

# Chapter 4

## A Regional Drought Monitoring and Outlook System for South Asia



**Faisal Mueen Qamer, Mir A. Matin, Ben Zaitchik, Kiran Shakya, Yi Fan, Nishanta Khanal, Walter Lee Ellenburg, Timothy J. Krupnik, Hasan Md. Hamidur Rahman, Bashir Ahmad, Shib Nandan Shah, and Man Kshetri**

### 4.1 Introduction

Current observations of the mean rainfall measurements in South Asia have placed in evidence a trend of decreasing monsoonal precipitation in the region (Hijioka et al. 2014). The changing rainfall patterns and their intensity are likely to increase the risk of drought—even during the monsoon period, especially when coupled with other climate-related events (like extreme temperature and winds) that can lead to water shortage and heat stress in the dry season. About 45% of the population (around 800 million people) of the region are now living in areas expected to become climate-stress hotspots under the projected changes in weather conditions. Heat waves are also likely to affect more than 200 million people by the year 2040

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F. M. Qamer (✉) · M. A. Matin · K. Shakya · N. Khanal  
International Centre for Integrated Mountain Development, Kathmandu, Nepal  
e-mail: [faisal.qamer@icimod.org](mailto:faisal.qamer@icimod.org)

B. Zaitchik · Y. Fan  
Johns Hopkins University, Baltimore, MD, USA

W. L. Ellenburg  
NASA SERVIR Science Coordination Office, Huntsville, AL, USA

T. J. Krupnik  
International Maize and Wheat Improvement Center, Dhaka, Bangladesh

H. Md. Hamidur Rahman  
Bangladesh Agricultural Research Council, Dhaka, Bangladesh

B. Ahmad  
Pakistan Agricultural Research Council, Islamabad, Pakistan

S. N. Shah  
Ministry of Agriculture and Livestock Development, Kathmandu, Nepal

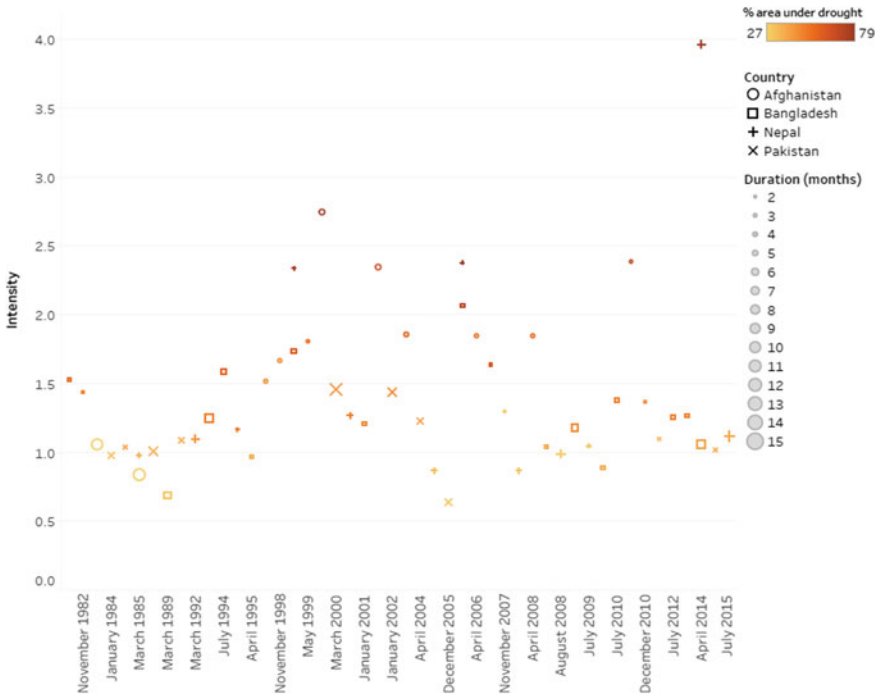
M. Kshetri  
World Food Programme, Kathmandu, Nepal

(Mani et al. 2018). Moreover, drought and heat stress are likely to have adverse impact on many of the crops grown in the dry season, which could have negative implications for food and nutrition security for households that are primarily subsistence based. Decreased water availability could also limit agricultural growth unless adaptation measures are implemented (Fig. 4.1). Further, declining snow-melt during spring and summer will likely affect surface water flow and ground-water recharge (due to less snow stored during the wintertime and the current faster rate of snowmelt) and as such, could reduce farm output from irrigable land in the near future. The projected increase in drier conditions will also likely have consequences for farmers relying exclusively on rain-fed agriculture. As variability exists in the South Asian monsoon patterns, droughts are ever likely to take place, thereby adversely affecting food production and agricultural sustainability of countries like Afghanistan, Nepal, Bangladesh, and Pakistan. Drought is a major driver of production risk in rain-fed agriculture in terms of lost yield and income. A major drought can hamper crop yields, force farmers to reduce planted acreage, decrease livestock productivity and can under extreme circumstances affect the price of irrigation water and animal feed (Enenkel et al. 2015; Dorigo et al. 2012; Chen et al. 2014). As water-related food security issues also spawn regional tensions (Bora et al. 2011), an accurate understanding of the availability and variability of water resources, particularly across geopolitical boundaries, is essential for improving food security, economic development, and regional stability. Drought episodes are characterized by an unusual and prolonged period of dry weather leading to situations of water shortage and crop damage. Various causes are at the origin of drought episodes; these can be classified, as done by Wilhite and Glantz (1985), into—meteorological, hydrological, and agricultural (these three are linked to physical situations); and socio-economical (linked to overuse of water by humans for several activities).

