observation Systems and working group on EWS	4
		Meteorological and hydrological coupled modeling (e.g. Medjerda)	Agro-meteorologists and personnel managing Observation Systems	2
		Development of observation products and MSG imagery for rainfall monitoring	Forecasters and personnel managing Observation Systems	2
	Remote sensing	Hydrometeorological radars: technology, use of products and maintenance	Radar project team	4
		Radar wind profile: technology, treatment and use of products		
		Implement a lightning system and integrate the data into the aerodrome automatic observation system	Personnel managing Observation Systems and their Operation and Maintenance (headquarters and regional units)	2
		Marine observation system: UHF radars and buoys	Personnel managing Observation Systems and their Operation and Maintenance; and marine services	2
		Development of composite products from satellite imagery (MTG)	Forecasters and personnel managing Observation Systems	2

Capacity Building / Training topics for INM (High priority) (cont.)

Direction	Training topic	Objective	Audience	Number of participants
	Calibration and Maintenance	Calibration of meteorological sensors	Personnel from the Calibration Lab dealing with Metrology	2
		Maintenance of equipment, in particular relating to present weather and its components, telemeter for cloud base height, dataloggers, etc.	Personnel dealing with Operation and Maintenance (headquarters and regional units)	2
	Information Systems and Communications	Management of continuous activity, as per the ISO regulation 22301	Personnel dealing with Information Systems and Communications	3
		Cisco Network administrator, certified CCNA		4
		Visualization of information systems		4
Regional Units and marketing	Satellite data and imagery	Analyze and use satellite data and imagery for nowcasting	-	-
	Optimization and automation of the observation network	Optimization and automation of the rainfall observation network	-	-
	Utilization of multi-hazard EWS	Use of multi-hazard EWS to mitigate the impacts of extreme hydromet phenomena	-	-
	Communication techniques	Communication techniques relating to the use of weather and climate data for various socioeconomic sectors	-	-
Geophysics and Astronomy	Seiscomp3	Complete and detailed installation and configuration of the Seiscopmp3 software.	Engineers and Technicians	3

Capacity Building / Training topics for INM (Priorities 2 and 3)

Direction	Training topic	Objective	Audience	Number of participants
Research and Development in Meteorology	Numerical Weather Prediction: Surface analysis	Contribution to improve quality of forecasts e.g. at the mesoscale	NWP Engineers	2
	Numerical Weather Prediction: microphysics	Contribution to improve forecasts e.g. at the mesoscale	NWP Engineers	2
	Climate change	Reinforcement of capacities in climate modeling (climate projections)	Engineers of the E3C service	2
Production	Marine forecasting	Wave modeling and use of Wavewatch III model	Framework of the Marine Forecast Service	
		Marine meteorology		
		Use and interpretation of ECMWF products (Marine)		
		ECMWF/EUMETSAT NWP-SAF Satellite Data Assimilation Training Course		
		ecCodes: GRIB data decoding and encoding software (Marine)		
		Exploitation and interpretation of SAF Nowcasting products (Marine)		
	General forecasting	Influence of climate change in extreme events in mid-latitudes	Framework of the General Forecasting Service	
		Building capacity to use scrolling satellite imagery (soil, vegetation, fire,....)		
	Aeronautic	WMO and ICAO Norms and regulations	Framework of the Aeronautical Forecasting Service	
	Quality control of data	Improve climate data management at INM: development of advanced methods for quality control of data	Data management Service / Service of climatological products	

Capacity Building / Training topics for INM (Priorities 2 and 3) (cont.)

