SECOND WORLD IRRIGATION FORUM
http://www.worldirrigationforum.net
06-08 November 2016, Chiang Mai, Thailand

Background Paper / Document d'information

Sub-Theme / Thème de stratégie 2

Management of Climatic Extremes with Focus on Floods and Droughts / Gestion des conditions climatiques extrêmes avec l'accent sur les inondations et les sécheresses

Tsugihiro Watanabe, Japan
Johannes Cullmann, WMO
Chandra S. Pathak, USA
Mika Turunen, Finland
Kamran Emami, Iran
Graziano Ghinassi, Italy
Yasmin Siddiqi, ADB

ICID•CIID

International Commission on Irrigation and Drainage
48 Nyaya Marg, Chanakyapuri, New Delhi - 110021, India
E-mail: icid@icid.org, Website: http://www.icid.org

Background Paper / Document d'information

Management of Climatic Extremes with Focus on Floods and Droughts / Gestion des conditions climatiques extrêmes avec l'accent sur les inondations et les sécheresses

ABSTRACT

The climate change is recognized as one of the most serious and urgent issue for human society and global environment. In the context of agriculture, improving irrigation and drainage systems and rural development will play a key role in achieving the rural water and food security under impending climate change, especially in the developing countries. This is a common understanding in the world irrigation and drainage community including the ICID.

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes. These climate extremes pose significant impacts on human and ecological systems, which are influenced by changes in climate, vulnerability and exposure, resulting in increased fatalities and economic losses especially in developing countries.

To reduce the disaster risks, the global and local society or community need to assess the weather and climate events with their magnitudes, frequencies, and variabilities; the exposure of the society for these events; and the vulnerability of the region and society to these extremes. Even while the current local hydrological regime are being modelled with high reliability, the future projection of events and their impacts are expected to be more uncertain. Under the given uncertainties in climate change impact projections, improving resilience by reinforcing the capability of societies to better cope with the extreme events is one of the most favoured approach. The adaptation includes the practical measures that not only reduce the disaster risk but also reinforce the base system.

This paper aims at summarizing the current practices of managing extreme climate events, assessment of impact under the climate change scenario, and development of adaptation strategy under the recently adopted sustainable development Agenda 2030.

RESUME

Le changement climatique est reconnu comme l'un des problèmes les plus graves et urgents de la société humaine et l'environnement mondial. Dans le contexte de l'agriculture, l'amélioration de l'irrigation et de drainage et du développement rural joueront un rôle important dans la réalisation de l'eau en milieu rural et de la sécurité alimentaire en vertu de l'imminence du changement climatique, en particulier dans les pays en développement. Il existe une compréhension commune dans la communauté mondiale d'irrigation et de drainage, y compris la CIID. Le changement climatique entraîne les changements dans la fréquence, l'intensité, l'étendue spatiale, la durée et le calendrier des phénomènes extrêmes météorologiques et climatiques, et peut entraîner des extrêmes sans précédent. Ces conditions climatiques extrêmes exercent des impacts importants sur les systèmes humains et écologiques, qui sont influencés par les changements climatiques, la vulnérabilité et l'exposition, donnant lieu à une augmentation des décès et des pertes économiques, en particulier dans les pays en développement. Pour réduire les risques de catastrophe, la société mondiale et locale ou communautaire doivent évaluer les événements météorologiques et climatiques avec leurs ampleurs, fréquences, et variabilités; l'exposition de la société à ces événements; et la vulnérabilité de la région et de la société à ces extrêmes phénomènes. Même si le régime hydrologique local actuel est en cours de modélisation avec une grande fiabilité, la projection future des événements et de leurs impacts devrait être plus incertaine. Selon les incertitudes données dans les projections de l'impact du changement climatique, l'amélioration de la résilience en renforçant la capacité des sociétés à mieux faire face aux événements extrêmes est l'une des approches la plus favorisée. L'adaptation comporte la prise des mesures pratiques qui non seulement réduit le risque de catastrophe, mais renforce aussi le système de base. Ce document vise à résumer les pratiques actuelles de la gestion des phénomènes climatiques extrêmes, l'évaluation de l'impact dans le cadre du changement climatique, et le développement de la stratégie d'adaptation dans le cadre du Programme 2030 de développement durable récemment adopté 2030.

1. Introduction

The climate change is recognized as one of the most serious and urgent issue for human society and global environment. A recent report by the World Bank finds that the most severe impact of a changing climate would be the effect on water supplies. The report suggested that by 2050, an inadequate supply of water could knock down economic growth in some parts of the world a figure as high as 6 percent of GDP, “sending them into sustained negative growth.” Regions facing this risk can at least partly be averted by better water management (World Bank Group, 2016).

Climate change hits water supplies in multiple ways. Warm temperatures can cause more evaporation of water from landscapes, while changes in precipitation can lead to both more intense individual downpours but also swings into drought conditions. The human activity that consumes the most water is agriculture. In the context of agriculture, International Commission on Irrigation and Drainage (ICID) believes that improving irrigation and drainage systems building rural resilience will play a key role in achieving the rural water and food security under impending climate change, especially in the developing countries.

Irrigation and drainage are fundamentally the human activity to manage the variability or fluctuation of natural hydrological regime for better agricultural production. They have been continuously developed to function to adapt climate variability and change to some extent. Then, the current problem is on “extreme events” beyond the threshold or expectation. The challenges due to the climate change should be considered as another driving force to improve the irrigation and drainage system.

Accordingly, ICID deliberated on the theme “Securing Water for Food and Rural Community under Climate Change” at its 22nd Congress held in Gwangju, Republic of Korea, in September 2014. Two Congress Questions raised included one that is directly related to climate change was “How Irrigation and Drainage play an important role in Climate Change Adaptation?”

Discussions during the Congress highlighted that the climate change needs to be recognized as an added stress on the increasingly uncertain complex and interlinked issues of rural development and food security under demographic changes due to environmental concerns and limiting natural resources. Intervention to mitigate the impacts of climate change and consequent extreme climate events, such as floods and drought, must therefore be considered in the entire decision making processes in the irrigation and drainage activities (ICID, 2014).

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes. These climate extremes pose significant impacts on human and ecological systems, which are influenced by changes in climate, vulnerability and exposure, resulting in increased fatalities and economic losses especially in developing countries. Increasing exposure of people and economic assets to the climate extremes has been the major cause of long-term increases in economic losses from weather- and climate-related disasters. Extreme events have greater impacts on sectors with closer links to climate, such as water, agriculture and food security, forestry, health, and tourism. As the general findings and outcomes, it was reiterated that intervention to mitigate the impacts of climate change and consequent extreme climate events have to be factored in all irrigation and drainage related decision making processes (Watanabe, 2016).