Food insecurity in rural areas is caused by biophysical and socioeconomic factors. The former includes climate change and climatic extremes. Food insecurity is also higher in the HKH mountain region than in the downstream plains of South Asia that tend to support more productive agricultural systems (Hussain et al. 2016). In Afghanistan, drought contributed to large losses of the production of maize (85%), potato (50%), wheat (75%), and 60% of overall agricultural production during the extended dry spell between 1998 and 2005 (NEPA 2013). As for Pakistan, situated in the sunny belt of 24°N–37°N latitude and 61°E–75°E longitude, it presents a variability in rainfall across its regions and drought is also a major threat that the country has to contend with (Mazhar et al. 2015; Dahal et al. 2016). Similarly, periodic and brief droughts in Nepal have caused losses in rice and potato yields (Luitel et al. 2015; Alamgir et al. 2015). Moreover, when farmers do not have access to irrigation, like in Bangladesh, they suffer crop losses due to droughts in the monsoon season (Ahmad et al. 2004; PMD 2008). A summary of major drought events that have occurred in Afghanistan, Bangladesh, Nepal, and Pakistan since 1980 is presented in Fig. 4.2.



**Fig. 4.1** Farmers in the mountains are heavily dependent on rainwater for agriculture. Photo by Jitendra Raj Bajracharya



**Fig. 4.2** Drought frequency and severity during 1980–2016 in Afghanistan, Bangladesh, Nepal, and Pakistan. (Source: Spinoni et al. 2019)

As is known, drought originates from a deficit in precipitation over a period of time (for a growing season or above), resulting in water shortage for some ecosystem function or societal need (NDMC 2015). Drought may also be defined conceptually and operationally. For example, a definition such as “drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield” (NDMC) is a conceptual definition. While this conceptual definition is important in establishing drought-related policies, the operational definitions are important in measuring the onset, end, and severity of droughts.

Beyond forecasting, the timely detection of onset of droughts is central to local and regional drought-mitigation plans, particularly in the water resources and agriculture sectors. A water resource manager may need information months in advance for resource planning, whereas a farmer may require a few weeks of lead time to take meaningful mitigation actions (Zambrano et al. 2018; Mariano et al. 2018). Early detection can allow farmers and institutional actors to take adaptive measures that include choosing alternative crop-management strategies, giving additional support for irrigation, or increasing insurance coverage. In operational terms, the decision makers need a fundamental understanding of drought-forecast models and products, along with their suitability in time and space, to design mitigation and adaptation strategies.

Recent advances in satellite-based remote sensing have greatly improved our ability to measure some of the key characteristics and impacts of drought, including their effects on food insecurity, human health, and migration. These improvements in drought monitoring can be facilitated by integrating climate, satellite, and biophysical data to extract actionable information for use by the decision makers.

#### ***4.1.1 Agriculture Drought Service in the Context of Afghanistan, Bangladesh, Nepal, and Pakistan***

Global-scale drought-monitoring activities strengthened in 1980s with the use of RS data from the National Oceanic and Atmospheric Administration’s (NOAA’s) Advanced Very High-Resolution Radiometer (AVHRR). In the South Asian region, capacities in the area of drought monitoring and management are extremely different; they vary across and even within country, from dedicated advance programs for national-level assessments, to farmer-level adaptation policies and practice, to an insignificant formal mechanism for coarser-level assessments at the national level. At present, the drought-monitoring systems in Afghanistan, Bangladesh, Nepal, and Pakistan rely primarily on meteorological station-based assessments, although most station networks are sparse and may suffer from inconsistency in measurements and data quality.

Several countries’ capacity in modeling and forecasting agricultural drought still tend to be limited despite noticeable improvements. So, regional networks on

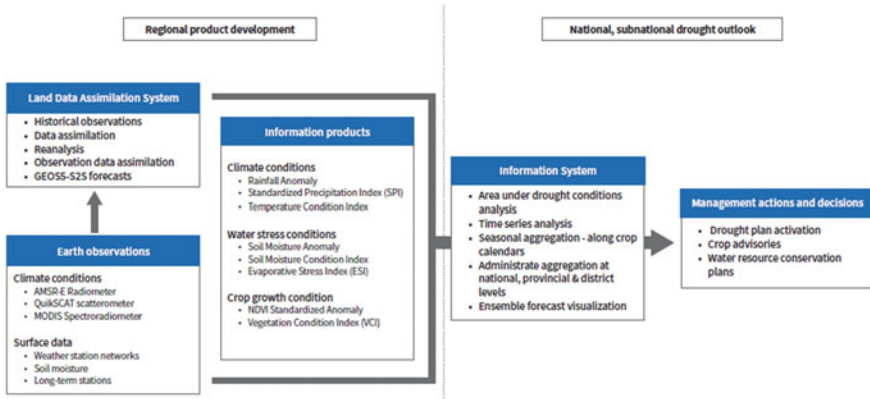
droughts could help strengthen these countries' ability to develop adequate drought-monitoring services and warnings.