Direction	Training topic	Objective	Audience	Number of participants
	Climate statistics	Climate statistics and statistical modeling of climate series	Data management Service / Service of climatological products	
	Cartography	ARCVIEW, ARCGIS or IDRISI GIS for cartography	Service of adaptation and control of forecasts	
Technologies of information and observation	Management of competences	Management of competences	Personnel management Observation Systems	5
Regional units and marketing	Satellite data and imagery	Analyze and use satellite data and imagery for nowcasting	-	-
	Optimization and automation of the observation network	Optimization and automation of the rainfall observation network	-	-
	Use of multi-hazard EWS	Use of multi-hazard EWS to mitigate the impacts of extreme hydromet phenomena	-	-
	Communication techniques	Communication techniques relating to the use of weather and climate data for various socioeconomic sectors	-	-
Geophysics and Astronomy	Seismic Inversion	Development of a 3 D crustal speed model up to 300 kms depth for Tunisia and the Tunisia-Italy basin	Engineers and Technicians	2
		Development of « shaking maps »		2
	Calibration of seismometers	Methodology and practical work for the maintenance and calibration of seismometers		2

ANNEX 2. COMPLETED AND ONGOING PROJECTS

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
1	Institutional support to strengthen the capacities of INM (twinning project between INM and Météo-France)	European Commission	Accomplished (2015–2018)	INM Météo-France		The main outcome of the project was enhanced capacity of the overall INM - Tunisia. Achieved results: » Strengthened regulatory Framework and institutional cooperation between INM and stakeholders in meteorology (weather and climate) and geophysics » Strengthened management and organizational capacities at INM » Strengthened technical capacities at INM » Developed commercial services at INM (in addition to meteorological services for air navigation)
2	Adapt'Action in Tunisia	AFD	Ongoing (2019–...)	INM ME MARHP		The main outcome of the project is enhanced capacity of INM in climate services, and ME (in coordination with other Ministries) in evaluating the impacts of climate change to the various sectors. Achieved results: Climate Portal » WMO 27 climate extreme indices calculated for Tunisia » Climate trends and projections for the intermediary (RCP4.5) and worse (RCP8.5) climate change scenarios, using EUROCORDEX models » Assess the impacts of climate change to socioeconomic sectors in Tunisia, in particular agriculture, using the INM climate products (statistics, trends, projections, etc.) products

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
3	Elaboration of the Water Vision and Strategy 2050 for Tunisia	African Water Facility ADB KFW GIZ	Ongoing (2018–…)	MARHP (BPEH), in coordination with all water-related Ministries	€1.5 million	The water strategy for 2050 in Tunisia aims to implement a new approach for integrated water governance, based on demand management and not supply management. Major components: » Define a long-term vision (horizon 2050), based on diagnosis of the water sector and sub-sectoral prospective studies » This vision will be used to develop a strategy that will define the objectives and agree on how these objectives can be achieved » The terms of reference for planning is the translation of the strategy into concrete objectives, activities and associated means
4	Improvement of Water Resources Management and Adaptation to Climate Change Project in Tunisia (Land Data Assimilation System Component, LDAS)	Global Environment Facility WB	Accomplished (2012–2015)	CNCT MARHP INM MDN MESRS	US$1.5 million	The overall objectives of this project included: (a) flood forecasting and mapping; (b) mapping of irrigated agricultural land and crop assessment; (c) drought study; (d) climate change study; and (e) groundwater study Within the framework of the LDAS component, whose objective is to estimate the flow upstream of Sidi Salem, the National Centre for Cartography and Remote Sensing (CNCT) in collaboration with its partners, especially those of the MARHP, installed the CREST (Coupled Routing and Express STorage) model at the DGRE in order to forecast floods in real time. The "Climate Change" axis of the project, which involved INM, produces projections of climate change scenarios for Tunisia in 2050 and 2100 for precipitation and temperature at a fine resolution using statistical and dynamic downscaling.