Based on these recognitions and discussion history on climate change and consequent extreme events, one of the sub-themes adopted for WIF2 is ‘Management of climatic extremes with focus on floods and droughts’ to facilitate discussion on various related topics such as adaptation of design and operation criteria for irrigation and drainage schemes in light of climate change impacts; managing impacts of extreme events – floods and droughts; dealing with climate change impacts on food security; regional water management. This Background Paper presents the framework of the expected discussion and information exchange on the sub-theme No.2, including the current world context, the development of impact assessment and adaptation strategy, and the challenges for managing extreme events on floods and droughts, with some introduction of past approaches and outcomes as well as state-of-the-art technologies.

2. Global Climate, Extremes and Agriculture

The latest IPCC report indicates once again, that future climate will depend on the combined influence of warming caused by already emitted green-house gasses, as well as future emissions on one hand and the natural climate variability on the other. A current analysis of green-house gas emissions shows (WMO, 2015) that, based on our current understanding of global warming mechanisms, humanity can continue to emit 12 to 15 years at current rate to surpass the threshold that marks the two degree warning at the end of the century with 0.66 probability.

Although a higher mean annual temperature, in combination with an increased CO2 level will have a positive impact on crop yields in parts of the world, in general climate change will have negative impacts on the production of major traditional food crops. Additionally, farmers remain concerned about an increasing intensity of extreme weather events that will occur as a result of climate change. Weather related events which have impact on agriculture include are:

(i) more frequent heatwaves,
(ii) erratic rainfall,
(iii) prolonged drought,
(iv) more intensive rainfall spells,
(v) increased winter storms and hurricanes, and
(vi) rising sea level and increased salinization

The IPCC fifth assessment report (IPCC, 2014) gives the following global data for the impacts of climate change on the yield of main crops (in %):

Irrigated Maize: - 4 to -7,	Rainfed Maize: -2 to -12
Irrigated Rice: - 9.5 to - 12,	Rainfed Rice: - 1 to +0.07
Irrigated Wheat: - 10 to - 13,	Rainfed Wheat: - 4 to -10

The extreme events will increase the vulnerability of food production and affect natural resources such as soil fertility; availability of water resulting in water stress; land degradation and desertification. Changing weather patterns, manifesting in changes in average temperatures and rainfall, will make it increasingly difficult to plan for activities such as sowing, planting, fertilizing and spraying. Rain-fed agriculture is especially vulnerable to changing weather patterns and the impacts of variable water availability. Some regions will experience excess water resulting in flooding and others will experience severe water scarcity. Annual average river runoff and water availability are projected to increase by 10 to 40 % at high latitudes and in some wet tropical areas, and decrease by 10 to 30 % over some dry regions at mid-latitudes and in the dry tropics.

The changes in the hydrological regime would be a matter of great concern of agriculture and rural society. Not only at the farm level, climate change and consequents extreme floods and droughts will affect the agriculture systems at the basin level. The IPCC Fifth Assessment Report stresses that major future rural impacts are expected through impacts on water availability and supply, food security, and agricultural incomes, including shifts in production areas of food and non-food crops across the world. These impacts are expected to disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure, and education.

The risk of extreme events on the agriculture (or for that matter any socio-economic activity) is not only caused by the magnitude and extent of the hazard, like the duration of flood and drought, but is also governed by the exposure to the hazard and the vulnerability of the system to that event. In this context, "vulnerability means the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." And, the exposure means "the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected."

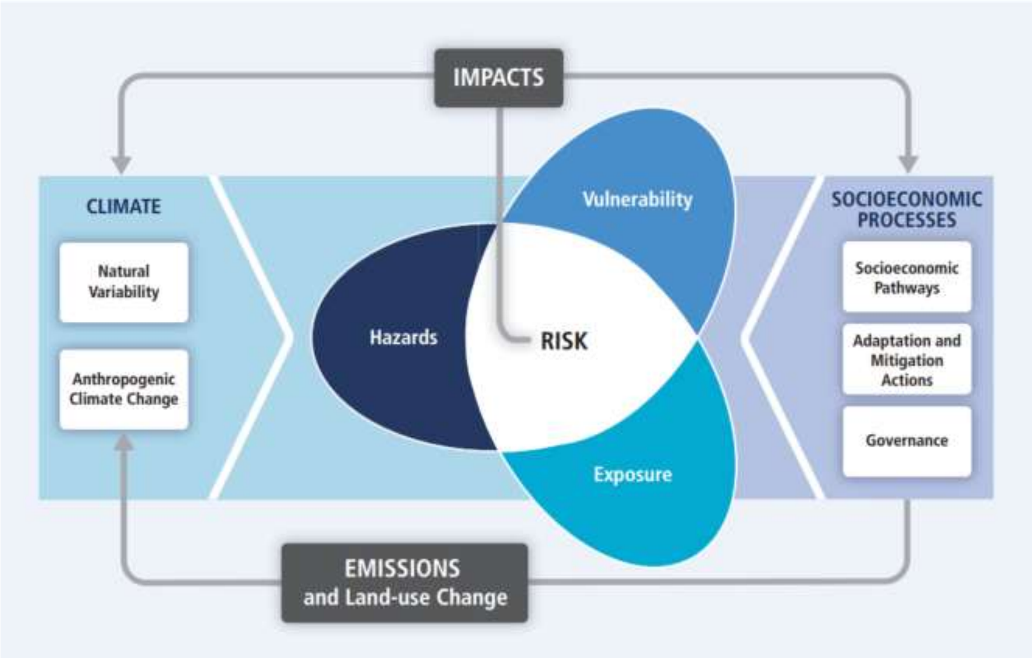

Figure 1. Risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems (IPCC, 2014)

These recognitions on the risk and impacts of climate change and consequent events are now becoming common in the global society. When we think the extreme flood and drought as the results of the climate change, this framework is to be essential. The impacts are subject to the special and temporal scale of flood and drought, the function and potential of water management system in the rural society and crops, farmland, infrastructures as well as farmers and people in the rural area. In a point of view of irrigation and drainage management, which is recognized as adaptation with mitigation actions, the assessments of the local structure on the risk of extremes of flood and drought is to be the base for its improvement under changing climate.

3. Development of Impact Assessment and Adaptation Strategy

In order to reduce impact due to these climate extremes it is essential to develop strategies for disaster risk management in the context of climate change which may include coping and adaptation mechanism, informed by and customized to specific local circumstances. Adaptation to climate change and disaster risk management provide a range of complementary approaches. An iterative process of monitoring, research, evaluation, learning, and innovation can reduce disaster risk and promote adaptive management in the context of climate extremes.

