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MICRO-CREDENTIAL

CLIMATE CHANGE FOR SUSTAINABLE LAND MANAGEMENT IN CENTRAL ASIA

5- Climate Extremes, Hazards and Risks

From Climate Hazard to Risk: A Practical Framework

PDF W05

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1. SUMMARY OF KEY IDEAS

Climate change is altering the water cycle through rising temperatures, changing precipitation regimes, intensifying evapotranspiration, accelerating glacier loss, and shifting the timing of runoff. For water-resource systems, the central issue is not only that average conditions are changing, but that variability, seasonality and extremes are changing as well.

The cryosphere, including glaciers, seasonal snow, permafrost and other frozen components of the Earth system, acts as a natural water tower in many mountain regions. Its degradation affects downstream irrigation, hydropower, ecosystems, and urban supply, especially where summer water demand coincides with reduced late-season snow and ice reserves.

Heatwaves, floods, droughts, and dust storms should not be treated as isolated hazards. In dryland and mountain regions they often interact through combination and cascading processes: heat increases atmospheric water demand, drought reduces vegetation cover and soil moisture, flood risk may rise when intense rainfall falls on degraded catchments, and exposed soil sediment surfaces increase dust activity.

The Aral Sea region demonstrates how climate stress, unsustainable water management, land degradation and public-health risk can reinforce one another. It is therefore a useful case study for understanding multi-hazard environmental change in Central Asia.

Effective response depends not only on the physical hazard, but also on exposure, vulnerability and adaptive capacity. Disaster risk reduction and early-warning systems are most effective when they are linked to long-term monitoring, clear institutional responsibility, transboundary coordination and the capacity to turn warnings into early action[1–3].

2. LEARNING OBJECTIVES

By the end of this module, the students will be able to:

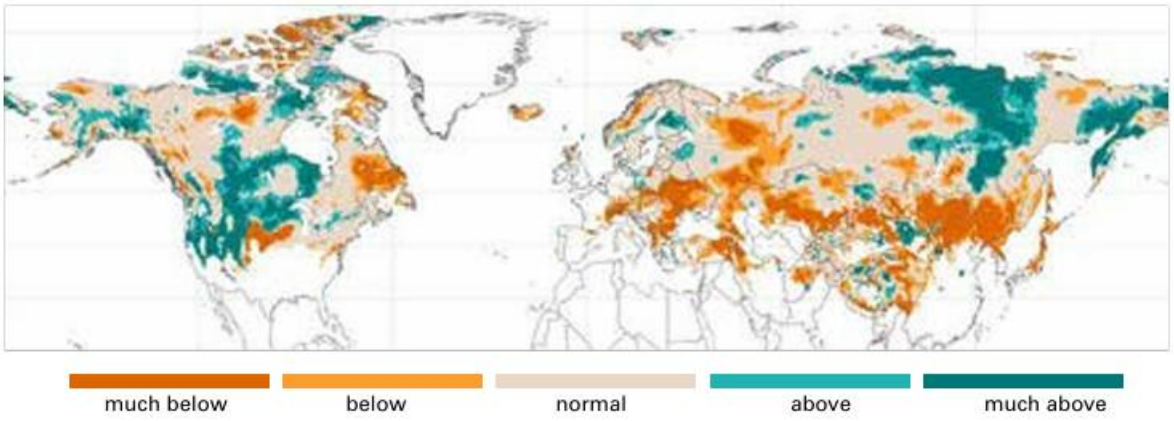
- Explain how climate change modifies water availability through changes in temperature, precipitation, evapotranspiration and cryospheric melt.
- Distinguish the hydrological significance of heatwaves, floods, droughts and dust storms. Describe how these hazards can interact.
- Discuss why the Aral Sea region is a classic example of multi-hazard environmental change shaped by both climatic and human drivers.
- Use the concepts of exposure, vulnerability and adaptive capacity to interpret differences in risk between regions and social groups.
- Evaluate the role of disaster risk reduction, monitoring and early-warning systems in reducing water-related climate risks.

