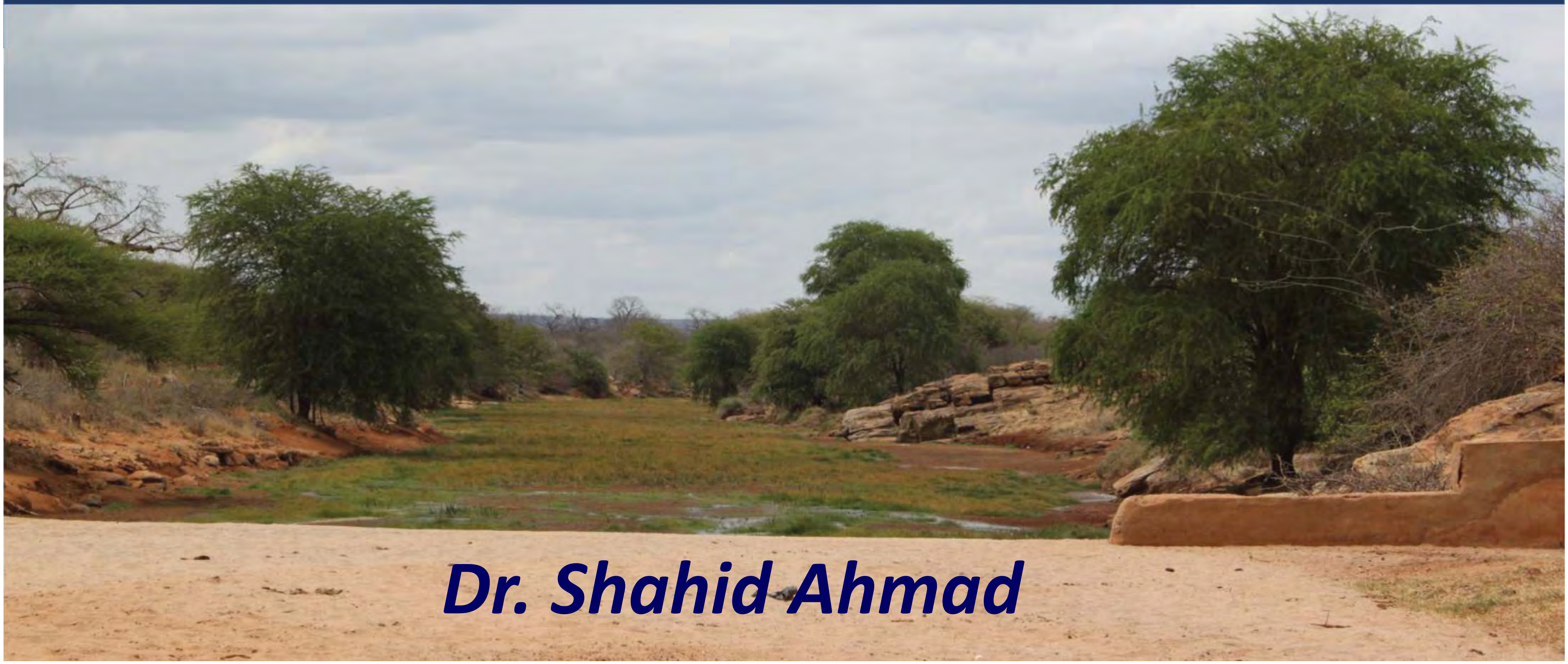
Alternative Concepts of Water Storage in Spate Ecology of Pakistan



