

# **Sustainable Water Resources Management Under Extreme Conditions**

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### Water Resources Management Challenges

Water resources face significant challenges due to climate change and extreme conditions such as severe droughts, floods, and rising temperatures. These factors affect water availability and distribution, making sustainable management critical.

Challenges include population growth, which puts great pressure on available water resources, arising from

increasing demands of:

- agricultural water uses,
- domestic water use,
- industrial use,
- tourism demands.

<u>Warmer temperatures due to climate change</u>, have great effects on weather patterns, resulting in more severe and frequent <u>floods</u> in some parts of the world, causing tremendous damages, and expected to <u>lead to more</u> <u>intense flooding and prolong existing monsoon seasons</u>, whereas <u>droughts</u> in some other parts lead to water scarcity in many regions and deserts expansion, reducing growing food land, causing water shortage on a regular basis.

# **Climate Change General Effects**

Warmer temperatures due to climate change, have great effects on weather patterns, resulting in:

- Hotter temperatures: change weather patterns, disrupt the usual balance of nature.
- More severe storms: temperature changes affects rainfall and its pattern, resulting in more severe and frequent storms as more greenhouse gases released.
- Flooding and landslides, that can destroy homes and communities. Climate models predict that 'climate change will lead to more intense flooding and prolong existing monsoon seasons' (Earth. Organisation).
- Increased drought: Water become scarcer in many regions. Deserts expand, reducing growing food land, causing water shortage on a regular basis.



Annual Temperature Anomalies 2022



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Berkeley Earth to 2022-09, ERA5 to 2022-09, GISTEMP to 2022-09, HadCRUT5 to 2022-09, JRA-55 to 2022-09, NOAAGlobalTemp to 2022-09

#### # Met Office



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### **Water Resources Management**

### **General Challenges Under Extreme Conditions**

- Water Scarcity and Allocation: Droughts reduce available water, affecting agriculture, industry, and domestic needs against. Prioritizing allocation while ensuring equity is difficult.
- Floods: Extreme rainfall overwhelms systems, causing infrastructure damage and water resources contamination.
- **Climate Change**: Change in precipitation patterns and temperature mess with long-term planning, making it hard to justify costly infrastructure upgrades or policy shifts.
- **Ecosystem Stress**: Extreme conditions degrade wetlands, rivers, and aquifers, which are critical for natural water storage and purification.
- Infrastructure: Many areas don't have robust infrastructure like desalination, rainwater harvesting, or smart grids. Upgrading or constructing these systems is costly and politically challenging.
- Economic Constraints: Funding adaptive measures such as drought-resistant crops or flood barriers competes with other priorities. Regions with limited resources, face the greatest challenges in responding.

### **Floods Impacts**

Floods, intensified by climate change through heavier rainfall, rising sea levels, and shifting weather patterns, cause widespread economic damage. Key sectors affected include <u>agriculture</u>, <u>infrastructure</u>, <u>manufacturing</u>, <u>housing</u>, <u>energy</u>, and <u>public health</u>.

Flood losses hit agriculture and infrastructure hardest due to direct exposure, while manufacturing and housing suffer from cascading effects.

- Agriculture and Livestock: Floods destroy crops, drown livestock, erode fertile soil, and disrupt planting/harvesting cycles. Economic impacts include direct losses, such as ruined harvests, and indirect effects (e.g., food price spikes, reduces exports). Increased rainfall intensity and unseasonal overwhelm drainage systems and farmland.
- Surface water overflows reduce groundwater recharge opportunities, while saturated soils limit future planting, amplifying long-term losses.
- **Energy Sector**: Extreme rainfall and storm surges flood energy infrastructure, especially in low-lying areas. Floods disrupt power generation, such as hydropower dams, coal plant, and distribution.