3. INTRODUCTION

Water resources connect the atmosphere, biosphere, cryosphere and human economy more directly than almost any other part of the climate system. Climate changes are therefore experienced not only as warming, but as altered snow cover, more variable rainfall, declining glacier mass, shifting groundwater recharge and greater uncertainty in seasonal water supply. For societies that depend on irrigation, hydropower, mountain runoff or drought-sensitive agriculture regions, these changes affect livelihoods, food security and regional stability.

The cryosphere is especially important because frozen water stores release meltwater across months or years rather than all at once. Seasonal snowpack regulates spring and summer runoff, while glaciers buffer dry years and sustain warm-season river flow in many mountain basins. Yet this buffering role is not permanent. In the early stages of glacier retreat, melt can temporarily increase runoff. However, over time, shrinking ice volume undermines that support and increases the risk of declining late-summer discharge. That is a process often described as “peak water”.

This document examines climate change, water resources and the cryosphere through four linked pillars. It first considers how heatwaves, floods, droughts and dust storms affect water systems. It then turns to the Aral Sea region as a case of multi-hazard environmental change. A third section explains why risk depends on exposure, vulnerability and adaptive capacity and not on hazard alone. A fourth section reviews disaster risk reduction and early-warning systems as practical tools for adaptation and preparedness[1–3].



Map 1. Example of below-normal snow water equivalent in the Northern Hemisphere in March 2023[2]

4. HEATWAVES, FLOODS, DROUGHTS AND DUST STORMS

4.1. Heatwaves and evaporative demand

Heatwaves intensify water stress even where rainfall totals do not decline sharply. Higher air temperatures increase atmospheric evaporative potential, accelerating water loss from soils, plantations, reservoirs and vegetation. For water managers, this means that the hydrological consequences of warming cannot be judged by precipitation alone. A basin may receive similar annual rainfall yet still experience greater effective dryness because more moisture is lost to evaporation and plant transpiration.

Heat extremes also matter because they compound cryospheric change. Warm anomalies reduce snow persistence, shift melt earlier into the year, and can intensify glacier mass loss. In basins that depend on mountain meltwater, the result is often a mismatch between water availability and peak summer demand. Heatwaves can therefore transform short-lived meteorological extremes into seasonal water-supply problems[1,4–6].

4.2. Floods in a warming hydrological cycle

A warmer atmosphere can hold more water vapour, increasing the potential for heavy precipitation in many regions. However, flood risk is never controlled by rainfall alone. Snowmelt timing, antecedent soil moisture, land cover, drainage infrastructure, reservoir operations and settlement patterns all of them, influence whether an intense event becomes a disaster. This is why climate change should be understood as altering the probability and character of flood-generating conditions rather than creating a uniform flood trend everywhere.

Mountain and cold-region catchments face an additional cryospheric dimension. Earlier snowmelt, glacier retreat and the growth of unstable proglacial lakes can change the timing and mechanisms of flooding. Some basins face higher spring runoff, while others face rain-on-snow events, debris flows or glacial lake outburst flood risk. These processes are especially significant where hazard monitoring remains weak and downstream populations are expanding[1,2,5,7,8].

4.3. Droughts, compound events and water scarcity

Drought is more complex than low rainfall. Meteorological drought may begin with precipitation deficit, but agricultural and hydrological drought emerge through soil-moisture decline, reduced river flow, falling reservoir levels and groundwater stress. Rising temperature often worsens each of these stages. This matters in dry continental interiors, where moderate precipitation decline combined with strong warming can produce severe water scarcity.

A hot drought is not simply drought and heat combined; it is a mutually reinforcing process in which drying soils reduce evaporative cooling, which in turn increases local temperature and atmospheric demand. Such an outcome can damage crops and plantations, strain electricity systems, reduce hydropower reliability and increase wildfire or land-degradation risk.