In this regard, in the case of South Asia, the South Asian Climate Outlook Forum (SASCOF), established in 2010, is the most prominent platform which functions under the World Meteorological Organization (WMO). Every year during the month of April, SASCOF regional experts review the global and regional climate conditions to produce the monsoon outlook for the upcoming rainy season. The other networks that are partly related to drought monitoring in the region include Global Earth Observation System of Systems (GEOSS) Asian Water Cycle Initiative, South Asian Association for Regional Cooperation (SAARC) Meteorological Research Center, Dhaka, and Global Crop Watch, Beijing. In the case of Pakistan, it is its Meteorological Department's National Drought Monitoring Center (NDMC) that provides drought information and warnings which are primarily based on ground-station data (PMD 2008). However, in the recent years, Pakistan has been able to develop a better and more active meteorological drought-warning system by improving its capability to integrate weather radar and GIS data for drought identification (Islam et al. 2013; Sarkar et al. 2010). Still, the country's prediction level in terms of onset of drought is rather limited (Islam et al. 2013).

In Bangladesh, while the Center for Environmental and Geographical Information System (CEGIS) has developed a Drought Assessment Model (DRAS) that has the capability to monitor agricultural drought and net irrigation (Prasad 2015), it is, however, not yet in operation as it is primarily a research product (Parvin et al. 2015). As for Nepal, there simply is no drought-monitoring system in operation (Abbas et al. 2016). This is despite the fact that an agricultural drought monitoring and warning system has been identified by several studies as crucial for Nepal. These studies include such diverse research projects as: a winter drought-monitoring case study by the Nepal Department of Hydrology and Meteorology (DHM); a governmental project on a crop insurance scheme for farmers; and a study on the use of space technology for drought monitoring and early warning, conducted by the Economic and Social Commission for Asia and the Pacific (ESCAP) (Abbas et al. 2016).

At the global level, there are a number of international agricultural drought-monitoring systems, including Integrated Drought Management supported by the WMO and the Global Water Partnership (GWP), which play a fundamental role in the decision-making processes that govern food aid and agricultural products in the global market. These systems are in operation to assist in: food security and famine early warning; monitoring production to ensure stable global and national markets for agricultural crops; and monitoring and modeling of agricultural land-use change (Hao et al. 2017). But these systems only provide general information at a rather coarse resolution for agriculture in the South Asian countries. There still remain large disparities between the monitoring capabilities of developed and developing nations.

One of the obstacles to the development of an effective and operational drought monitoring and early warning system for the region lies in the lack or absence of a



**Fig. 4.3** Framework for establishing an integrated platform for drought data products and dissemination service

sufficiently reliable regional hydro-meteorological monitoring system as well as due to data gaps from country to country. To counter these issues, ICIMOD has introduced a Regional Drought Monitoring and Outlook System (RDMOS). The aim of the service is to produce a reliable drought indicator for countries in the HKH region. In this system, the drought and vegetation indices are based on climatic models, EO data as well as land-surface models to produce a mechanism whereby drought is monitored in a near-real-time span. It also provides a seasonal outlook, every four months, in order to help the countries of the HKH region be better prepared to take drought management actions.

In this regard, a twofold framework has been developed based on the goal of establishing an integrated modeling platform to produce scientifically robust regional-level drought data products and the development of appropriate information systems to contextualize data and support related decision-making by key institutions working on climate adaptation (Fig. 4.3). The system has two distinct components, one of monitoring the current drought conditions and the other of framing a seasonal drought outlook, ranging from four to nine months. Thus, the system gives prominence to both the quality of meteorological forecast and the accuracy of the modeled initial hydrological state, particularly during the early period of prediction.

### 4.1.2 Indicators for Operational Drought Monitoring

In order to provide a quantitative measure of the main episodic characteristics of a drought, data are assimilated from several variables, like precipitation and evapo-transpiration, to build drought indices. A drought index can be used to quantify moisture conditions in a particular location, and thereby identify the onset and



intensity of a particular drought event. However, as a drought may involve various characteristics, an efficient drought-monitoring system must take into account the type and characteristics of the event. Therefore, several drought indices have been derived for the effective monitoring of the intensity, duration, severity, and spatial extent during the various stages of a drought (WMO and GWP 2016; Mishra and Singh 2010). In this regard, as part of our co-development philosophy, several consultation workshops were held with the key collaborators with the aim to generate agreement on the relevant drought indices that can be suitable for national and regional operational needs. Currently, four key variables related to drought indices are being used by the RDMOS: the Standardized Precipitation Index (SPI); the Evapotranspiration Deficit Index (ETDI); Soil Moisture Anomaly (SMA); and the Vegetation Conditions Anomaly (VCA). These methodologies and the input data are discussed below. While the methodology to compute the drought indices tends to be the same globally, the input data may vary across regions. A more harmonized and standardized set of indices can help in getting better information on the main causes of drought (Steinemann and Cavalcanti 2006).

**Standardized Precipitation Index (SPI):** SPI is the most notably used indicator for drought detection and monitoring. It is based on a statistical comparison of the total amount of precipitation received by a region for a specific period of time and provides long-term trends for a specified period of the year. It is generally calculated on the basis of monthly intervals for a moving window of  $n$  months, typically 1, 3, 6, and 12 months.

**Evapotranspiration Deficit Index (ETDI):** A useful tool to monitor short-term agriculture drought, the ETDI, alongside the Soil Moisture Anomaly, provides information on the actual evapotranspiration as compared to crop evapotranspiration. This water stress ratio can be compared with the median water stress ratio obtained from longer-time framework observations.

**Soil Moisture Anomaly (SMA):** Agricultural drought is characterized by soil moisture deficiency that can adversely impact crop yield and production. SMA is the main instrument used to measure soil moisture content and to identify potential agricultural drought episodes. Soil moisture is an important component of the hydrological cycle, and its evaluation is critical in forecasting the changes in the water balance of a region. In an agricultural system, the spatial variability of soil moisture and its deficits may result in a decline in crop yields or in the variability in yields.