Dr. Shahid Ahmad

META

Spate Irrigation Network Pakistan

Spate Irrigation Network

THE WORLD BANK
Working for a World Free of Poverty

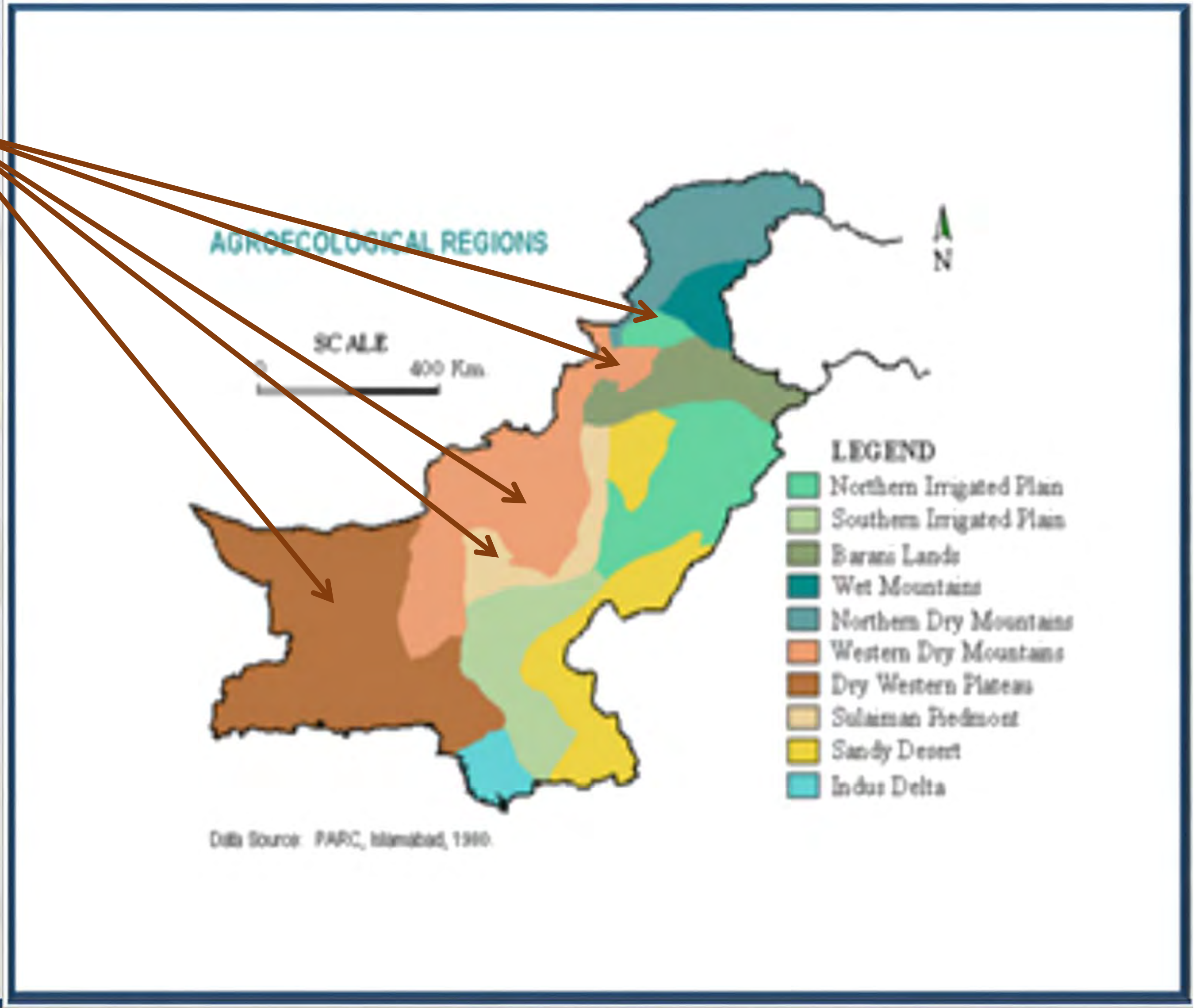
IFAD
Enabling poor rural people to overcome poverty

UNESCO-IHE
Institute for Water Education

Situational Analysis and Challenges

Agro-Ecological Regions of Pakistan

Spate Ecologies of Pakistan



Agro-ecological Regions having Scope for Storage in Spate Ecology

- **Indus delta**
- **Southern irrigated plain**
- **Sandy deserts**
- **Northern irrigated plain**
- **Barani lands**
- **Wet mountains**
- **Northern dry mountains**
- **Western dry mountains**
- **Dry western plateau**
- **Sulaiman piedmont**

ICOLD Classification of Dams

- 143 dams >15 m high are large dams
- Mangla and Tarbela are major dams of >100 m high
- Large dams between 15 to 100 m are:
  - AJK - 4 dams
  - Balochistan - 67 dams
  - KP - 9 dams
  - Punjab - 50 dams
- 32 dams >15 m high are under construction or in planning phase.
- WAPDA and provincial Irrigation Departments are responsible for constructing dams of over 15 m

Objectives of the Study

"Develop and promote alternative concepts for dam development on ephemeral rivers using innovative ideas of managing floodwater and sediments to maintain hydrological equilibrium".

Activities

- Review of projects – covering sedimentation, groundwater recharge, flood management and changes to river morphology, present/potential benefits of current uses
- Overview of best national and international practices and propose cost-effective alternatives
- Innovative options of underground geo-synthetic barriers in a cascade to enhance recharge and reduce peak and prolong duration of flood
- Conduct case studies of small dams and develop strategy for integrated watershed management, reservoir operation, command area development and Spate irrigation

Situational Analysis

- **Selection of Site**
- **Planning Dam and Command Area**
- **Design of Dam, Irrigation Network and Command Area**
- **Lack of Watershed Management**
- **In-adequate Utilization of Storage Water for Aquatic Food Resources**
- **Lack of Integration of Small Dams with Spate Irrigation**

Situational Analysis

- **Slow Development from Barani and Spate Farming to Perennial Irrigated Agriculture**
- **Low Productivity of Water/Non-remunerative Agriculture**
- **Forgone Benefits from Multiple Uses of Water – Freshwater Fisheries**
- **Limited Operation and Maintenance Budget**