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
5	Water Sector Investment Program – Phase I (PISEAU I)	African Water facility Government of Tunisia WB AFD KfW	Accomplished (2001–2007)	MARHP ME Other Water-related Directorates	€187,43 million	The main objectives of PISEAU I were to : (i) promote integrated water resources management through the establishment/application of an institutional framework, implementation of sectoral reforms, improvement of the operating capacities of the main stakeholders and better real-time water management; and (ii) promote the conservation/protection of water resources. PISEAU I enabled the establishment of irrigated perimeters, drinking water networks, the strengthening of the capacities of the Agricultural Development Group (GDA) and the design, by a specialized computer science office, of a National Water Information System (SINEAU), initially focused on water resources. The organizational, technical and functional architecture of the initial version of SINEAU was studied, and technical specifications were drawn up for the development of SINEAU and the acquisition of the corresponding computer hardware and software.
6	PISEAU II	African Water facility Government of Tunisia WB AFD KfW	Accomplished (2008–2013)	MARHP ME Other Water-related Directorates	€122 million	PISEAU II was intended to promote efficient and integrated management of both conventional water resources (i.e. mobilized by dams, hill lakes, boreholes and surface wells) and non-conventional water resources (wastewater and brackish water), thus making Tunisia better able to meet the growing challenge of water scarcity. It was intended to be a tool to manage water scarcity via stakeholder participation in the management of resources and infrastructures and promoting appropriate pricing systems. Achieved results: » Expansion of the hydrological network » Implementation of SYGREAU » Establishment of soil district laboratories

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
7	Urban flood risk management strategy	WB	Ongoing	ME (DHU)		Terms of reference have been developed for the implementation of an urban flood risk reduction strategy. Elements identified: (a) at the planning and land-use planning level take into account hydromet information and climate change; (b) the establishment of an observation system for floods in cities and the identification of dangerous levels; and (c) increasing lead time of alerts and warnings.
8	Integrated basin management for flood control on the Mejerda River	JICA	Ongoing	MARHP (DGBGTH)		This project relates to integrated basin management focusing on flood control in the Mejerda River, in the downstream area between the Laoussia and Pont de Kalaat Landalous dams. A master plan was developed and has been implemented, which comprised levees, flood control basins and other structural measures, as well as non-structural measures, including flood forecasting warning system, flood control and evacuation system, organization skill building, and land use restriction management in the flood plain. There have been some experiments with MIKE modelling.
9	Water Storage and Flood Protection in the Medjerda Catchment Area	KfW	Ongoing	MARHP (DGRE and DGBGTH)	€262 million	This project concerns: (a) construction of the Raghai dam; (b) raising of the Bou Heurtma dam; (c) protection against flooding of the upper Medjerda valley by the construction of dykes, diversion channels and other protective infrastructure. For flood control in the Mejerda River - upstream area, the following activities are being carried out: (a) hydrological/hydraulic modelling of the Mejerda wadi in real time (DGRE), taking into account dam drills (DGRE - DGBGTH), and for the development of structural measures.

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
10	Information System for Water Resources (SINEAU)	African Water facility ADB GIZ	Accomplished (2008–2013)	MARHP MEDD ANPE INS	€3.35 million	The objective of this project is to optimize the management of surface and underground water resources and agricultural soils in irrigated perimeters, by setting up monitoring systems using standardized, interoperable data stored in a single information system (SINEAU), which will integrate the various aspects to: (i) understand the current state of water and irrigated soil resources; (ii) monitor their use; and (iii) help in taking preventive decisions. The main results of the project are: (a) the SYGREAU database operational and accessible on an Intranet, and integrating all existing data; (b) a national information system on irrigated water and soils available, functional and accessible to national decision-makers; and (c) more rational decisions on the use and conservation of irrigated agricultural water and soils.
11	Establishment of a territorial observatory on the relations between water - agrometeo-rology - agricultural production	GIZ	Ongoing	MARHP (DGACTA)		The Water Strategy 2050 includes the idea of a territorial observatory on the relations between water - agrometeorology - agricultural production.
12	Sustainable agriculture	GIZ	Ongoing	MARHP		This project makes use of hydrometeorological information (including the establishment of hydromet stations) for sustainable agriculture.
13	Protection and rehabilitation of degraded soils	GIZ	Ongoing	MARHP		This project has strong focus on adaptation to climate change.