**Vegetation Conditions Anomaly:** This indicator measures the anomalies of satellite-measured normalized difference vegetation index (NDVI) and is used to highlight areas of relative vegetational stress during agricultural drought. For large-area monitoring, season-integrated NDVI offers an effective approach to measure crop production as it closely relates to the overall plant vigor, canopy expansion, and water stress during the season of growing.

### ***4.1.3 Assembling Land Data Assimilation System***

The NASA Land Information System (LIS) is a widely used, open-source land-surface modeling, and data assimilation infrastructure developed by the Hydrological Sciences Lab at NASA Goddard Space Flight Center (Kumar et al. 2006). The original goal of LIS was to enable flexible and high-resolution land-surface modeling at the same spatial and temporal scales as RS measurements. From the LIS, other systems were developed such as the Land Data Assimilation System (LDAS), a land-surface modeling software for specific purpose and domain. LDAS is based on the merging of standard, ground-based observation, and satellite observation with a numerical model to obtain an accurate estimate of the land-surface state. Models suffer from errors due to limitations in the structure, imperfect input data sets, and parameter uncertainty, while observational data sets are generally incomplete in space or time, capture only select aspects of the hydrological cycle, have limited predictive potential, or are subject to their own measurement errors. Acknowledging these limitations but also recognizing the tremendous information content in today's observation systems and advanced land-surface models, LDAS merges models with observation data sets using statistical algorithms that weigh inputs according to their relative uncertainty. In practice, this means that LDAS makes use of the best available input data, including information on meteorology and landscape (in terms of soil, topography, land cover, etc.), applies these inputs to drive an ensemble of land-surface model simulations, and then periodically applies updated observations of the modeled variables (in terms of soil moisture, snow cover, etc.) to nudge the model toward the observed conditions.

The South Asia Land Data Assimilation System (SALDAS) is a collaborative modeling initiative that is representative of these efforts. SALDAS employs the Noah-MP land-surface model at a 5-km resolution with input meteorology from MERRA2, GDAS, and Climate Hazards Group InfraRed Precipitation estimates (CHIRP) (Funk et al. 2015) in a monitoring mode as well as from the downscaled Goddard Earth Observing System model (GEOS5v2; Rienecker et al. 2008) surface fields in a forecast mode. SALDAS also includes the simulation of the processes of irrigation and groundwater withdrawal (Nie et al. 2018), including some data assimilation capabilities (Fig. 4.4).

### ***4.1.4 Evaluation of Satellite Precipitation Estimates***

In the case of process-based hydrological simulations and forecasts, accurate meteorological estimates are critical. But the mountainous regions of South Asia have limited in situ meteorological stations and river-discharge measurements. In this situation, RS and model-derived meteorological estimates are the useful inputs for distributing hydrological analysis.



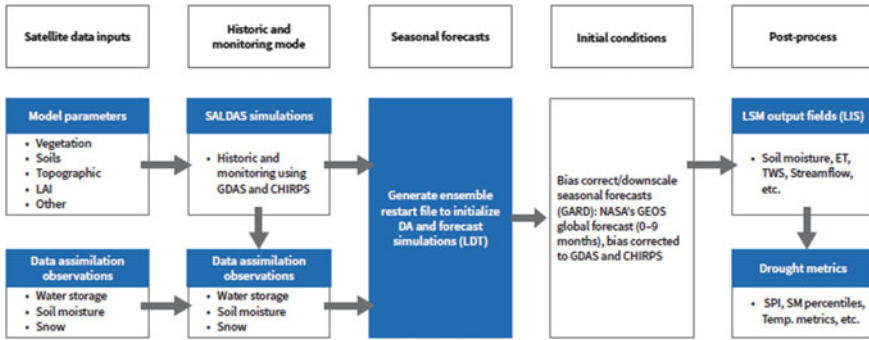


Fig. 4.4 Elements and process of the SALDAS system for producing drought data products

Among the available satellite precipitation data products, the long-term CHIRP is available at a high spatial and temporal resolution and can provide an opportunity to develop drought monitoring and early warning applications in data-sparse regions using rainfall estimates. However, CHIRP data also have some level of uncertainty, which could affect the accuracy of predictions when they are used in a drought outlook scenario.

In the case of precipitation data products, they are being tested in different time frames in different regions of the world that represent different climate conditions. To proceed with this evaluation, various statistical metrics like the root-mean-square error (RMSE) and the bias and regression correlation coefficient of determination ( $R^2$ ) are used (Habib et al. 2009; Jiang et al. 2012; Nelson 2016). But in South Asia, such information is difficult to validate on account of limited access to meteorological station data. In this evaluation, we compared the monthly precipitation estimates, during 1980–2018, from CHIRP with APHRODITE and the data from 130 rain gauges collected from Bangladesh, Nepal, and Pakistan that represent seven key climate divisions of South Asia (Fig. 4.5). The performance of the precipitation products was evaluated by using continuous (ME, MAE, and  $R^2$ ) and categorical (PBIAS, RSR) statistical approaches (Fig. 4.6). These metrics are based on a pair-wise comparison to evaluate the performance of the monthly CHIRPS-2.0 product, which estimates the amount of rainfall on each rain gauge and then is summarized for each climate division. Overall, CHIRP performs better in wet regions than in arid and semiarid areas, and achieves greater accuracy during summer than in winter.