While we have been integrating local knowledge with additional scientific and technical knowledge, which can improve disaster risk reduction and climate change adaptation, however, lack of sufficient scientific knowledge to better understand what is going on and what can be predicted in climate change with reasonable accuracy. Meanwhile, we cannot wait until understandings of the future climate change is clear and its impacts are known. It is therefore necessary to factor known impacts of climate change in all processes of planning, design, implementation, operation, maintenance and management of the irrigation and drainage activities.

3.1 Development of Impact Assessment

The climate extremes can result in droughts and floods due to an accumulation of weather or climate events and may not be caused by a single individual extreme event.

Evidence of the impacts of climate change on sea level rise, change of frequency and severity of tropical cyclones or extreme water-related disasters, and prolonged drought periods are being studied by the scientists all over the world. To understand, how climate change will influence over the long-term the risk landscape that governments, businesses and citizens need to prepare for, it needs to be weighed against other major trends influencing our exposure to these hazards and threats and our capacities to deal with them. Climate change is expected to influence other risk factors beyond natural hazards themselves. Water, food, and energy security could be affected in a number of regions or countries, making these areas more vulnerable to hazards and threats, affecting their economic development, the well-being of their citizens and eventually their stability, which could lead to undesirable impacts on humanity.

There are many interconnected climate risks such as prolonged droughts increase the risks of forest fires. Droughts can also lead to more catastrophic floods when water management practices adapt to the trend of reduced water resources without considering that high flows still can reach highest levels. Brisbane floods in Australia in 2011 and UK floods in winter 2013 followed prolonged drought periods. Droughts impact also aquifers whose depletion can affect soil stabilities, leading to subsidence in urban areas and reduced structural resilience to earthquakes.

Thus, these climate extremes have significant impact on earth's environment. Extreme events have greater impacts on many elements of the environment and human systems including such as water, ecology, sedimentation, forestry, flora and fauna, and human health. Impact from climate extremes on environment are mostly observed at the watershed level. Whereas, impacts on human system are experienced at the regional and local level.

In order to understand and determine qualitative and quantitative impact of climate extreme over short-term (5-10 years) and long-term (10 to 50 years), impact assessment needs to be developed on the environmental and human systems. Impact assessment for environmental system could include rainfall, snowpack, evapotranspiration, natural and man-made surface water storage, surface water flow, groundwater storage and recharge as well as other elements. These assessments need to be completed and are expected at regional or watershed level.

Studies indicate that gross irrigation water requirements may increase or decrease depending on the future efficiency of irrigation and conveyance systems, the effect of population growth on food (and water) demand and the climate change impacts, while the first two seem to have the strongest influence Fader et al (2016). The Mediterranean area as a whole may require an increased gross irrigation between 4 and 18% due to climate change alone. Population growth increases these numbers to 22 and 74 %, respectively.

Studies show that the changes in projected future peak flows due to snow melt fall outside the range of natural variability compared with current natural variability in southern Britain than in the north (Bell et al, 2016). In a recent research (Clark et al, 2016) on important sources of uncertainty, it has been reported that these are commonly neglected by the water management community, especially, uncertainties associated with internal climate system variability, and hydrologic modelling. It also articulated issues with widely used climate downscaling methods.

Studies on the effects of climate change on groundwater recharge of the upper Tiber River basin in central Italy (Behulu et al, 2016) presented summaries and overview of several climate change studies over the Italian territory. Specifically, it presented study on a calibrated and validated SWAT watershed model that used the climate model outputs obtained from three dynamically downscaled regional climate models in order to evaluate the groundwater recharge characteristics of the basin.

A review of existing multi-risk assessment concepts and tools applied by organizations and projects providing the basis for the development of a multi-risk methodology from a climate change perspective have been carried out (Gallina et al, 2016). It developed the assessment of multiple natural hazards -

floods, storm surges, and droughts affecting a given area for the year, season, and decade timeframe. Several methodologies were used to assess the vulnerability of multiple targets to specific natural hazards by means of vulnerability functions and indicators at the regional and local scale. It recommended that the climate impact assessors should develop cross-sectorial collaborations among different expertise (for example - modelers, natural scientists, economists) integrating information on climate change scenarios with sectorial climate impact assessment, towards the development of a comprehensive multi-risk assessment process.

When planning for the long term and assessing risks, it is important to integrate how the different trends interact in a comprehensive manner to identify risk scenarios for the future. These trends influence and reinforce each other, and determinate risk levels through interconnected processes that are difficult to separate them in order to get a real sense of future risks, and policies that need to be setup to reduce them.

3.2 Development of Adaptation Strategy

3.2.1 Synergy between adaptation and mitigation

Coordinated and effective adaptation strategies are essentially needed to ensure the long-term sustainability of food production under changing climatic conditions. Adaptation to climate change is, however, inevitably a multidisciplinary problem, as it requires the consideration of agro-climatological, technical and socio-economic issues. Thus adaptation management demands integration of methods from different disciplines (Howden et al. 2007). Uncontrolled autonomous adaptation, defined as responses implemented by individual farmers and communities without the intervention of governments or international agreements, is projected to increase consumption of energy, water and land resources and lead to land degradation (Tubiello and van der Velde 2010; Smith 1997) which would potentially result in increased carbon losses. Thus synergy between adaptation and mitigation is needed as a part of the adaptation strategies. The strategies should include practices, which reinforce climate change mitigation potential.

Adaptation to the changing climate is considered being particularly challenging in the developing countries, as they are highly vulnerable to the climate change due to their warm baseline temperatures, the predominance of agriculture in their economies, the relatively low amount of available capital and high exposure to extreme events (Tubiello and van der Velde 2010). Despite the challenges, several technical response options are already available.

In temperate and tropical regions, the management options are expected to have the potential to counterbalance the climate change impacts in the low-to-moderate warming conditions (1–2 °C), although they are expected to face limits under more severe climate warming (Howden et al. 2007). These methods include a) adapting farm management, b) changing crop varieties and species and c) improving water management practices. The methods are mainly extensions of widely known farming practices and are more specifically introduced (Tubiello and van der Velde 2010).