	Program/project title	Donor/ implementer	Status (including implementation period)	Involved organization/ beneficiary	Budget	Description
14	EWS for Risk Management of Climate Extremes in Tunisia – Feasibility Study	KfW	Accomplished (2016)	ME		This project only included the feasibility study for the implementation of an EWS for Risk Management of Climate Extremes in Tunisia. The actual activities described in the feasibility study have not been implemented.
15	Local EWSs in 3 municipalities	UNDP	Ongoing	ME ONPC		The objective of this project is the establishment of EWS at the local level in 3 municipalities (Ain Draham, Bou Salem and Tataouine) in coordination with ONPC. Risk management centers are being established, as well as meteorological stations in these municipalities. There has been collaboration with INM to establish specifications for meteorological stations.
16	EWS	AFD	Ongoing	ONPC		This project supports the ONPC to optimize its school and implement a platform to integrate all elements of the Early Warning System.
17	Global Preparedness Partnership	WFP	Ongoing	All EWS stakeholders, in particular ONPC and ME		This project focuses on institutional aspects of Disaster Risk Reduction (DRR). Major achievements so far are: » The establishment of a Committee of the Global Preparedness Partnership (GPP) » A joint declaration, which defines an emergency preparedness and response program divided into the following sections: (a) emergency services / standby arrangements and prepositioning; (b) hazard/ risk analysis and early warning; (c) institutional framework and risk financing; (d) coordination and contingency planning; (e) information management and communication; and (f) communication awareness and vulnerabilities.
18	Coastal resilience	UNDP GCF	Ongoing	APAL		This project focuses on the establishment of coastal observations, including buoys; and information and decision support systems as an element of a EWS for coastal areas.

Source: Development Partners and Donors

ANNEX 3. SERVICE DELIVERY PROGRESS MODEL

The Service Delivery Progress Model is adapted from the WMO Strategy for Service Delivery and Its Implementation Plan (WMO 2014). The model can be used as a tool for assessing an NMHS's level of development and for creating an action plan to improve service delivery. Full details can be found in WMO (2014).

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Strategy element 1 Evaluate user needs and decisions	The users and their requirements for products or services are not known.	Users are known, but no process for user engagement exists. User requirements for service delivery are not well defined.	Users are able to contact the NMHS and their feedback is recorded. There are some formal processes to integrate feedback into the development of services. User requirements are defined with limited documentation.	NMHS seeks input on an ad hoc basis from users to facilitate the development of services. Requirements are defined in documents agreed upon with the user but are not routinely updated.	An ongoing dialogue is maintained with users regarding their needs and the services they receive. Requirements are defined in documents agreed upon with the user and routinely updated using feedback from users.

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Strategy element 2 Link service development and delivery to user needs	No concept of service exists; products are simply issued.	Services do not adapt to changing user needs and new technology. Products are documented with limited descriptive information.	Services are developed and changed as technology allows, but engagement with users is ad hoc. Products and services are documented, and this information is used to inform management of changes.	User feedback informs management of changes and development of services. Products and services are consistently documented. Service-level agreements (SLAs) are defined.	Users are consulted to facilitate development of products and services. The service defined in the SLA is agreed upon with the user based on user consultation.

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Strategy element 3 Evaluate and monitor service performance and outcomes	No measures in place for assessing performance, in terms of either accuracy or service delivery.	Some measures of development are in place. The verification of accuracy and/or service delivery takes place, but no systematic process exists to use this information to improve the service.	Measures of verification and service delivery are in place but are not informed by user requirements.	User requirements are used as input for performance measures. Findings are used to identify areas for improvement. Subsequent actions are taken in an ad hoc manner.	Measures of performance are based on user needs, which are regularly reported and consistently used to inform improvements.

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Strategy element 4 Sustain improved service delivery	No concept of service delivery principles.	The concept of service delivery has been introduced and an assessment of current status has been undertaken.	An action plan has been created to improve the current level of service delivery, and resources have been identified to implement it.	The action plan is being implemented to improve service delivery, and the outcomes are being monitored.	The status of service delivery is reviewed on a regular basis. The action plan evolves in response to the outcome of the reviews.