#### 4.1.5 Season to Sub-season (S2S) Forecasting

Monsoon prediction is a key element in water-related agricultural management and disaster preparedness. However, being able to forecast the monsoon dynamic has

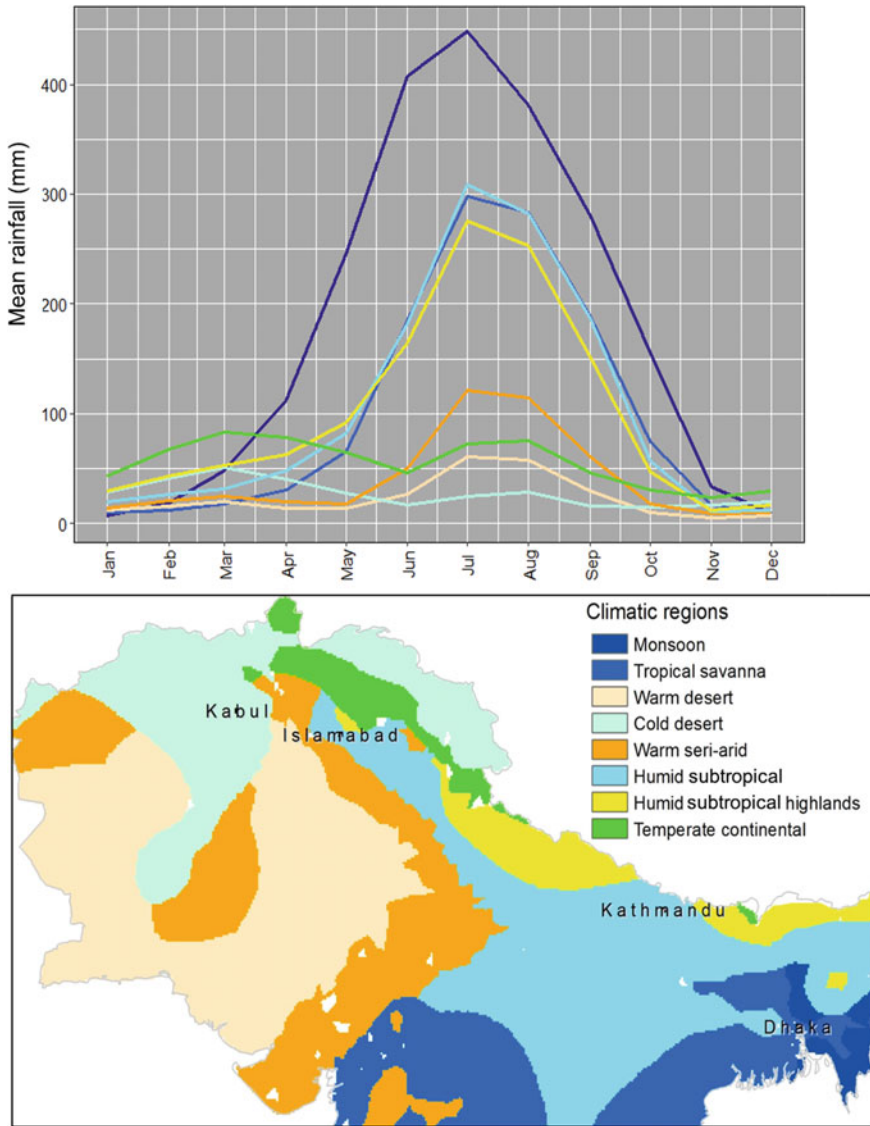
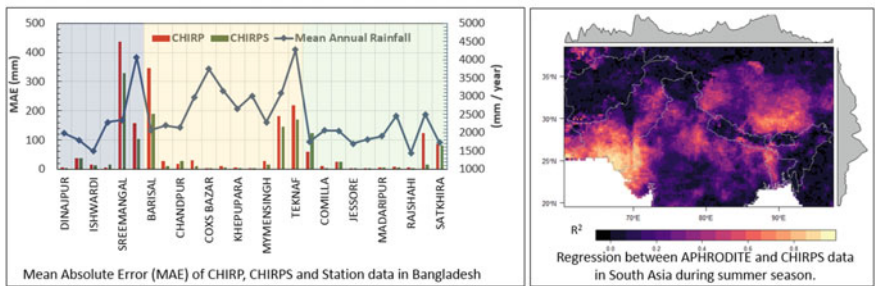
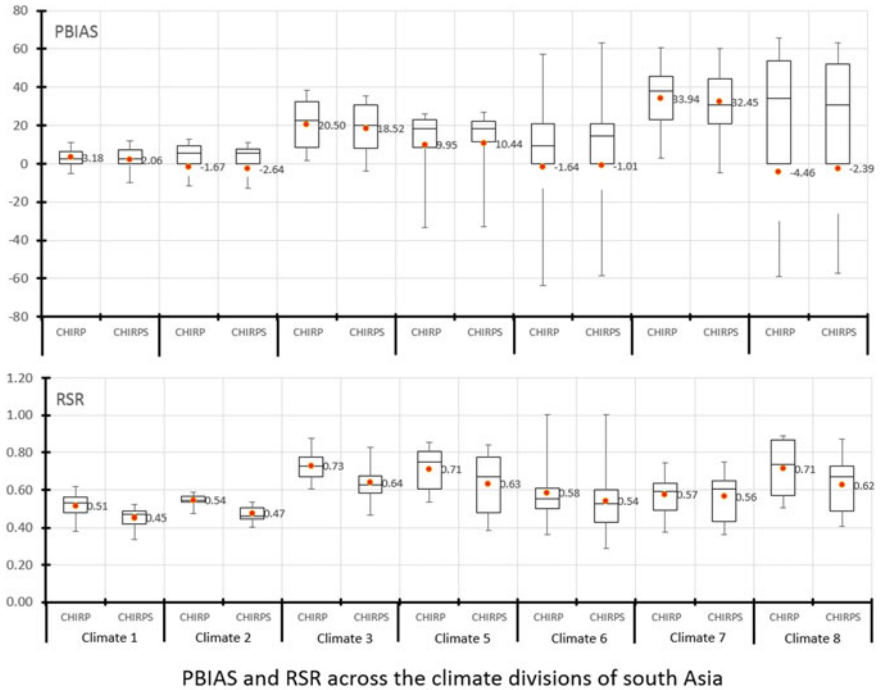