The impacts of the existing management options also have inter and intra-regional variation and in some countries adaptation options may not be sufficient to offset the negative impacts of climate change (Butt et al. 2005). Benefits of technical adaptation methods vary also with the type of crop and with the changes in temperature and rainfall (IPCC 2007). Predictions of the adaptation potential also include uncertainties related e.g. to pest and disease incidence and ability of farmers to adapt to increasing climate variability and frequency of extreme weather events. The expected future contribution of genetically modified crops is also considered controversial (Tubiello and van der Velde 2010) although some novel findings can help to develop e.g. rice varieties, which can enhance rice production in flood-prone areas (Hattori et al. 2009). Despite the prevailing uncertainties in the impacts of the adaptation methods, the technical adaptation options could also be supported by changes in resource allocations and alternative land-use and livelihood options to increase the adaptation potential of the regions.

3.2.2 Changing policies and adaptation to extreme weather events

Coordinated adaptation measures through changing policies are necessary to ensure the long-term benefits and social equity of the adopted measures. In order to build capacity for better collective understanding as well as to build stronger strategic and technical capability for adaptation, the adaptation policies need to support information communication as well as research and analysis operations (Howden et al. 2007). Training inhabitants to new jobs will be essential where climate change leads to large land-use changes (Howden et al. 2007). To have the capability to support new technical management and land-use arrangements, new infrastructure, funds and institutions are also essential (Tubiello et al. 2009).

New policies may be needed and would also require the capacity to be able to continuously improve adaptation to include targeted monitoring of the costs, benefits and impacts of the adapted policies (Howden et al. 2007). Climate change and socio-economic pressures are expected to increase the demand for food as well as other resources.

Adapting to extreme weather events can be considered more challenging in comparison with the adaptation to the increased mean temperatures, since the extreme events may not have historical analogues. In general, adaptation to extreme events is, however, possible through reducing vulnerability and enhancing resilience of the food production systems. For example, practically capacity building rather than disaster relief would increase the resilience to extreme events (Mirza 2003) and improved flood forecasting and warning practices would reduce the vulnerability of agricultural systems. Recent technical advancements have increased the ability to adapt to extreme climate variation (Cane et al. 1986). Also the early warning systems related to extreme events have improved (Dilley 2000). However, social inequities can also prevent part of the society from benefiting from these adaptation options and thus hinder the adaptive capacity of the society (Pfaff et al. 1999).

3.2.3 Costs and bottlenecks of adaptation

Costs of the coordinated adaptation to climate change and the associated risks in developing countries have been estimated to require annually approximately 100 billion US dollars, which markedly exceeds the projected financial flows in rural development in the coming decades (Tubiello et al. 2009). Potentially a large part of the required financial flow is expected to be generated through carbon markets by boosting activities related to both agriculture and forestry, including methods such as reducing deforestation (Tubiello and van der Velde 2010). Without the carbon markets the funding needs are estimated to fall an order of magnitude short (Tubiello and van der Velde 2010). Currently the clean development mechanism projects are, however, regionally unevenly distributed and only approximately 1% of their financial flow reaches Africa (Tubiello and van der Velde 2010), which suggests that the geographic distribution of the projects need to be widened.

Generally, further increasing the number of these projects include both administrative and technical challenges, including investor risks, inadequate infrastructure and unclear land tenure (FAO 2008). Further, more agricultural activities could be included in the list of clean development funding projects and aggregation of different actors within a region could be one method to further scale up the projects and thus increase the attractiveness of the projects for investors (Tubiello and van der Velde 2010).

4. Challenges for Management of the Extreme Events

4.1 Flood Management

Since the dawn of time (WMO, 2006), civilizations have prospered on flood plains, taking advantage of the benefits of floods, which are much more than just a hazard. Housing is often located in flood-prone areas, together with economic activities. These zones often represent a major source of income, livelihood and housing for thousands of communities, while floods play a key role in these processes.

Until 1927, the main flood policy of U.S. Army Corps of Engineers was "levees only". After the great flood of 1927, flood management by the reservoirs was also included. The concept of non-structural measures (NSMs) was first used in the context of flood control some 50 years ago, as a means to reduce the ever increasing damages, without unduly expanding the costly infrastructure. In that sense, NSMs were perceived rather as complementary additions to the essentially structural solutions to flood control, in order to reduce costs and enhance efficiency. This concept has changed in the last few decades with the introduction of new approaches as documented in the following publications:

(a) Development of the new Swiss Safety concept for dams in 1985.
(b) Publication of “Manual on non-structural approaches to flood management” by ICID (ICID, 1999).
(c) Bulletin on ICOLD, "Non-structural risk reduction measures; Benefits and costs for Dams in 2001 (ICOLD, 2001)
(d) Integrated Flood Management Concept Paper, WMO No 1047 in 2003,
(e) Publication of U.S. Army Corps of Engineers manual on “Adaptive Management for Water Resources Project Planning” in 2004.
(f) Publication of the proceeding of Q53 of ICID congress on Harmonic coexistence with floods in Beijing in 2005.
(g) UN Water 2010 recognizes Integrated Flood Management approach as robust and adaptive for adaptation to climate change

In the specific case of floods, a recent paradigm shift, moving from “flood control” to “Integrated Flood Management” (IFM) (WMO, 2006), that is, from the “need to master” floods from a technical standpoint to the “need to manage them” from every point of view – technical but also social, political and economic, by anticipating the event rather than undergoing it. In the 21st century, it is recognized that the approach to flood management has to be increasingly adaptive and a combination of non-structural and structural.

Integrated Flood Management is the approach that promotes an integrated – rather than fragmented – approach to flood management. It integrates land and water resources development in a river basin, within the context of IWRM, and aims at maximizing the net benefits from the use of floodplains and minimizing loss of life from flooding. Uncertainty and risk management are defining characteristics of choice, and risk management is a necessary component of the development process, essential for achieving sustainable development.

Figure 2. Integrated Flood Management approach

The application of a risk management approach provides measures for preventing a hazard from becoming a disaster. Flood risk management consists of systematic actions in a cycle of preparedness, response and recovery, and should form a part of IWRM. The actions taken depend on the conditions of risk within the social, economic and physical setting, with the major focus on reducing vulnerability. UN System (UN Water, 2010) recommends Integrated Flood Management as a robust and adaptive approach to manage floods. Flood risk assessments, which form an essential element in such approaches, should incorporate climate change effects on the magnitude of floods and the vulnerability of populations.

An important aspect of evolving concepts of engineering practice is the way uncertainty is recognized and addressed. It is today widely appreciated that many consequences of civil engineering investments cannot be precisely forecasted. Whether the objective is to take advantage of new opportunities or to insure against bad outcomes, the goal is to create the capacity to respond appropriately as new situations which may include unforeseen surprises develop. Flexibility over the life of the project is essential to effective development and functioning of civil engineering systems.