#### **Effects of Floods on Water Resources Infrastructure.**

- **Physical Damage**: Floodwaters erode, crack, or destroy infrastructure like dams, levees, reservoirs, and treatment plants. Debris and sediment accelerate wear, while extreme pressure can cause dam breaches or pipeline ruptures.
- Contamination: Floods introduce pollutants (sewage, chemicals, sediments) into water systems, overwhelming treatment facilities and contaminating reservoirs or groundwater.
- Operational Disruption: Inundated facilities such as pumping stations, treatment plants, often shut down, halting water supply or wastewater processing.
- Sediment and Debris Blockages: Silt and debris clog reservoirs, canals, and intake systems, reducing storage capacity and flow efficiency.





- **Erosion and Scouring**: Floods reshape riverbanks and channels, undermining infrastructure foundations like bridges or diversion structures
- Increased Maintenance Costs: Post-flood repairs, from fixing eroded embankments to replacing equipment, which divert funds from routine upgrades or resilience projects.
- Long-Term Design Challenges: Intensifying flood patterns expose outdated infrastructure designs, forcing costly retrofits or rebuilds to handle higher volumes and velocities.
- Measures like flood-resistant designs, real-time monitoring, or nature-based solutions (e.g., wetland restoration) could mitigate effects, but implementation might be delayed in many regions.
- Impacts cascade; damaged infrastructure disrupts supply, delays recovery, and hikes costs, while poor water quality risks public health.



# **Drought and Drought Impacts**

A drought is defined as <u>"a deficiency of precipitation over an extended period of time (usually a season or more), resulting in a water shortage.</u>" (<u>https://www.c2es.org</u>).

- Climate change increases temperature, which increases evaporation, and hence, <u>reduces surface water and dries out soils</u> <u>and vegetation.</u>
- Warm temperature might increase precipitation variability, and hence, more periods of extreme precipitation, and drought.
- Wet places, such as tropics and higher latitudes, might get wetter, while dry places in the subtropics, where most deserts are found, might become drier.



Farmers planting during a rainy season in Dali, North Darfur, Sudan. Photo: UN Photo / Albert Farran



#### Severe droughts can affect :

- Water supply; during droughts, water access is limited for household use; drinking, cooking, cleaning, and watering plants, as well as for agriculture, transportation, and power generation. Also, droughts may lead to higher water costs, and demolition of important water sources like wells.
- **Agriculture**; droughts affect livestock and crops. Globally, drought might struck major breadbasket regions, adding to food price instability, and cost spikes can lead to civil disturbance, and migration.
- **Transportation**; droughts can lower river water levels and hence, affect transport through rivers, threatening commerce on rivers. Drought can cause wildfires which affects travel by closing roadways and railroads and grounding planes when smoke is thick.
- Energy: droughts can affect the reliability of electricity produced from plants that require cooling water to maintain safe operations. In addition, heat waves during droughts can increase demands of electricity, causing stress on the grid.



## Water Resources Sustainable Management

Sustainable water resources management involves balancing the use and conservation of water to meet current and future needs while protecting ecosystems. Sustainability must include a whole range of aspects on various spatial and time scales, where water should be always; available, save, and secure.

The sustainability in water resources management need to meet water demands with acceptable water quantity and quality, considering national security, economic health, and societal well-being.

- Emphasis needs to be given to development of infrastructure, regulation of water uses, assessment and management of both surface and groundwater resources, in parallel with new discoveries.
- Maintaining water resources under extreme conditions requires a blend of technological innovation, effective policies, and international cooperation to ensure water availability for current and future generations.
- With rising temperatures and shifting rainfall patterns due to <u>climate change</u>, water becomes scarcer or less predictable. Hence, protecting natural ecosystems like wetlands and forests, which act as natural water reservoirs and help regulate the water cycle, is important.