Water Scarcity and Need for Storage

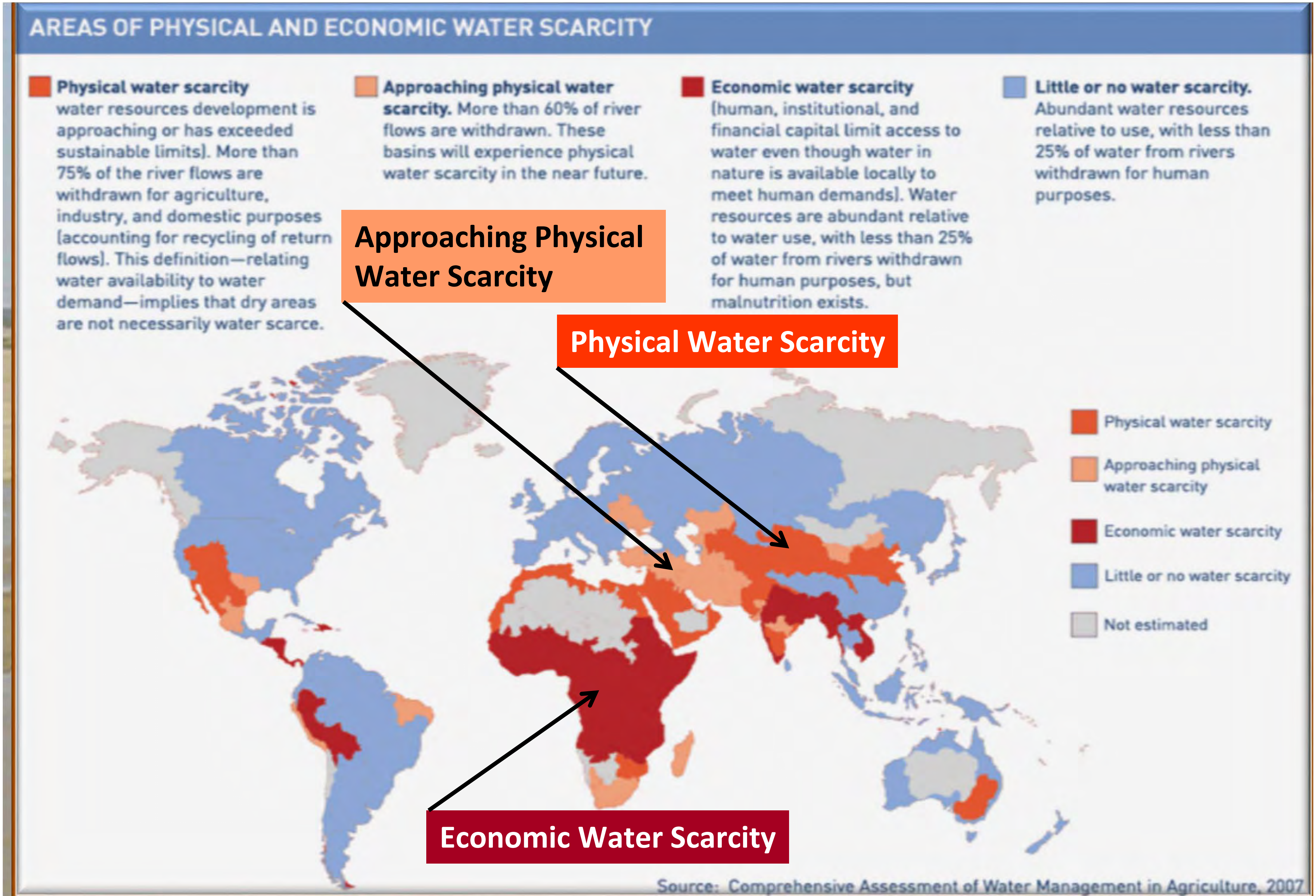
- Common ways of storing water in:
  - soil profile – Short-term storage
  - Aquifers – Long-term storage
  - Reservoirs – Medium/Long-term storage
- Hydrological, operational, and economic aspects of last two options
- Environmental aspects are location specific and complex

Water Scarcity and Need for Storage

- aquifers and reservoirs all serve an indispensable role in water storage, and each technology has strong comparative advantages under specific conditions of time and place
- where it is possible to do so, substantial gains can be achieved by combining the two storage technologies in an integrated fashion

Water Scarcity and Need for Storage

- Shortage of freshwater storage
- If climate change manifests, need for freshwater storage will become even more acute
- Increasing storage through a combination of groundwater and reservoirs is critical to meet water requirement of the 21st century
- Essential for sub-humid to arid environments of Pakistan


AREAS OF PHYSICAL AND ECONOMIC WATER SCARCITY
Physical water scarcity water resources development is approaching or has exceeded sustainable limits). More than 75% of the river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.
Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
Approaching Physical Water Scarcity
Physical Water Scarcity
Economic Water Scarcity
Physical water scarcity
Approaching physical water scarcity
Economic water scarcity
Little or no water scarcity
Not estimated
Source: Comprehensive Assessment of Water Management in Agriculture, 2007

Challenges

- Two schools of thoughts
- First supports storage of water for water scarcity and taking advantage of climate change over-emphasize storages
- Second is promoting indigenous water harvesting systems like Spate irrigation, rainfed farming and runoff farming, in addition to groundwater recharge.
- Groundwater recharge is common to both. First promotes it as an outcome of inefficient irrigation – and brought definition of global water efficiency