Public awareness for and education in flood risk are key elements for flood management in flood prone areas. A high level of awareness for flood-related risks is required to have effective and efficient flood risk reduction measures; e.g. successful evacuations require awareness and planning among the population of what to do and where to go in a flood emergency (WMO, 2009). Flood Maps are tools to visualize flood information for decision makers and the general public. These maps form the basis for developing flood risk scenarios based on land use, various environmental and climate conditions; and form the basis for the planning and implementation of development alternatives (WMO, 2013).

Adaptive management concepts and practices represent innovative, current thinking on resolving conflicting demands and adjusting to changing social preferences and priorities. Many of adaptive management's benefits come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and should therefore improve management decisions. Benefits of better future management decisions will be realized in the future. These benefits, however, are difficult to measure and translate into dollars, the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, up-front costs of adaptive management programs, such as ecosystem monitoring programs, scientific staff, and institutional support. The strategies of Adaptive Flood Management (AFM) are shown in Figure 3. (ICID, 2016)

Figure 3. The strategies of Adaptive Flood Management (AFM)

As an example, in August 2016, a very strong El Niño was forecasted in Iran and subsequently a study was undertaken for six selected basins in Iran, which indicated a good teleconnection of strong ENSO events and associated precipitations in autumn. These forecasts were used for the real time water management during the extreme floods in the south-west basins. In fact, the appropriate authorities issued large floods forecast for the months of November and December (2015) several months in advance. This forecast matched closely with the observed floods and consequently reduced the devastating effects of the floods.

4.2 Drought Management

Drought is a natural but temporary imbalance of water availability, originated from a deficiency of precipitation (e.g., persistent lower-than-average), of uncertain frequency, duration and severity, of unpredictable or difficult to predict occurrence, resulting in a reduced gap between water supply and demand, and reduced carrying capacity of the ecosystems (Wilhite and Glantz, 1985; Pereira et al., 2009).

Drought is a relative, rather than absolute, condition, and occurs in all climatic regimes, from low to high rainfall areas. Although agriculture is the sector most affected by drought, in both developing and developed countries, other sectors such as energy production, transportation, tourism and recreation, urban water supply, and the environment, are facing significant impacts.

Some drought types are recognized (i.e., meteorological, agricultural, hydrological, and socio economic), depending on the interaction between the natural characteristics of the event and the specific human activities related to the water supplied by precipitation. When meteorological drought (e.g., a lack of precipitation over a region for a period of time) is adopted, precipitation is used for drought analysis (Paulo et al., 2012). Precipitation-based indices have been developed over time in order to quantify a drought as departure of precipitation from the “normal”. Widely used indices, such as the Palmer Drought Severity Index (PSDI), the NOAA Drought Index (NDI), and the Standardized Precipitation Index (SPI), use precipitation either singly or in combination with other elements (Shatanawi et al., 2013).

Satellite observations can supply in situ data at high spatial density. Indices, such as the Normalized Difference Vegetation Index (NDVI), the Vegetation Condition Index (VCI), the Temperature Condition Index (TCI), and the Vegetation Health Index (VHI), can be derived (Kogan, 1995). They can profitably be used for monitoring drought events according to vegetation response to environmental stress.

Differently from other natural events, drought is a slow-onset hazard, whose effects accumulate slowly over a rather long period of time. Since duration of drought (i.e., onset and end) is difficult to determine, disagreements between researchers and policy makers can occur with respect to the actual length of a drought event. Drought has both a natural and social dimension, the latter being the factor that moves a hazard into disaster (Whilite et al., 2014). Due to the absence of a unique definition of drought, some confusion can arise on the existence and the degree of severity.

A critical feature of drought is that impacts are non-structural and can spread over areas larger than those hit by other natural hazards, often beyond national borders. This may lead to difficulty both in quantification of the impacts and in disaster relief. In addition, both economies and environment can be affected for long time periods. Natural disasters originate from the interactions between the climate extremes and the vulnerability of human and natural ecosystems to such extremes (WMO, 2013).

Response to drought have been reactive in most part of the world largely adopting crisis management approach. This approach revealed ineffective in most cases, mainly because it does not reduce the risks associated with drought. It is imperative that a more risk-based approach to respond to drought, based on well-established national drought policies and preparedness plans is adopted. Improving the level of preparedness for drought results in a reduction in the societal vulnerability.

Figure 4. The cycle of disaster management (Wilhite, United States National Drought Mitigation Center)

Impacts associated with drought are the results of a wide range of climatic and societal factors. Whether a drought event becomes an emergency or disaster, depends on the vulnerability of people and the environment to such event (IPCC, 2012). In recent years, due to increase in the vulnerability, together with the incidence of drought, the approach to reduction of risks associated with drought is gaining emphasis.

Two main paths can be followed to face drought events: better planning to improve operational capabilities, and mitigation measures to reduce drought impacts. Mitigation of drought effects requires the use of all components of the cycle of disaster management (Figure 4), that is both risk and crisis management.

4.2.1 Post impact interventions

When drought occurs, governments and donors normally follow the steps in the recovery section of the cycle. The return to a pre-disaster state with little attention given to risk management (i.e., preparedness, mitigation, early warning or other prediction actions) can address a short-term need but cannot avoid or reduce future impacts and lessen government and donor interventions. Countries with policies based on crisis management have little reduction in risk when moving from one drought event to another (WMO and GWP, 2014).

These responses to drought are generally reactive both at the national and regional scale (Whilite and Pulwarty, 2005). Treatment of symptoms is often untimely, poorly coordinated, and ineffective to reduce the impacts of droughts, since driven by crisis rather than prevention. Reactive approach is partially due to the uncertainty and unpredictability of drought events, especially in the past. This situation have hindered development of different approaches to drought management, no longer based on reactive practices but on the underlying causes for the vulnerability.

Post-impact interventions, carried out by both developing and developed nations worldwide, are normally in the form of emergency assistance programs to the victims of the drought. This reactive approach does not sustain the reduction of vulnerability, since behaviours or resource management practices are not expected to change. This attitude does not encourage neither self-reliance nor coping capacity.

4.2.2 Pre-impact government programs

Concern that droughts are increasing in frequency, severity and duration due to climate change, together with available technologies to support drought early warning and information delivery systems, stimulates governments throughout the world to switch from responses to drought based on crisis management towards national drought policy based on risk management. Drought policy is developed in advance of drought and maintained between drought events.

Pre-impact programs aim to reduce vulnerability and impacts through a large number of non-structural mitigation measures. Among others, they include seasonal forecasts, water conservation (demand reduction), and increased exploitation of ground waters, water reuse and recycle, construction of reservoirs, interconnection of water supplies between communities, drought planning and education (Wilhite and Rhodes, 1993). Insurance also can be categorized in this policy type.