- Coordination across sectors (agriculture, industry, domestic use) to minimize waste and ensure equitable distribution is essential.
- There should be water supply and demand management strategies, considering extreme conditions and climate change affects:
  - <u>Water supply strategies</u> should be based on the increase of both conventional and nonconventional water resources, development of groundwater aquifers, and water distribution systems.
  - <u>Water demand management programs</u> should be through the conservation and efficient use of water resources, the expansion and construction of new water sources, wastewater collection and treatment facilities, and water distribution networks.
  - <u>Domestic water supply</u> should be met and the deficit in water resources is reduced, even during extreme conditions.



The <u>Government</u> should develop <u>regional water strategies</u> to help adapting any future changes in water resources. These strategies should consider the climate change modelling with understanding how water resources might be impacted by climate change.

#### Key strategies should include:

- Efficient Use: Implementing drip irrigation, low-flow fixtures, and water recycling to reduce waste.
- **Conservation**: Protecting watersheds, reforesting, and restoring wetlands to maintain natural water cycles. Urban planning can integrate green infrastructure like rain gardens.
- Equitable Access: Ensuring fair distribution, especially in water-scarce regions.
- **Pollution Control**: Treating wastewater and regulating industrial/agricultural runoff.
- **Climate Adaptation**: Building resilient infrastructure like rainwater harvesting systems or desalination plants to address droughts and floods.
- **Governance**: Integrated Water Resources Management (IWRM) frameworks which promote stakeholder collaboration.



#### Actions Required for sustainable water management under extreme conditions:

- Enhancing Infrastructure Resilience: such as upgrading dams, levees, and pipelines to withstand floods and droughts.
- **Promoting Efficient Use**: Implement smart irrigation, water-saving technologies, and public awareness campaigns.
- **Protecting Ecosystems**: Restore wetlands and watersheds to regulate water flow and improve quality.
- Advance Technology: Investing in desalination, rainwater harvesting, and AI-driven water monitoring systems.
- **Strengthening Policy**: Enforce regulations for equitable water distribution and incentivize conservation.
- **Building Community Capacity**: Train local groups for emergency water management and resilience planning.



# Climate change adaptation should include both risk prevention measures and measures that increase the climate resilience:

- **<u>Risk prevention measures</u>**: to prevent negative effects of climate change in water resources by:
  - Reducing urban development in flood-prone areas.
  - Implementing water-saving technologies in agriculture and industry.
  - Restoring and protecting wetland.
  - Planting forests.
- Measures to increase sustainability : to reduce negative effects of climate change in water resources by:
  - Increasing resilience of effected areas.
  - Replacing crops that need less moisture, and salt-resistant ones.
  - Constructing dams and reservoirs where required, and transforming floodplains for agriculture.

Some innovative ideas and new technologies for sustainable water resources management under extreme conditions like floods and drought as below:

#### Floods:

- AI-Powered Flood Prediction: Use machine learning models (e.g., Flood Forecasting Initiative) to analyse rainfall, river levels, and urban runoff for precise, hyper-local flood warnings.
- Smart Flood Barriers: Deploy modular, self-activating barriers that automatically rise with water levels, protecting infrastructure without permanent walls.
- Drone Mapping: Utilize drones with LiDAR to monitor flood-prone areas in real-time, aiding rapid response and damage assessment.
- Implementing advanced green roofs with IoT sensors to optimize water retention and reduce urban runoff during heavy rains.
- Blockchain for Aid Distribution: Using blockchain to ensure transparent, efficient delivery of emergency water and supplies to flood-affected communities.

#### **Droughts:**

- <u>Drought and Water Scarcity</u>: In regions experiencing chronic drought, innovative techniques like rainwater harvesting and wastewater recycling can be used to ensure sustainable supplies.
- Atmospheric Water Generators: Deploying solar-powered devices (like Zero Mass Water's SOURCE) to extract drinking water from air humidity, ideal for arid regions.
- Nanotech Filtration: Using graphene-based membranes for ultra-efficient desalination and wastewater recycling, cutting energy costs significantly.
- Smart Irrigation Systems: Integrating IoT-enabled drip irrigation with soil moisture sensors and weather forecasts to minimize water waste in agriculture.
- Synthetic Biology: Exploring bioengineered microbes that enhance soil water retention, boosting crop resilience during droughts.
- Digital Water Platforms: Using Al-driven platforms to optimize water allocation across cities, farms, and industries in real-time.