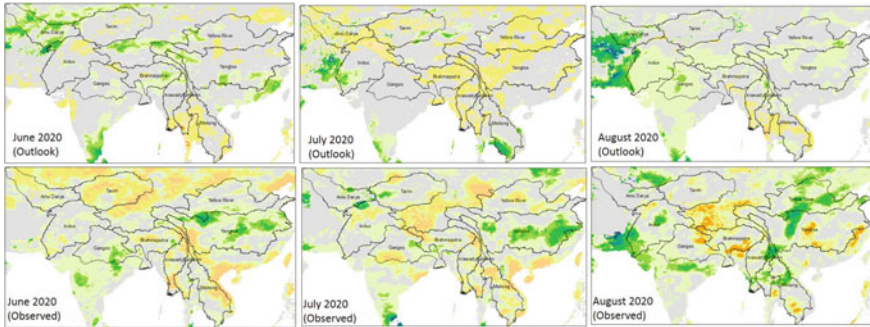
Fig. 4.5 Climatic regions of the northern portion of South Asia

proven to be a difficult exercise. The current development in the S2S meteorological forecast as well as improvements in EO applications could be exploited to provide a more accurate monitoring of the hydrological states and thus better forecasting. The information from these sources is currently being merged in the S2S Land Data Assimilation System (S2S-LDAS) (Yifan et al. 2020).



**Fig. 4.6** Key results of the satellite-based precipitation estimates

The SALDAS S2S system merges models with satellite observations to optimize forecasts on initial conditions, downscale forecast meteorology, and to forecast hydrological water fluxes. SALDAS runs in the S2S forecast mode once every month. The system reads in the GEOS5v2 forecast ensemble, downscales using the Generalized Analog and Regression Downscaling (GARD) (Gutmann et al. 2017) technique, and runs Noah-MP forward with the forcing, using the SALDAS monitoring system to provide the initial surface-state conditions. While the HKH-S2S simulations are performed at 5-km resolution, the forecasts of meteorology and hydrology are presented through interactive applications that offer users access to the ensemble mean, to the output of each ensemble member, and to



**Fig. 4.7** Regional seasonal outlook for precipitation based on the initial condition in April–May 2020 and comparison with the conditions observed by the CHIRPS data set

ensemble statistics presented as ranked anomalies. In keeping with the S2S target-time horizon of the system, the outputs are presented as temporal averages at decadal and monthly resolutions. The evaluation of the system is being conducted by comparing on-ground data with satellite observation data for the water fluxes. It is expected, that in principle, better sub-seasonal hydrological forecast would be of great use for governmental and other organizations in better assessing the risk of drought and taking mitigating actions. In the month of May 2019, the first seasonal forecast was produced for the 2019 monsoon season and the results were shared with relevant professionals from meteorological and agricultural institutions, including the Nepal PPCR program agriculture advisory team. Similarly in 2020, the seasonal outlook was produced in May 2020 and Fig. 4.7 shows the results of the months of June, July, August and its comparison with the observed conditions measured by CHIRPS data sets the end of the season. The analysis of the match and mismatch between the predicted and observed conditions has helped in gaining the initial confidence of users.

#### **4.1.6 Information System Development**

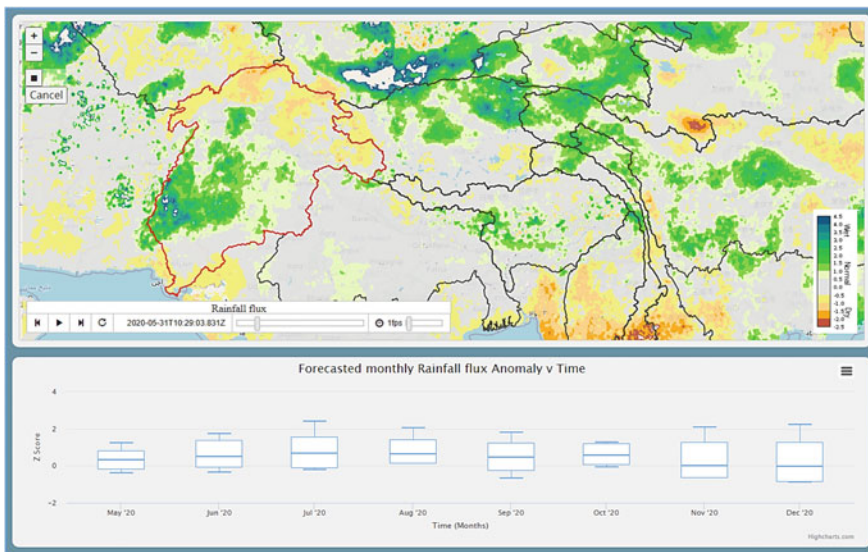
Efficient and effective water-related information systems should be able to house different aspects like climate parameters and water, soil, and socioeconomic indicators which clearly identify the key characteristics of the severity of a drought, its geographical extent, and its impacts (WMO 2006). Additionally, the delivered information via the warning system should be formulated in a manner that is clear and easy to understand in order to not exclude its use by non-specialist decision makers.