Where vulnerabilities are identified (population groups, regions, sectors), measures that are able to reduce the risk associated with future drought events can also include adaptation measures (WMO and GWP, 2014). Vulnerability of a region is a function also of the sensitivity of the water management that in turn is characterized by adaptation to changing circumstances. Many adaptations are reactive, but others are planned for the future. Adaptation to altered circumstances allows to respond to some consequence of climate change (i.e., drought events). Adaptation in the water sector to cope with adverse impacts follows two approaches: supply side and demand side. Supply side techniques include building new supply and distribution infrastructure, and more efficient management of existing sources. Demand side techniques aim to reduce the demand for water resources through a wide range of measures, such as public awareness campaigns and statutory requirements for water use efficiency (Parry, 2000).

Some economic and agronomic adaptive options are available in agriculture. Most of agronomic strategies are demand side oriented and can be grouped in short-term adjustments and long-term adaptations. Short-term adjustments are the first defence tools to face the event. They include changes in planting dates and cultivars (i.e., early planting), changes in external inputs (i.e., fertilisers and pesticides), and practice to conserve moisture (i.e., conservation tillage and irrigation management). Long-term adaptations include major changes to overcome the adversity, such as changes in land allocation, introduction of more resistant crop varieties, substitution of crops, enhancement of irrigation efficiency, and changes in farming system.

4.2.3 Preparation of national drought policies and planning techniques

Drought events differ with respect to their physical characteristics between climatic conditions, resulting in local impacts defined by unique characteristics. Preparation of national drought policies and planning techniques should define the key components of the policy, its objectives and the steps in the implementation process. This type of policy response include organizational frameworks and operational arrangements developed in advance of drought and maintained between subsequent drought events. The goal of this approach is to create institutional capacity to improve coordination and collaboration within and between different levels of government and with stakeholders. A national drought policy has specific objectives, different from nation to nation. However, in principle these objectives intend to encourage vulnerable elements (i.e., economic sectors, population groups) to adopt measures promoting risk management, to promote sustainable use of agricultural and natural resources, to facilitate early recovery from drought according to actions consistent with the national policy objectives (Whilite et al., 2014).

4.3 Integrated Water Resources Management

Increasingly competing demands for finite water resources and impacts of climate variability require a more holistic approach to resource management. The Asian Water Development Outlook 2013 (Asian Development Bank) estimates up to 75% of the Asia-Pacific region being water insecure. Combined with increasing demands, water can no longer be looked at from a single lens. The impacts of one user on another and associate trade-offs need to be considered.

According to the definition of the Global Water Partnership, "Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." It is pertinent to note that IWRM is a process and not an end in itself.

IWRM strategies are based on the Dublin Principles which were presented at the World Summit in Rio de Janeiro in 1992. These include recognition of water as finite resource with multiple uses; (ii) requiring more holistic management based on supply and demand considerations; (iii) social and economic value of water; (iv) recognition of stakeholder participation in decision making and (v); women's role in water management.

Over the past decade much progress has been made with increasing awareness on the concept of IWRM in the Asia Pacific region and subsequently, embedding in the water policy framework of an increasing number of developing and middle income countries. For example, in India the main objective of the National Water Mission is "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management." In the People's Republic of China, the 2002 Water Law reinforces the need to strengthen the responsibilities of river basin commissions and local water bureaus in respect to integrated water resources planning. Multilateral development banks like the Asian Development Bank have also endeavoured to embed IWRM through strategic and operational plans and support to regional knowledge partners like the Network for Asian River Basin Organizations.

Adaptation to climate change is closely linked to water and its role in sustainable development. To recognize this reality and to respond accordingly presents development opportunities, various necessary adaptation measures that deal with climate variability and build upon existing good land and water management practices have the potential to create resilience to climate change and to enhance water security and thus directly contribute to sustainable development. Creating the infrastructure for water resources development and distribution has shown high human and macroeconomic benefits; conversely, countries lacking this capability have suffered damaging shocks from droughts and floods. More water storage is required to manage increased variability of water resources (UN-Water 2010)

A good example is the ADB financed loan, the Karnataka Integrated and Sustainable Water Resources Management Investment Program, India. The state of Karnataka is water-stressed, with increasing water demands from urban and industrial sectors. This is exacerbated by uneven spatial and temporal distribution of water resources and the predicted impacts of climate change. Overall, the investment program area is found to be vulnerable to increased incidence of seasonal droughts. This increases the need for a well-planned and methodical approach to water resources management. An integrated approach to water resources management is a means to reconcile varied and changing water uses and demands since it provides greater flexibility and adaptive capacity than conventional water resources management approaches.

Adaptation to climate change to reduce vulnerability in the water sector should involve far more than just water managers. Increasing social vulnerability to water stress (in terms of drought and flood) in many parts of the world reflects a wide range of pressures, many of which are outside the responsibility of water managers. Reducing vulnerability to climate change-induced flood and drought will require decisions about issues such as development and planning control, fiscal incentives (such as subsidized insurance or government disaster relief) to occupy (and continue to occupy after loss) hazard-prone land, and wealth enhancement.

The fourth edition of the World Water Development Report (WWAP, 2012), 'Managing Water under Uncertainty and Risk' seeks to demonstrate, among other messages, that water underpins all aspects of development, and that a coordinated approach to managing and allocating water is critical. It highlights that more responsible action by all water users has enormous potential to lead to better outcomes - but requires political, social, economic and technical responses at all levels of government, businesses and communities, from local to international.

Over the past decades the translation of IWRM into water policy, planning and institutional development has also had the knock on effect of a more prescriptive rather than location or basin/sub basin specific approach. The latter would be based on understanding the goals or targets for basin/sub basin water resources for example, improving agriculture water productivity and defining a prioritized set of actions to achieve. In certain cases, activities like performance benchmarking of a river basin organization may be regarded as a priority action – using a blueprint rather than tailored approach.

Rethinking IWRM in the context of water security and climate change adaptation may be a way to move forward. The Asian Water Development Outlook (AWDO) has five key dimensions of water security which would be affected by population dynamics and impacts of climate change.