#### Infrastructure for sustainable water resources under extreme conditions;

Infrastructure plays a pivotal role in ensuring water sustainability, especially when faced with challenges like droughts, floods, or climate-induced variability. Effective systems must be resilient, adaptable, and efficient.

#### Key aspects of water infrastructure tailored to extreme conditions:

**1. Groundwater Recharge Systems**: In flood-prone areas, the focus should be on sustainable storage strategies such as enhancing groundwater recharge, hence, capture surplus surface water and direct it into aquifers to replenish groundwater reserves. In drought-prone areas, managed aquifer recharge that uses injection wells or infiltration basins to store water underground, protecting it from evaporation. During floods, these systems prevent waterlogging by channelling excess runoff.

2. **Dams and Reservoirs**: Store water during periods of excess (e.g., heavy rainfall or floods) for use during shortages. Modern designs incorporate adjustable spillways and sediment management systems to handle erratic weather patterns.



3. <u>Pipelines and Distribution Networks</u>: Transport water efficiently from source to demand areas. Leak-proof, durable pipelines reduce losses in arid regions where every drop counts. Smart monitoring systems with sensors detect leaks or pressure changes in real-time, critical during water scarcity. In flood zones, elevated or reinforced pipelines withstand inundation.

4. <u>Desalination Plants</u>: Convert seawater into freshwater for coastal regions facing freshwater shortages. Energy-efficient reverse osmosis plants, often powered by solar or wind energy, provide a reliable water source during droughts.

5. <u>Wastewater Treatment and Reuse Facilities</u>: Recycle used water for agricultural, industrial, or even potable use. Advanced treatment plants using membrane bioreactors or UV purification can operate under constrained water availability, turning wastewater into a resource. In flood scenarios, decentralized systems prevent overload and contamination.

6. <u>Green Infrastructure</u>: Use natural systems to manage water sustainably. Rain gardens, permeable pavements, and urban wetlands absorb excess water during floods and filter it for reuse, while reducing runoff. In dry climates, bioswales and retention ponds capture rare rainfall effectively.



# **Sustainable Flood Management**

- As the floods has great effects on different aspects of life and environment, <u>integrated flood</u> <u>management is essential</u>
- Flood management should include;
  - Floodplain management (prevention activities, and environmental activities),
  - Response activities,
  - Recovery activities.



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#### **Pre-Flood Actions (Prevention and Mitigation):**

- **Risk Assessment**: Map flood-prone areas using historical data, topography, and climate models to identify vulnerable zones.
- Flood-Resilient Infrastructure : Build and maintain flood defences like levees, dams, floodwalls, and retention basins to control water flow.
- Natural Barriers: Emergency Water Storage: Use temporary reservoirs to capture floodwater for later use.
- **Drainage Systems**: Upgrade stormwater drains, culverts, and canals to handle heavy rainfall and prevent backups. Restore wetlands and mangroves to absorb excess water and mitigate flooding.
- Early Warning Systems: Install sensors, river gauges, and weather monitoring tools to predict floods and issue timely alerts.
- Land Use Regulation: Enforce zoning laws to limit development in floodplains and preserve natural buffers like wetlands or forests that absorb water.
- **Public Awareness**: Run campaigns to teach residents about flood risks, evacuation routes, and emergency contacts.