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Strategy element 5 Develop skills needed to sustain service delivery	No concept or communication of service delivery principles.	No formal training in service delivery is provided, though service delivery principles are informally communicated.	Most staff of the NMHS are aware of the importance of service delivery. Some formal training is provided.	All members of staff are fully aware of the importance of service delivery. Formal training is provided. There is an ad hoc process for staff to offer ideas to improve service delivery.	There is a culture of providing best possible service delivery. Innovative ideas are routinely integrated into the continual service improvement process.

Strategy element 6 Share best practices and knowledge	NMHSs are encouraged to share best practices in service delivery through formal training, twinning, mentoring and other methods.

ANNEX 4. OBSERVATION AND TELECOMMUNICATION PROGRESS MODEL

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Modeling and Forecasting Systems	NMHS has very few manual synoptic stations and hydrological stations. It does not share station data on the Global Telecommunication System (GTS).	NMHS has the capacity to support a synoptic meteorological network and hydrological network; it shares these data on the GTS; and it has sufficient staff to maintain its observing networks.	Automation of observing network with quality control is routine. NMHS accesses satellite data with the capacity to derive precipitation estimates. The observing network is sustainable with sufficient budget for operations and maintenance. The vertical structure of the atmosphere may be routinely measured.	Observations extend to smaller scales and include ground-based remote sensing techniques, such as radar. The NMHS may be able to integrate observations from other parties. It may access observations by outsourcing its observing requirements.	NMHS conducts research, introducing new observational technologies and techniques as needed. The observing network is comprehensive and sufficient to meet main user needs, incorporates external observations from other suppliers, for example, agro-meteorological network operated by Ministry of Agriculture or hydrological network operated by Ministry of Energy or Water Resources.

ANNEX 5. MODELING AND FORECASTING PROGRESS MODEL

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Modeling and Forecasting Systems	NMHS provides up to a two-day deterministic forecast based on graphical forecast products retrieved from different Web sources. There is no verification of forecasts. The NMHS does not operate forecasting on a 24-hour, seven-day-a-week basis; and warnings are not issued.	NMHS can provide at least a three-day deterministic forecast based on access to global and regional NWP data and products available on the GTS and/or graphical products available from WMO Regional Specialized Meteorological Centers; monitors the current weather and hydrological system; has basic data-processing and archiving systems; and carries out subjective forecast verification. There is no R&D, and the quality management system is rudimentary. The NMHS may not operate forecasting on a 24-hour, seven-day-a-week basis. Warnings are limited.	The NMHs can provide zero- to five-day forecasts using global and regional deterministic NWP and EPS data and products from Global Producing Centers; issues nowcasts and very-short-range forecasts of up to 12 hours based on extrapolating NWP and blending remote-sensing observations; is able to monitor major rivers and generate short-term flow and flood forecasts; has protocols for emergencies, back-up of data and products, and off-site storage facilities; carries out verification and post-processing; has some R&D and a QMS. The NMHS operates forecasting on a 24-hour, seven-day-a-week basis.	LAM systems are available locally or through regional centers. Using local data assimilation, high-resolution short time scale forecasts are produced with emphasis on zero to six hours for extreme events. The forecasting system extends from zero to at least seven days based on a combination of global, regional, and national deterministic NWP and EPS data and products. The NMHS has the capacity to manipulate digital data and tailor forecasts to specific users; operates a multi-hazard warning system; generates seasonal streamflow outlooks and specialized hydrology products; and has full R&D capability. There are well-established relationships with partner agencies.	NMHS has an extensive research program and introduces new forecasting technologies and techniques; has the capacity to support requirements of other NMHSs; and is able to run global, regional, and national NWP and EPS systems. Forecasts of weather and hydrological impacts on specific sectors are routine and generally developed with users of these forecasts. The NMHS has a well-developed education and training unit.