Challenges

- Second promotes groundwater as a designed intervention and not as an inefficiency leading to waterlogging and taken it as recharge
- Analysis of small/medium dams indicated:
  - economic returns were much lower than expected and benefits were foregone due to lack of full development of command area
  - inflow of heavy sediments into reservoirs
  - Many conflicts among upper and lower riparian on water rights and allocations

Productive and Water Secure Spate and Barani Farming Systems

- Landscaping watershed for production of fuelwood, pastures, arid fruits, etc.
- Aquaculture in reservoir including reservoir fisheries, cage fish production on the periphery of reservoir, aquatic food and flower plants, etc.
- High value and high efficiency irrigated agriculture in command area

Productive and Water Secure Spate and Barani Farming Systems

- Provision of floodwater to left-over Spate farmers whose lands will not fall in command area, such developments have to be an integral part of small dams
- Farmers' cooperatives and involvement of corporate sector in provision of services related to high-efficiency and high-value agriculture and aquaculture

Alternative Concepts for Augmenting and Managing Water

Case Studies of Innovative Water Storages in Spate Ecologies

- **Shebo Headworks and Water Tanks, Pishin, Balochistan, Pakistan**

- **Tanda Dam Off-Stream Storage, Kohat, Khyber Pakhtunkhwa**

Case Study of Shebo Headworks

- **Only weir-controlled gated water diversion and off-stream water storage system in ephemeral rivers since last 134 years**
- **Later developments are largely in a limited concept of on-stream storage dams**
- **Reduction in command area mainly due to deferred maintenance of water tanks and water conveyance. Even today 33% of command area is still cultivated. This reduction is also due to other lucrative livelihoods instead of agriculture i.e. smuggling**
- **Department of Agriculture could not introduce best practices for high efficiency and high value agriculture in command area and next generation is involved in other ways of livelihood**

Case Study of Shebo Headworks

- Concept of managing sediments through off-stream diversion and storage worked well over 134 years
- Future schemes be designed focusing water productivity instead of cropping intensity and/or command area
- System can be operated in a semi-perennial mode and development of command area is essential for efficient irrigation.
- Orchards' drip irrigation can be introduced with additional sand filters to eliminate sediments of stored water
- Ecology suitable for fruits and vegetables
- Need for conjunctive water use - floodwater, stored water and shallow groundwater

Case Study of Tanda Dam

- **Off-stream storage helped in managing inflow of sediment load**
- **Dam successfully worked for over 52 years and provides an excellent example of advantages of off-stream dams**
- **Cropping intensity is higher than designed and some farmers are getting cropping intensity of over 200%**
- **Higher cropping intensity is due to groundwater use, as the tail-end farmers are facing shortage of canal water**
- **Fisheries production is reasonable and Department auction contracts for fisheries. Fish fetch higher price due to freshwater fish of large size and of commercial varieties**

Case Study of Tanda dam

- Multi-purpose dam as it provides water for irrigation, hydropower, fisheries, and recharge to groundwater.
- Farmers have installed hundreds of dugwells or tubewells to meet their deficit in irrigation
- Farmers work in a cooperative manner and they tried their level best to resolve conflicts but there is a lack of formal FO. Farmers are not getting any support from line departments for enhancing their water productivity or adoption of high-efficiency and high-value agriculture.

Conclusion of Case Studies

- Shebo and Tanda are innovative options
- Excellent options for off-stream storages to avoid sedimentation in reservoir, groundwater recharge, fisheries and tourism
- Shabo provides an opportunity for developing off-stream water reservoirs in Spate ecologies. These sites can be used for trainings for development of integrated and innovative concepts of off-stream water storage and multiple uses of stored water
- Manage these as model sites because schemes constructed since 70s, for Spate irrigation or Barani farming were hardly sustainable