The purpose of a viable information system should not be limited to making data accessible, but it should also pay attention to the target audience and the intended support for decision-making. The United Nations International Strategy for Disaster

Reduction (UNISDR 2006) suggests that early warning systems must be location specific and people centered while integrating four elements: monitoring and early warning service; providing information on the risks faced; disseminating easily understandable warnings to those at risk; and awareness and preparedness to act. In accordance with these key principles, discussions were held with the key users. The consultations highlighted the need for data analysis at two levels: first, at the basin level to understand the general patterns, irrespective of administrative boundaries—this mainly focused on water-management decisions; and second, at the district level to support local-level actions.

As it is known, any web-based data analysis system includes front-end clients, application services, and back-end data repositories. So, to facilitate the implementation of these components, information on functional requirements were gathered and a statistical analysis of the needs was identified. The Tethys platform used for the application services contained open-source software selected with the aim of addressing the particular needs of web applications related to water resources. The web application was developed using the Python software development kit. Additionally, the Tethys platform was supported by the Django Python web framework, thereby offering a strong web foundation with high performance and security (Fig. 4.8).

The Regional Drought Outlook System also provides the means to visualize seasonal outlook anomalies at the basin level. An average of seven ensembles is regarded as defaults, while the user can select individual ensembles as well.



**Fig. 4.8** Interface of the regional drought outlook system (<http://tethys.icimod.org/apps/regionaldrought/>)

Similarly, the drought indicators and the basin can also be selected interactively by the users.

In the national and subnational contexts, while agricultural practitioners have knowledge about agro-meteorology, it is usually cumbersome to perform climate data analysis in a particular area. So, to facilitate the process of data analysis and aggregation, a user-friendly system was developed for the four target countries as a “National Agricultural Drought Watch” in close consultation with the key national stakeholders and the user community. The convenience in use of the system could aid in increased use of the related data products for practical decision-making. Meanwhile, an orientation workshop on the usability of the system was also held. At this point of time, the system is being adopted by the user community for regular use in their decision-making process.

The National Agricultural Drought Watch provides interactive maps of administrative units, as also near-real-time graphs of rainfall, evapotranspiration, soil moisture, and temperature. Additionally, a specific seasonal assessment window provides a systematic way for users to complete a seasonal aggregated assessment where the user can choose an administrative boundary and the time period of assessment according to a crop calendar.

The four bar graphs in Fig. 4.9 represent the aggregated assessment in terms of the percentage of areas under conditions between  $-2$  to  $+2$  based on the standard anomaly calculation of rainfall, soil moisture, evapotranspiration, and temperature. All the calculations are masked to display only the cropped areas. The percentages in the normal graph represent the conditions aggregated for an entire selected administrative boundary.

After the formal launching of the drought outlook service in July 2019, the major focus has been on the adoption of the system by the partner agencies in Afghanistan, Bangladesh, Nepal, and Pakistan. The National Agriculture Management Information System (NAMIS) of Nepal is utilizing the drought watch

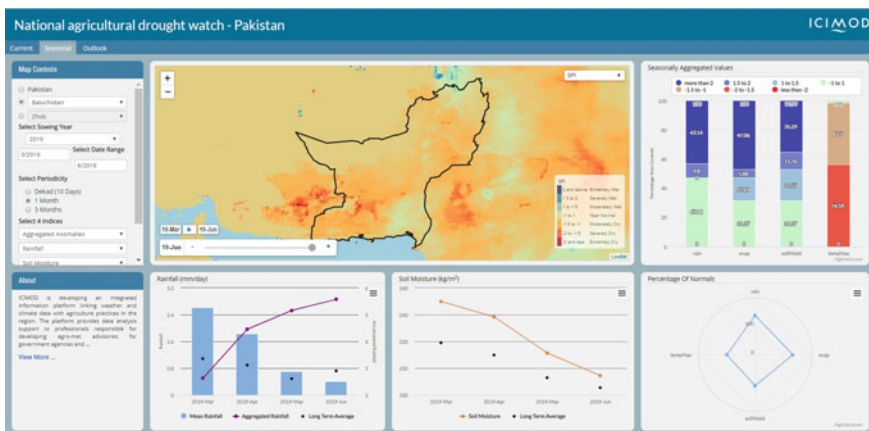


Fig. 4.9 National agricultural drought watch interface (<http://tethys.icimod.org/apps/droughtpk>)



service to disseminate information on the drought conditions and outlook among the stakeholders in the country, while the World Food Programme of Nepal is utilizing the drought data products in their quarterly food security assessments. Besides, building on SERVIR agriculture drought products and learning, the Climate Service Initiative of ICIMOD is establishing a localized agriculture advisory in Nepal's Chitwan District.

In the case of Bangladesh, the Bangladesh Agriculture Research Council (BARC) is working toward hosting the drought outlook system. Similarly, the Pakistan Agriculture Research Council (PARC) is in the process of establishing an Agriculture Decision Dashboard under the Ministry of Food Security and Research for planning decisions on food security which will also incorporate SERVIR's seasonally aggregated drought data products.