ANNEX 6. CLIMATE SERVICES PROGRESS MODEL

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Climate Services	NMHS may operate a limited national climate observing system; collects data in paper form; retrieves climate data from different sources to generate national climate products; participates in regional climate outlooks; and has very limited or no interaction with users. Typically, NMHSs in this category do not have staff dedicated to carrying out climate services.	NMHS designs, operates, and maintains national climate observing systems; manages data, including QA/QC; develops and maintains data archives; monitors climate; oversees climate standards; performs climate diagnostics, climate analysis, and climate assessment; disseminates climate products; participates in regional climate outlooks; interacts with users; and performs the functions of national climate centers providing basic climate services. Staff are proficient in climate statistics, homogeneity testing techniques, and quality assurance techniques.	NMHS has the capacity to develop and/or provide monthly and longer climate predictions, including seasonal climate outlooks, both statistical and model-based; is able to conduct or participate in regional and national climate outlook forums; interacts with users in various sectors; adds value from national perspectives to products from Regional Climate Centers and in some cases Global Producing Centers for long-range forecasts; conducts climate watch programs; and disseminates early warnings. Staff are proficient in developing and interpreting climate prediction products and in assisting users in the uptake of these products.	NMHS generates subseasonal to seasonal forecast products, develops specialized climate products; downscales long-term climate projections and interprets annual to decadal climate predictions; covers all elements of climate risk management (risk identification; risk assessment, planning, and prevention; services for response and recovery from hazards; information relevant to climate variability and change; and information and advice related to adaptation); builds societal awareness of climate change issues and provides information relevant to policy development and a national action plan. Staff have knowledge of climate modeling and methods for downscaling/ calibration, risk and risk management, and financial tools for risk transfer.	NMHS has research capacities and runs global and regional climate models (subseasonal to decadal and longer); works with sector-based research teams, and develops application models, software, and product suites for customized climate products. Staff have multi-disciplinary modeling and statistical expertise and can downscale/calibrate global scale information to regional and national levels. The NMHS is able to receive and respond to user requirements for new products.

ANNEX 7. HYDROLOGICAL SERVICES PROGRESS MODEL

	Undeveloped	Development Initiated	Development in Progress	Developed	Advanced
Hydrological Services	The NMHS may operate and maintain a very small hydrological observation network; collect data in paper format; and have very limited or no interaction with users. Typically, staff of NMHSs in this category are not trained in hydrology.	Functions of NMHS may include operation and maintenance of a small hydrological observation network; hydrological data management, with basic hydrological data processing, archiving, and communication system; little or no backup/off-site storage; and some interaction with users of hydrology data and products. There is no R&D, and a rudimentary quality management system. There are no relationships with partner agencies.	The NMHS is able to operate and maintain a hydrological observational network to monitor major rivers, and take and integrate some hydrological observations from other parties. The NMHS operates an interoperable hydrological data management system and has well-established protocols for emergencies, backup of hydrological data, and minimum off-site facilities. The NMHS carries out water-level and flow monitoring and is able to generate short-term flow forecasts (low flows), flood forecasts, and hydrological data products for design and operation of water supply structures. There is a small R&D unit and a quality management system. There are some relationships with partner agencies.	The NMHS operates and maintains a comprehensive hydrological observational network to monitor major and some smaller rivers, and integrates most hydrological observations from other parties. The NMHS operates a well-developed interoperable hydrological data management system and has well-established protocols for emergencies, backup of hydrological data, and off-site facilities. The NMHS carries out water-level and flow monitoring, and is able to generate short-term flow forecasts (low flows), flood forecasts, and hydrological data products for design and operation of water supply structures. The NMHS is also able to generate seasonal streamflow outlooks and specialized hydrology products. There is a research and development unit; and a well-established quality management system. There are well-established relationships with partner agencies.	In addition to the foregoing capabilities, the NMHS has an extensive R&D program; and strong relationships with partner agencies, taking a leading role in advice and decision support. NMHS has the ability to generate customized hydrological products and hydrological application tools.

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