As an adaptation action it would be useful to consider gradual improvements on the IWRM spiral as a reflection of enhanced water security. This would require planners and decision makers to consider the following:

(1) Risks to the basin or sub basin (including climate change impacts on hydrology).
(2) Critical users within the basin (e.g. if domestic users then assess their water security status – under key dimension 1 based on relevant indicators like access to piped water supply and sanitation).
(3) Assess the basin or sub basin targets or vision for the future – e.g. is there a net shift in allocations required between agriculture and domestic use, have water quality targets been set for improved domestic supply and river health and are there environmental base flow requirements.
(4) Consider the risk of climate change impacts to ascertain the trade-offs required.
(5) Based on the assessment consider the priority actions to increase water security in the sub basin and to respond to adaptation requirements. E.g. installation of river flow measurements, use of remote sensing to establish agriculture water productivity, strengthening institutional capacity for climate proofed domestic water supply design, monitor water quality, stakeholder awareness raising and establishing performance targets for the basin etc.
(6) Develop a road map with indicators, roles of agencies and timelines.
(7) Review performance and achievements, and constraints and update road map with continuous monitoring.

We are increasingly witnessing increasing frequency and magnitude of extreme events and regional climate variability in the Asia region. This not only introduces an element of disaster risk management into the overall equation of improved and integrated water resources management, but further reinforces the need for tailor made adaptive solutions.

The past decade has demonstrated that moving from a concept of IWRM to applying the process in an operational context requires further contextualization. An example is the initiative for Improved Management of Extreme Events through Ecosystem-based Adaption in Watersheds (ECOSWat). The program is commissioned by the German Federal Ministry for Environment, Nuclear safety and Buildings (BMUB) and supported by the Government of Thailand. It provides a more locally based approach with local water agencies (in pilot river basins) to plan and assess ecosystem-based adaptation measures for protection against the effects of extreme events. Lessons learned from the project have been fed into national-level adaptation strategies for the water sector.

Much of the base work has been accomplished in increasing regional understanding of a more integrated approach to water management. There is also an increasing awareness of the risks and impacts of climate variability and extreme events. What is more challenging is taking the lead in drilling down further into tailored solutions and approaches and highlighting their benefits to all stakeholders.

5. Conclusions

This paper, overviews the background and structure of the issues about management of climatic extremes with special focus on floods and droughts, aiming at facilitating the discussion on this topic as the sub-theme 2 for the Second World Irrigation Forum.

To reduce the disaster risk, the global and local society or community need to assess the weather and climate events with their magnitudes, frequencies, variabilities as well as the forces, the vulnerability of the region and society, and the exposure for the events. The climate change, however, is not easy to prediction and carries high level uncertainty.

Under the current uncertainties in climate change impact projections, improving resilience of the local systems is one approach to reinforce the capability of societies to better cope with the extreme events. In this situation, one of the essential and significant attitude is the adaptive approach. Since the factors associated with climate change and its apparent impacts are difficult to be projected and evaluated at the present level of scientific understanding it would be more effective and feasible to manage the extreme flood and drought through integrated and adaptive approaches. Particularly the coordinated adaptation measured are needed since autonomous adaptation might lead to the increase of emissions and degradation of ecosystems, which could further reinforce the negative impacts of the climate change.

The concept and approach of adaptive management is found in many sections of this paper. Here, main points of the sections are summarized as follows:

The extreme events will affect natural resources such as soil fertility and available water resulting in increased vulnerability of agricultural production as the negative impacts, with serious water stress, land degradation and desertification as well as water logging and land inundation. The extreme flood and drought with changing temperature affect the hydrological condition of a basin and farmland, and will make it increasingly difficult to plan for cultivation activities such as each process in the cultivation and water management practices.

When planning for the long term and assessing climate change risks, it is important to integrate how the different trends interact in a comprehensive manner to identify risk scenarios for the future. These trends influence and reinforce each other, and determinate risk levels through interconnected processes that are difficult to separate them in order to get a real sense of future risks, and policies that need to be setup to reduce them. Coordinated and effective adaptation strategies are essentially needed to ensure the long-term food and water security under changing climatic conditions.

Adaptation to climate change is inevitably a multidisciplinary problem, and it requires the consideration of agro-climatological, technical and socio-economic issues. The adaptation management demands integration of methods and synergy with mitigation of climate change. Innovative, coordinated and effective adaptation strategies require the capacity to adaptation to be continuously improved and targeted monitoring of the costs, benefits and impacts of the adapted policies.

Many of adaptive management's benefits come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and should therefore improve management decisions. These benefits are difficult to measure and translate into the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, up-front costs of adaptive management programs, such as ecosystem monitoring programs, scientific staff, and institutional support.

Response to drought, which has been reactive in most part of the world have proved to be ineffective in most cases. Whether droughts characteristics will change or not, it is imperative a more risk-based approach to respond to drought, and based on developed national drought policies; preparedness plans and widely disseminated drought early warning systems.

Floods need to be recognized as natural phenomenon that have multi-faceted ecological benefits but do turn into disasters if the vulnerable sections of the society are exposed, particularly in the extreme events. Integrated Flood Management approach that draws maximum benefits of flood plains within the framework of Water Resources Management, Land use planning and Risk Management principles need to be adopted.

Adaptation to climate change to reduce vulnerability in the water sector should involve far more than just water managers. Mechanisms for interaction among various stakeholders, coordination among various agencies and collaboration among various disciplines for establishing better management systems needs to be promoted, not only against the climate change but also for everlasting improvement of the systems.

6. References

ADB, 2016. Water Security Framework of Five Interdependent Key Dimensions. Philippines.

Bell, V.A., Kay, A. L., Davies, H. N., Jones, R. G., 2016. An assessment of the possible impacts of climate change on snow and Peak River flows across Britain. Climatic Change. DOI 10.1007/s10584-016-1637-x

Behulu, F., Melesse, A.M., and Fiori, A., 2016. Climate Change Impact Assessment on Groundwater Recharge of the Upper Tiber Basin (Central Italy). Chapter 30. Landscape Dynamics, Soils and Hydrological Processes in Varied Climates (Ed: A.M. Melesse and W. Abtew). ISBN: 9783319187860. Springer.

Butt, T.A., McCarl, B.A., Angerer, J., Dyke, P.T., Stuth, J.W., 2005. The economic and food security implications of climate change in Mali. Climatic Change 68, 355-378.

Cane, M.A., S.E. Zebiak and S.C. Dolan, 1986: Experimental Forecasts of El Nino. Nature, 321, 827-832.

Chattopadhyay, S. and Manoj K. Jha, M.K., 2013. Assessment of Climate Change Impact on Watershed Hydrology. Proceedings of the 2013 National Conference on Advances in Environmental Science and Technology. pp 3-11.

Clark, M.P., Wilby, R.L., Gutmann, E.D., Vano, J.A., Gangopadhyay, S., Wood, A.W., Fowler, H.J., Prudhomme, C., Arnold, J.R., and Brekke, L.D., 2016. Characterizing Uncertainty of the Hydrologic Impacts of Climate Change. Curr Clim Change Rep. DOI 10.1007/s40641-016-0034-x

Dilley, M., 2000: Reducing vulnerability to climate variability in Southern Africa: the growing role of climate information. Climatic Change, 45, 63-73.