Sand Dams for Augmenting Groundwater and Creating New Aquifers

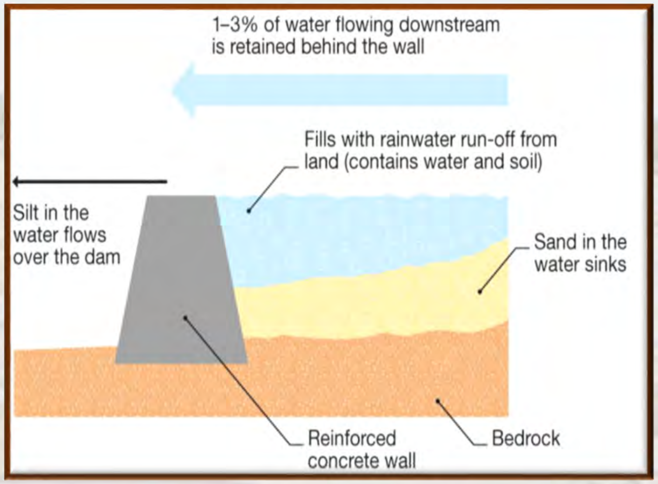
A Case Study of Sand Dams in Kenya

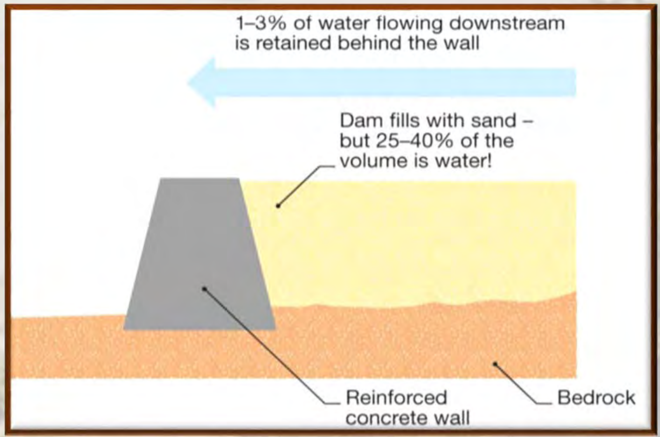
Sand dam is masonry or reinforced concrete wall built in seasonal riverbeds to capture and store water beneath sand, help in filtering and protecting stored water. Advisable to raise dam in phases so that only sand is deposited upstream, otherwise high dams would allow deposition of silt along with sand. It is a lowest-cost runoff or floodwater harvesting solution based on size of dam and storage capacity

A Case Study of Sand Dams in Kenya

Seasonal rains quickly fill the reservoir with water and sediments.

- **Sediments are characterised as clay, silt, sand and gravel.**
- **Gravel and heavier sand sinks behind the dam, whilst the lighter silt washes downstream and clay particles take longer time to settle – this is a common phenomenon in upstream where coarse materials deposit first and fines deposit later in downstream having low gradient**





Gravel and sand particles accumulate until reservoir is completely full of gravel and sand up to spillway

- **Water is stored within the sand making up 25-40% of the total volume of the reservoir based on the porosity of the fill material.**
- **The studies conducted in Kenya indicated that small sand dams store less than 10 million litres of water depending on the particle size of sand and size of the reservoir. In reality, the storage capacity of the reservoir would depend on the site-specific conditions, area and height of the dam.**

Benefits of Sand Dams

- **Reduce surface evaporation to a bare minimum as water stored in pore spaces**
- **Mix of gravel and sand also filters water, clean and protects it from parasite carriers (mosquitoes and snails)**
- **No growth of aquatic weeds - common in shallow reservoirs/ponds in Spate irrigation areas**
- **Storage of water in sand fill material reduces incidence of diseases in children of <5 years of age**

  - malaria and diarrhoea

Getting Water from Sand Dams

Sand Dams Improves Water Supply

- Sand dam creates a local, reliable, clean water supply system adequate for provision of water to few villages over a span of 50 years based on the Kenyan experience but it will vary from location to location and community demand
- Sand dam stores water in each season and recharges groundwater based on site-specificity and demand
- Water held below sand and evaporation is insignificant
- Provides enough water for people to drink, water their animals, and irrigate their high value vegetables and fruits.

Sand Dams Enable Food Production

- Sand dams save farmers 2-12 hours every day in Kenya. In Pakistan as women is involved in domestic water, stockwater and washing clothes so their time will be saved and drudgery is reduced from their daily life
- Time saved can be used for activities to initiate income generation activities

Sand Dams Benefit Health and Income

- Mosquitoes cannot breed in water stored in sand, thus reducing incidence of malaria. Water is stored under hygienic conditions in sand matrix so it reduces incidence of diarrhoea
- Snails carrying bilharzias virus cannot survive – dramatically reducing risk of diarrhoea
- Animals cannot contaminate water, which is a serious issue in surface ponds, where human and livestock drink from same pond and women wash clothes on banks and effluents are disposed back to pond.
- Sand dam is suitable and cost-effective option where surface water is used for drinking
- Income generated from marketing of produce

Impacts of Reliable and Clean Water Supply

- Diets improve as farmers have time to improve productivity and production; and diversify crops, especially input of vegetables in their diets add vitamins and minerals
- Incomes improve as people have time to spend on livelihoods.

Sand Dams Transform Environment

- Raise water table and provides sustainable adaptation for drought if cascade is built
- Bio-diversity improves, as trees and indigenous species are able to thrive.
- Very little amount of water flowing downstream is captured by sand dams meaning water is not diverted away from downstream users
- Sand dams reduce flood risks by reducing flood peak and spread duration of flood. It increases downstream sub-surface flow during dry seasons – creating added benefit for downstream users