#### **During-Flood Actions (Response):**

- Activate Emergency Plans: Trigger coordinated response protocols involving police, and disaster agencies.
- Issue Alerts and Evacuations: Broadcast warnings and enforce mandatory evacuations in high-risk areas, setting up shelters for displaced people.
- **Control Water Flow**: Operate dams, sluice gates, or pumps to redirect or reduce water levels where possible.
- Rescue Operations: Deploy boats, helicopters, and trained teams to save stranded individuals and deliver supplies.
- **Traffic Management**: Close flooded roads, redirect traffic, and set up barricades to prevent people from entering dangerous zones.
- Utility Oversight: Shut down or monitor power grids, gas lines, and water systems to minimize hazards like electrocution or contamination.
- **Real-Time Monitoring**: Track flood progression with drones, satellites, or ground reports to adjust response efforts dynamically.

#### Post-Flood Actions (Recovery and Assessment):

- **Damage Assessment**: Survey affected areas to evaluate infrastructure damage, economic losses, and environmental impact.
- **Debris Removal**: Clear roads, homes, and waterways of mud, wreckage, and hazardous materials to restore access and safety.
- Water and Health Safety: Test and treat drinking water supplies; distribute clean water and medical aid to prevent disease outbreaks.
- Infrastructure Repair: Rebuild or reinforce roads, bridges, levees, and utilities, prioritizing critical systems like hospitals and power plants.
- Financial Aid: Provide grants, loans, or relief funds to affected residents, businesses, and farmers.
- **Review and Adapt**: Analyze what worked or failed during the flood response to update plans, improve defences, or adjust policies for future events.
- Environmental Cleanup: Address contamination from sewage, chemicals, or oil spills to restore ecosystems and farmland.



# **Drought Management**

# Identifying the vulnerability to drought and improving resilience can be carried out through:

- Drought forecasting by using predictive models to plan water rationing and crop adjustments.
- Preparation for both future droughts and climate change <u>by practicing and promoting water conservation</u> and enhancing water efficiency throughout landscapes, city plans, and water infrastructure.
- Identifying alternative water supplies, creating drought emergency plans, and encouraging farmers to plant drought-resistant crops.
- Recycling and reuse by expand wastewater treatment for irrigation and industrial use.
- Groundwater management by regulating aquifer use and recharge through artificial infiltration.
- Public Engagement by launching campaigns to encourage voluntary water-saving behaviours.
- Deploying green infrastructure for stormwater management, and increasing energy efficiency in buildings by using less power from plants that rely on water to function, and using renewable energy like solar, that isn't reliant on water, to improve resilience to drought as a co-benefit.

# **Conclusions**

Water resources face significant challenges due to climate change and extreme conditions such as severe droughts, floods, and climate change effects. These factors affect water availability and distribution, making sustainable management critical, hence;

- Sustainable water resources management involves balancing the use and conservation of water to meet current and future needs while protecting ecosystems.
- Sustainability must include a whole range of aspects on various spatial and time scales, where water should be always; available, save, and secure.
- Infrastructure plays a pivotal role in ensuring water sustainability, especially when faced with challenges like droughts, floods, or climate-induced variability. Effective systems must be resilient, adaptable, and efficient.
- Emphasis needs to be given to development of infrastructure, regulation of water uses, assessment and management of both surface and groundwater resources, in parallel with new discoveries.
- The Government should develop regional water strategies to help adapting any future changes in water resources. These strategies should consider the climate change modelling with understanding how water resources might be impacted by climate change.

- There should be water supply and demand management strategies, considering extreme conditions and climate change affects.
- Long-term water supply strategies planning should be adopted to account for reduced water availability during low rain periods or droughts.
- Climate change adaptation should include both risk prevention measures and measures that increase the climate resilience.
- Floods has great effects on different aspects of life and the environment, hence, integrated flood management\_is essential. Floodplain management should include; prevention and environmental activities, response activities, and recovery activities.
- Designing storm water infrastructure to withstand the higher rainfall and storm events, during flood times, which are expected due to climate change, is essential.
- Ultimately, maintaining water resources under extreme conditions requires a blend of technological innovation, effective policies, and international cooperation to ensure water availability for future generations.





# THANK YOU

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