4.4. Dust storms, land degradation and water insecurity.

Dust storms are often discussed as atmospheric hazards, but they are also water-related hazards because they emerge from dry, sparsely vegetated and disturbed surfaces. Drought, overgrazing, poor irrigation practices, exposed lake beds and reduced river inflow can all increase dust-source activity. Dust can degrade air quality, reduce visibility, damage crops, transport salts and pollutants and create serious public-health burdens.

In Central Asia, dust risk is linked to desiccation and land degradation. The exposed bed of the former Aral Sea, often termed the Aralkum (the desert that formed on seabed of the Aral Sea after it dried up), has become a major regional source of salt and dust aerosols. This shows how hydrological mismanagement can create long-lasting atmospheric and health hazards that persist long after the initial water diversion decisions were made[9–12].

5. ARAL SEA REGION: A CASE OF MULTI-HAZARD ENVIRONMENTAL CHANGE

The Aral Sea crisis is a strong teaching case because it shows that environmental disasters are rarely monocausal. The dramatic shrinkage of the sea was driven primarily by large-scale diversion of the Amu Darya and Syr Darya for irrigation during the Soviet period, rather than by greenhouse warming alone. Nevertheless, climate change now acts as a risk multiplier in the basin by intensifying heat stress, increasing evaporative demand, aggravating drought pressure and complicating already fragile water governance.

As the Aral sea contracted, the region experienced a cascade of ecological and social consequences: collapse of fisheries, salinisation, loss of delta ecosystems, exposure of contaminated sediments, worsening dust and salt storms, and deterioration of local health conditions. The drying seabed did not merely become a symbol of environmental degradation, but an active hazard source. This is why the Aral Sea should be analysed through a multi-hazard lens rather than as a single story of shoreline retreat.

That case also demonstrates the importance of scale. Some interventions, such as the Kokaral Dam and related restoration efforts in the Small Aral, have produced measurable local improvements. Yet broader basin-wide sustainability still depends on upstream-downstream coordination, efficient irrigation, ecosystem restoration and climate-resilient water allocation[12–16].



Figure 1. Shrinkage of the Aral Sea between 2000 and 2014. Satellite images show the dramatic reduction of the Aral Sea, with the eastern lobe of the southern basin drying completely by 2014. Faint white outlines indicate the approximate 1960 shoreline[17].

6. EXPOSURE, VULNERABILITY AND ADAPTIVE CAPACITY

Climate risk is commonly described as the interaction of hazard, exposure and vulnerability. Hazard refers to the potentially damaging physical event or trend; exposure refers to the people, infrastructure, ecosystems and assets located in “harm's way” and vulnerability refers to the conditions that make those exposed elements more susceptible to loss. Adaptive capacity describes the ability of systems and communities to adjust, cope, learn and reduce future harm.

This framework explains why identical hydrometeorological events produce unequal outcomes. A flood of given magnitude is more damaging where settlements occupy floodplains, warning systems are weak, drainage is inadequate and recovery finance is scarce. Similarly, a drought becomes more severe where livelihoods depend on rain-fed agriculture, water governance is fragmented and households lack access to irrigation, insurance or social protection.