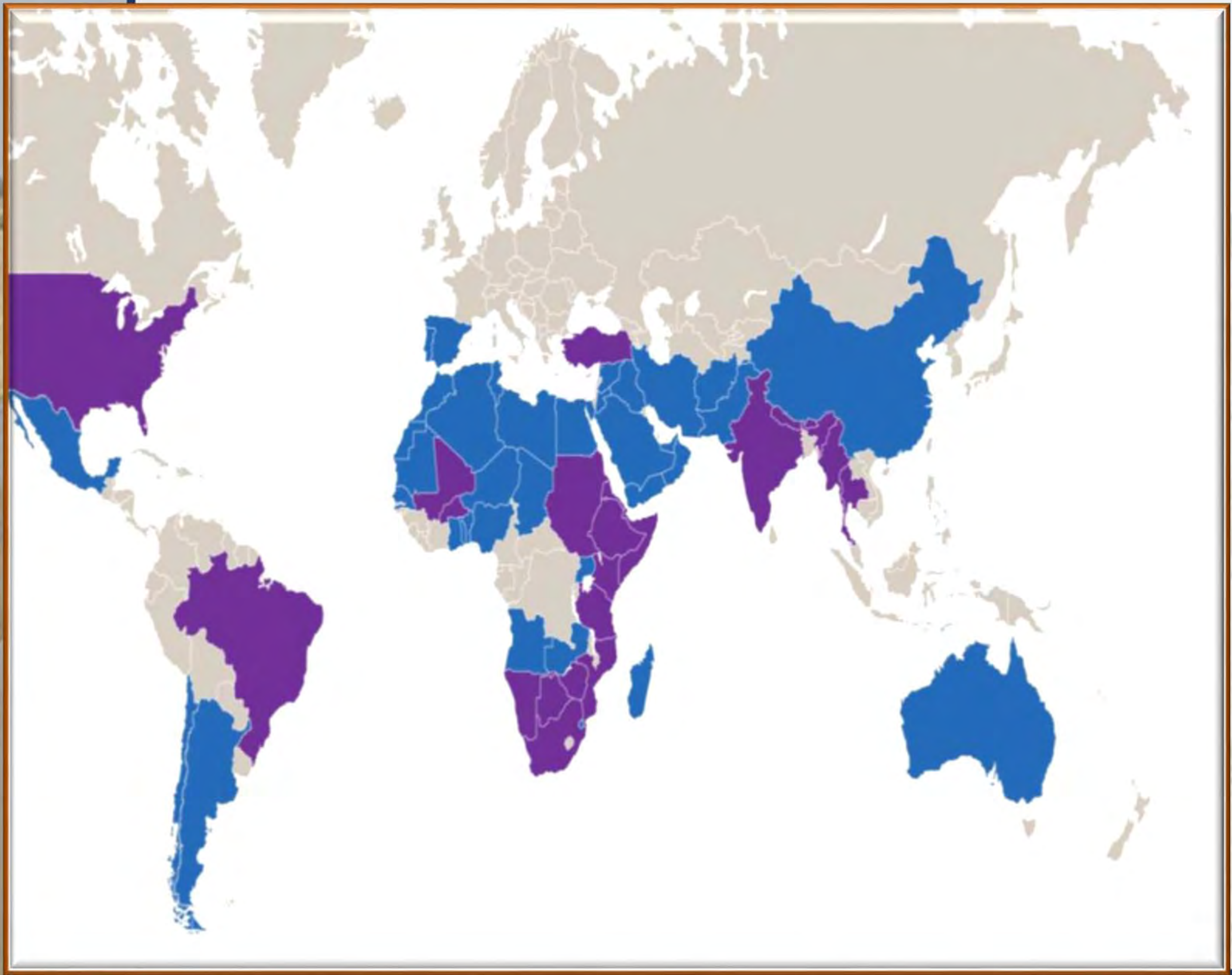
Sand Dam Offer Excellent Value for Money

- Sand dams are world's lowest-cost method of capturing floodwater in arid and semi-arid lands and for rural communities
- Sand dams recharge naturally every season Rabi or Kharif or with any rain storm contribute to runoff or floodwater, storing water year round
- Sand dams are built to last over 50 years with no operational costs and require little or no maintenance

Potential of Sand Dams

- 40% of world's land is classified as arid having no facility for irrigated agriculture
- 2.3 billion people live in arid lands
- 80% of world's poor rely on arid land resources
- 44% of world's food is produced in arid lands
- Sand dams can be built in places having seasonal rivers with sandy sediment, conditions that are found across the world
- In Pakistan these areas are located in provinces, FATA, AJK, ICT, GB, etc.
- Currently 150 sand dams are being built per year worldwide, mainly in Kenya. Excellent Development is committed to change this situation and interested to introduce this technology all around the world especially in arid regions

Potential of Sand Dams



Countries having Sand Dams

Countries having Potential of Sand Dams

How to Build a Sand Dam?

a. Community identifies 3 or more potential sites that meet their needs
b. Optimum site selected, design completed and materials quantified
c. Community collects rocks, sand and water and land above dam site terraced
d. Legal agreements with adjacent land owners signed
e. Excavation of river sediment to bedrock for building foundation of sand dam
f. Weathered rock removed and fissures sealed with mortar
g. Infiltration gallery constructed upstream of dam connected to piped outlet or pump
h. Timber formwork erected
i. Vertical steel reinforcement bars drilled into bedrock
j. Stone masonry (rocks bonded by sand and cement mortar placed in the formwork)
k. Horizontal lines of barbed wire every 30 cm binds the steel bars and rocks
l. Formwork removed after one day and dam watered morning and evening for 30 days to cure the cement