Fader, M., Shi, S., von Bloh, W., Bondeau, A., and Cramer, W., 2016. Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. Hydrol. Earth Syst. Sci., 20, 953–973, 2016. DOI: 10.5194/hess-20-953-2016.

FAO, 2008. Financial Mechanisms for Adaptation to and Mitigation of Climate Change in the Food and Agriculture Sectors. High-Level Conference on World Food Security.

Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T. and Marcomini, A., 2016. A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. Journal of Environmental Management 168 (2) 123-132.

GWP, 2012, Water Security Background Paper, http://www.slideshare.net/globalwaterpartnership/water-security-background-paper-by-gwp-technical-committee-members

Hattori, Y., Nagai, K., Furukawa, S., Song, X.J., Kawano, R., Sakakibara, H., Wu, J., Matsumoto, T., Yoshimura, A., Kitano, H. and Matsuoka, M., 2009. The ethylene response factors SNORKEL1 and SNORKEL2 allow rice to adapt to deep water. Nature 46, 1026-1030.

Howden, S.M., Soussana, J-F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. Proceeding of the National Academy of Sciences of the United Stated of America 104 (50), 19691–19696.

ICID, 1999. “Non-structural Approaches to flood Management”, ICID.

ICID, 2014. Page for the 22nd ICID Congress. http://www.icid2014.org/congress/cogress_2.asp?sMenu=cog2.

ICID, WG-CAFM. 2016. “Adaptive Flood Management”, to be published.

ICOLD, 2001. Non-structural risk reduction measures; Benefits and costs for Dams.

IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P.

IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation - Special Report of the Intergovernmental Panel on Climate Change.

IPCC, 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, 2014. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

Kogan, F.N., 1995. Droughts of the Late 1980s in the United States as Derived from NOAA Polar-Orbiting Satellite Data, in: Bulletin of the American Meteorological Society, Vol. 76, No. 5, May 1995, pp. 655-668.

Mirza, M.M.Q., 2003. Climate change and extreme weather events: can developing countries adapt? Climate Policy, 3, 233-248

Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf.

Parry, M.L. (Editor), 2000. Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project. Jackson Environment Institute, University of East Anglia, Norwich, UK, 2000, 320 pp.

Paulo, A.A., Rosa, R.D., and Pereira L.S., 2012. Climate Trends and Behaviour of Drought Indices Based on Precipitation and Evapotranspiration in Portugal. Natural Hazards and Earth System Sciences, Vol. 12, No. 5, pp. 1481-1491.

Pereira, L.S., Cordery I., and Iacovides I., 2009. Coping with Water Scarcity, Springer, and ISBN 9781402095795-9781402095788.

Pfaff, A., Broad, K., Glantz, M., 1999. Who benefits from climate forecasts? Nature 397, 645-646.

Shatanawi, K., Rahbeh, M., and Shatanawi M., 2013. Characterizing, Monitoring and Forecasting of Drought in Jordan River Basin. Journal of Water Resource and Protection, 5, pp. 1192-1202.

Smith, J.B., 1997: Setting priorities for adapting to climate change. Global Environmental Change.7, 251-264.

The Europe Acacia Project, 2002. Assessment of Potential Effects and Adaptations for Climate Change in Europe

Tubiello, F. and Rosenzweig, C., 2008. Developing climate change impact metrics for agriculture. The Integrated Assessment Journal 8 (1), 165-184.

Tubiello, F.N., Rahman, A., Mann, W., Schmidhuber , J., Koleva, M., Müller, A., 2009. Carbon financial mechanisms for rural development. Climatic Change 97, 3–21.

Tubiello, F. and van der Velde, M., 2010. Land and water use options for climate change adaptation and mitigation in agriculture. SOLAW Background Thematic Report – TR04A. New York: GET-Carbon. Available at: http://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_04a_web.pdf.

UN-Water, 2010, Climate Change Adaptation: Pivotal Role of Water, A Policy Brief, http://www.unwater.org /fileadmin/user_upload/unwater_new/docs/unw_ccpol_web.pdf

WWAP (World Water Assessment Programme), 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO. http://unesdoc.unesco.org/images/0021/ 002156/215644e.pdf

Watanabe, Tsugihiro. 2016. How Irrigation and Drainage Play an Important Role in Climate Change Adaptation. Irrighation and Drainage, 65. PP.189-196. DOI:101002/ird.1980

Wilhite, D.A., Sivakumar, M.V.K., and Pulwarty R., 2014. Managing drought risk in a changing climate: The role of national drought policy, in: Weather and Climate Extremes, Volume 3, June 2014, Pages 4–13, High Level Meeting on National Drought Policy, doi:10.1016/j.wace.2014.01.002, Elsevier.

Wilhite, D.A., and Glantz, M.H., 1985. Understanding the Drought Phenomenon: The Role of Definitions. Water International 10(3):111–120.

Wilhite, D.A., Rhodes, S.L., 1993. Drought mitigation in the United States: progress by state government, D.A. Wilhite (Ed.), Drought Assessment, Management, and Planning: Theory and Case Studies, Kluwer Academic Publishers, Dordrecht, The Netherlands (1993), pp. 237–252.

Wilhite, D.A., and Pulwarty, R.S., 2005. Drought and water crises: lessons learned and the road ahead, D.A. Wilhite (Ed.), Drought and Water Crises: Science, Technology, and Management Issues, CRC Press, Boca Raton, Florida, pp. 389–398.

WMO and GWP, 2009, Integrated Flood Management: Concept Paper, WMO No 1047 http://www.apfm.info/publications//concept_paper_e.pdf

WMO and GWP, 2013, Flood Mapping, Integrated Flood Management Tool Series No 13 http://www.apfm.inf o/publications/tools/APFM_Tool_20.pdf

WMO, 2013 (a). Global Climate 2001–2010: A Decade of Climate Extremes—Summary Report. WMO No. 1119, World Meteorological Organization, Geneva, Switzerland.

WMO and GWP, 2016, Public Perception of Flood Risks and Social Impact Assessment, Integrated Flood Management Tool Series No 25 http://www.apfm.info/publications/tools/ Tool_25_Public_ Perception_ of_ Flood_ Risk_and_Social_Impact_Assessment.pdf

WMO and GWP, 2014. National Drought Management Policy Guidelines: A Template for Action (D.A. Wilhite). Integrated Drought Management Programme, Tools and Guidelines Series 1.

World Bank Group, 2016. High and Dry: Climate Change, Water, and the Economy.

❖❖❖❖❖