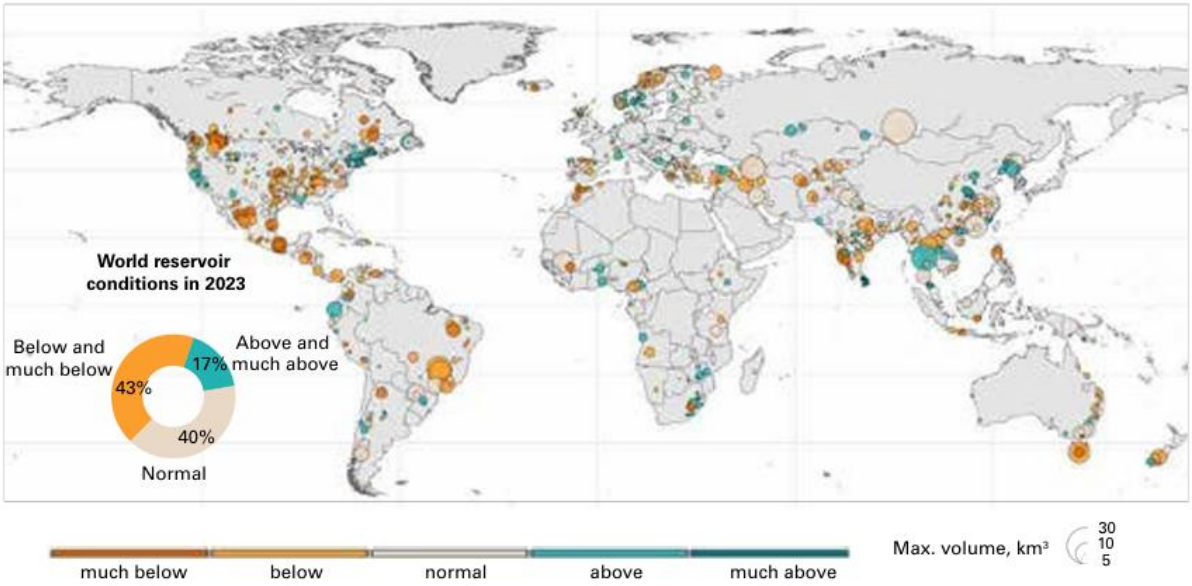
In cryosphere-dependent regions, vulnerability is often shaped by seasonality and infrastructure. Communities may be exposed to the same long-term glacier retreat, yet their capacity to respond differs according to storage infrastructure, data quality, institutional coordination, transboundary agreements, poverty levels and whether adaptation planning includes mountain hazards. Adaptive capacity is therefore social and political as well as technical[3,4,12,18].

7. DISASTER RISK REDUCTION AND EARLY-WARNING SYSTEMS

Disaster risk reduction seeks to prevent new risks, reduce existing risks, and strengthen resilience before disasters occur. In water and cryosphere contexts, this means moving beyond reactive emergency response toward risk-informed planning, monitoring, ecosystem management, resilient infrastructure, and preparedness. The Sendai Framework places strong emphasis on understanding disaster risk, strengthening governance, investing in resilience, and improving preparedness.

Early warning systems are a central part of this agenda, but they are effective only when treated as complete systems rather than as forecasting devices alone. A functional multi-hazard early warning system links risk knowledge, monitoring and forecasting, warning dissemination, and response capacity. Without trusted communication channels, local preparedness, or pre-agreed action protocols, a technically accurate forecast may fail to save lives or reduce losses.

For water-related and cryospheric hazards, monitoring is particularly important. Stream gauges, snow and glacier observations, groundwater records, remote sensing, weather forecasting, and impact databases all improve the ability to anticipate danger. In transboundary basins, data sharing is equally critical because upstream cryospheric and hydrological change often determines downstream risk. The long-term challenge is therefore institutional as much as scientific. Warning systems must be embedded in governance structures that can convert knowledge into timely action[3,19,20].



Map 2. Global pattern of below-normal reservoir inflow in 2023, illustrating why monitoring and early warning matter for water management. Source to cite in caption: World Meteorological Organization, State of Global Water Resources 2023[2]

8. CONCLUSIONS

Climate change affects water resources through multiple, interconnected pathways: warming raises evaporative demand, precipitation patterns shift, extreme events intensify, snow and glacier regimes change, and the timing of runoff becomes less dependable. The cryosphere is therefore not a peripheral topic in water studies; it is central to understanding present and future water security in mountain-fed regions.

The four pillars examined in this paper show that climate hazards must be understood as interacting processes. Heatwaves, floods, droughts and dust storms are linked through the hydrological cycle, land-surface conditions and human water use. The Aral Sea region illustrates how poor water governance can intensify environmental stress and produce cascading ecological, economic and health consequences.

Finally, effective adaptation requires a shift from hazard-centred thinking to risk-centred thinking. Exposure, vulnerability and adaptive capacity determine who suffers, who can recover and whose livelihoods remain at risk. Disaster risk reduction and early-warning systems are therefore secondary components of climate policy; they are essential parts of water governance in a warming world.

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