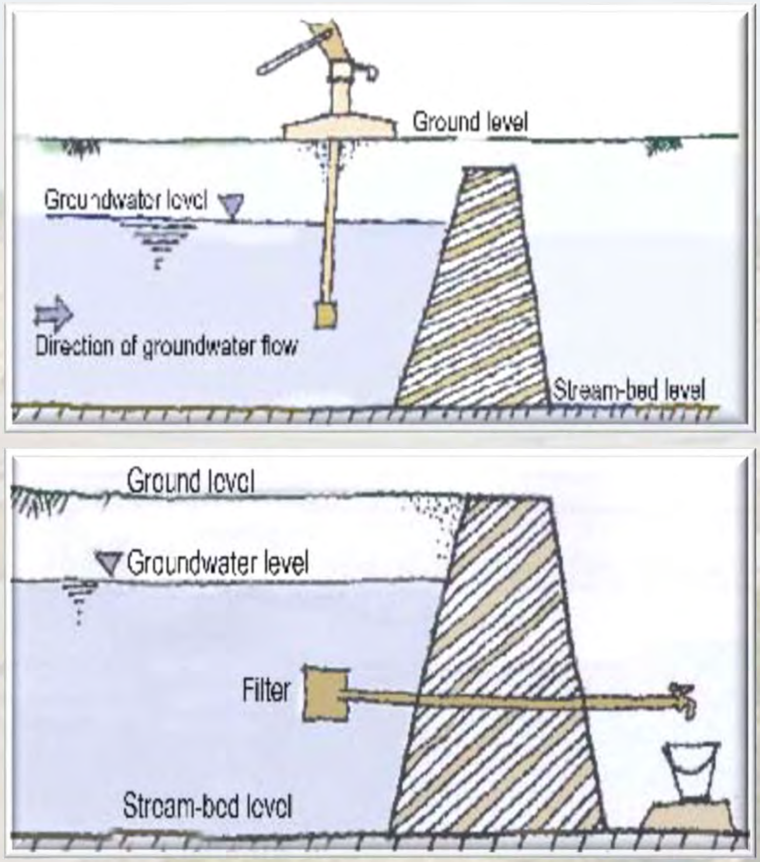
Findings of Sand Dams

- Environment-friendly, cost-effective and healthy for storing water
- Quality is reasonable for drinking and domestic uses
- Dugwell, low-discharge multi-filter pumping systems and infiltration galleries are essential part of sand dams
- In open ponds difficult to avoid infestation of aquatic weeds due to shallow depth of water and evaporation is significant
- Technology can be adapted to all sorts of topographic and hydrological conditions
- Insignificant O&M cost and users' organizations can easily managed systems
- Perform perfectly if bed rock is present at a depth of 5-10 m
- Sub-surface flow in dry season will contribute to recharge sand dam or natural aquifer.
- In absence of hard-rock barriers a Cascade of sand dams is effective in recharging groundwater.
- Support development of new shallow aquifers for multiple uses

Sub-surface Dams for Augmenting Groundwater and Creating New Aquifers

Sub-surface Dams

Sub-surface dams are structures that intercept or obstruct natural flow of groundwater and provide storage of groundwater. They have been used in several parts of the world, notably India, Africa and Brazil. They are used in areas where flows of groundwater vary considerably during course of year, from very high flows following rain to negligible flows during dry season.



Advantages of Sub-surface Dams

- Evaporation losses are much less as it is confined to upper layer of a sand reservoir
- Risk of contamination of stored water from surface is reduced because parasites cannot breed in underground water
- Contamination of water by insects and animals cannot take place because water is not visible at surface. Health hazards such as mosquito breeding are avoided.
- Problem of submergence of land is associated with surface dams
- Minimal social and ecosystem impacts
- No silting problems and do not suffer from reduction of storage space
- Absence of surface structures does not obstruct flow of water
- Allows migration and interaction of living creatures
- Increases capacity of traditional wells, simple and less expensive to construct, replicable and easily maintainable by community
- Causes less contamination of water and a temporary availability of water avoids attracting permanent human settlement

Dis-advantages of Sub-surface Dams

- Since utilization of stored groundwater in a sub-surface dam requires pumping, operating costs are higher than those of a surface dam. The size of voids between the solids of sand determines capacity of basin. When particle size is small, only 5% of water can be extracted. But surface dams may require pumping of water as in certain cases command area is at higher elevation
- Survey, design and construction processes require trained persons to avoid possible failures. Strict control of subsurface dam water is difficult because water can easily been stolen, simply by digging a well. To prevent such practices, agreements must be made on land use and economic activities in sub-surface dam reservoir area, and concerned parties must develop morals to protect water resource but it is also true in the surface dam.