#### ***4.1.7 Trainings and Capacity Building***

A well-structured and rigorous effort has been made in the institutional capacity building of the national agriculture agencies in Afghanistan, Bangladesh, Nepal, and Pakistan. A comprehensive resource book has been prepared which has both theoretical and practical information on the drought monitoring and forecast approach adopted under the RDMOS by the four countries (Qamer et al. 2019a, b). Several training exercises have also been conducted, including regional, national, and on-the-job trainings where a good number of professionals were exposed to drought-monitoring issues.

In this regard, the Regional Knowledge Forum on Drought held at ICIMOD from 8 to 10 October 2018 brought together 100 participants—academicians, policy practitioners, researchers, and media persons—affiliated to 50 institutions based in 13 countries in Asia and beyond. The forum discussed the ways to establish a regional partnership through the participation of national and regional institutions, the private sector, and local and international organizations to improve climate services using EO applications and thereby facilitating agricultural decision-making that can strengthen the food security situation in the region (Qamer et al. 2019a, b). Discussing examples from South and Southeast Asia, the panelists showcased the value that EO technologies and climate services can bring to establish national and regional drought monitoring and early warning systems, as well as agro-advisory services.

#### ***4.1.8 Learnings and Future Directions***

In South Asia, only a few scientific resources are available on operational drought services and associated mitigation tools. The establishment of the RDMOS provides support for drought assessment and mitigation in South Asia. The system produces



key drought indicators including at decadal, monthly, and trimonthly intervals and is equipped with the ability to analyze these indicators on a seasonal scale according to crop calendars or the period of interest of the users. Besides, meteorological and hydrological forecasts are presented through interactive applications that offer users access to the ensemble mean, to the output of each ensemble member, and to ensemble statistics presented as ranked anomalies. In keeping with the S2S target-time horizon of the system, the outputs are presented as temporal averages at decadal and monthly resolutions. In addition, the system produces seasonal forecasts on precipitation, soil moisture, evapotranspiration, and temperature to evaluate potential drought hazards. The program has also developed operational agriculture-monitoring data products and dissemination platforms through its network of partners in NASA, USAID, CIMMYT (International Maize and Wheat Improvement Center), and globally renowned universities, as well as in close collaboration with national experts from Afghanistan, Bangladesh, Nepal, and Pakistan.

To enhance the usability of these platforms, extensive capacity building efforts have taken place to promote the use of EO data among the national-level managers, relevant development partners as well as field-level agriculture extension professionals. As an operational service, it is expected to reduce regional crop loss caused by drought-associated damage. The advisory support system, over time, is expected to achieve impacts by catalyzing and supporting the processes of innovation through two pathways: acquisition of new knowledge; and capacity building of individuals and institutions. The knowledge pathway is anticipated to facilitate and support stakeholders in gaining better access to the necessary products for the smooth running of the service. The second pathway of capacity building has been designed to enable individuals and institutions to generate and use EO and GIS information to develop advisories relevant at the farm level. The gradual uptake of the service is under way via trainings of partner agencies in Afghanistan, Bangladesh, Nepal, and Pakistan.

The current system provides analysis at the district level and is a guide to any emerging agricultural drought situation. However, systems with higher resolutions will be needed in the future, as most agricultural decision makers require more localized information. The linkages between community-based adaptation approaches and the national early warning systems are still very weak (Pulwarty and Verdin 2013), and this can only be improved by roping in the expertise of agricultural extension professionals.

Drought-warning systems provide excellent means of alleviating the issue of short-term food insecurity and thereby save lives. But the current crisis management approach has several limitations. A paradigm shift to proactive approaches based on the edifice of drought-risk reduction and building greater societal resilience to drought impacts is the need of the moment. This calls for improving long-term agricultural land use and efficient water resource planning based on

quantitative resource assessments. In this region, China is already moving from a drought-emergency response (reactive) approach to a drought-risk management (proactive) approach, which involves integrated systems of monitoring, prediction, and modeling of hydrological and meteorological influences on water resources, coupled with demand management for water conservation. Agricultural drought monitoring and other early warning systems can be useful only to the extent that they offer actionable information that can be used to avoid or minimize the economic and social impacts of the predicted risk (Tadesse et al. 2018). This strategy should also take into consideration the drought impacts on health which involve the vulnerability of the people living in drought-prone areas. Such a scheme of things could help build a more drought-resilient society (Li et al. 2017; Wall and Hayes 2016). And it goes without saying that to mitigate the impacts of drought on human life and the environment, and to ensure production of adequate food to avoid food crises, developing strong early warning and mitigation strategies are critical (Zambrano et al. 2018; Mariano et al. 2018).

As part of climate adaptation strategies, crop insurance programs could aid in buffering the financial impacts of drought-induced crop failure. However, the implementation of index-based crop insurance in South Asia is rather constrained due to the sparse hydro-meteorological network in the region and due to high variability in the agro-meteorological conditions stemming from the complexity of the terrain (World Bank 2009; USAID 2014). In such a context, locally calibrated RDMOS can play a supporting role in implementing crop insurance as well as forecast-based financing in the agriculture sector.

Currently in South Asia, crop yield assessment is largely done through crop-cut surveys, which are time-consuming and expensive. The integration of process-based crop models with the current SALDAS system could also potentially improve efficiency in crop monitoring, but more research is required in this area (Xia et al. 2019).

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