Difference between Sand and Sub-surface dams

- Sand storage dams are used when topographical gradient is high and subsurface dams are used when topographical gradient is low
- An advantage of sub-surface dams over sand storage dams is their simple design. Water does not flow through dam and no spillway is needed. Unlike a sand storage dam, a subsurface dam is not exposed to forces of flowing water. It is clear that different circumstances ask for different solutions or combination of two technologies.

Abstracting Groundwater from Sand and Sub-surface Dams

Advantages of Dugwells

- High degree of involvement of local community during whole process of dugwell planning and construction
- Under supervision, not highly skilled workers are required because dugwell labour is already available and their rates are much higher than ordinary labour, as they charge per feet depth of digging in dry and aquifer zones, separately. The rates are also different if hard rock is there then they normally work on labour charge rates.
- Simple equipment sufficient for both construction and maintenance
- Low cost of O&M
- Involvement of local well diggers
- Use of locally available materials
- Yield can be increased by increasing diameter and depth of water column

Dis-advantages of Dugwells

- Long construction phase – labour intensive technology
- Danger of excavation where chances of well collapse and gases
- Pump is required to lower water table during construction phase
- Application restricted to regions with rather soft geological formation and relatively high groundwater levels or dry riverbeds
- Alteration of water level can adversely affect surrounding environment
- Weight of lining rings (concrete) up to 900 kg – difficult to handle under certain situations
- Dependence on water table fluctuations, shallow aquifers are susceptible to pollutants infiltrating from surface (e.g. leachate from pit latrines)
- Contamination in open dugwells likely to occur: mud, vegetation, animals, waste & use of buckets/ropes. There is a need for careful O&M. People (i.e. children) can fall into the well if it is uncovered
- Cost of digging is now much higher than drilling as skilled labour rates are much higher for digging in water and for hard rock formations. In Pakistan, now there is shortage of skilled manpower for digging of wells especially digging in difficult situations.

Infiltration Galleries for abstracting Storm Water

- **Infiltration structures designed to deliver captured runoff to subsoil through sub-surface reservoirs usually composed of rock or gravel**
- **Below grade infiltration structures can provide innovative storm water treatment in areas where space is limited.**
- **Ensure adequate infiltration rates**
- **Consider possible pollutant loads and include pre-treatment devices to help minimize maintenance cost.**
- **High flow bypasses be included in design. Infiltration galleries are appropriate as secondary treatment for runoff from impervious surfaces. Runoff discharged to groundwater is subject to maximum pollutant loads.**
- **Potential impacts of structural subgrade materials and possibility of surface instability caused by soil piping and/or slope destabilization.**

Hydrologic Landscape

- Spate irrigation in the context of a watershed covering catchment, water bodies and command area
- Need to integrate concept of landscape with hydrologic landscape
- Grasses, shrubs and trees of local species must be given due consideration in designing landscape.
- Watershed contributes to Spate flows for multiple uses.
- Landscape helps to avoid environmental pollution and degradation
- Flows are channelled into reservoirs or conveyed directly for Spate irrigation
- Water flow in Spate areas is a mud flow.
- Natural landscape is built on foundations of arid to semi-arid mountains devoid of vegetation and has to be protected to flourish wildlife and sustained ecosystem

Landscape of Fort Manro – Spate Ecology

Major Components of Water Storage in Spate Ecology

Integrated land Use for Small Dams

Watershed Area
- Fuelwood Plants
- Timber Plants
- Shrubs
- Fruit Plants
- Herbs
- Livestock

Reservoir
- Reservoir Fisheries
- Cage Fisheries
- Aquatic Food Plants
- Aquatic Flowers

Command Area
- Crops
- Vegetables
- Fruit Plants
- Timber Plants
- Livestock
- Tail-end Fisheries

Left-Over Spate Area
- Barley
- Coarse Grains
- Pulses
- Fuelwood Plants
- Livestock
- Forages

Strategy

- **Strategy - comprehensive, holistic and integrated**
- **Strategic goal - "Productive and Sustainable Spate Irrigation and Water Storage for Enhanced Livelihoods" covering watershed, reservoir, command area, and left-over farmers of Spate irrigation**
- **Concept of *"Justice to All"* has to be accepted for providing *"Fair Deal to all Users"* from different components of Spate irrigation and Water Storage**
- **Until everyone in local community has rights on water and livelihood investments made in water storage reservoirs will not provide targeted benefits**

Elements of Strategy

- Water storage in Spate irrigation should not be considered as an alternate rather as a complimentary intervention to bring reliability and sustainability
- Problems associated with in-stream water storage in terms of sustainability of storage due to heavy load of sediments, slow development of command area and foregone benefits and reservoir's fisheries, water conflicts among water users and O&M problems can be avoided by shifting to off-stream dams, sub-surface dams and sand storage dams
- Sub-surface and sand storage dams can help to generate new aquifers and to bring sustainability to Spate irrigation.
- Integrated options are not only sustainable, but are also cost-effective

Elements of Strategy

- Sub-surface and sand storage dams can contribute to develop new aquifers to provide sustainability for multiple water uses in Spate ecologies
- A cascade of sub-surface dams can help to create much more sustainable river basins and generate new livelihoods
- Groundwater in Spate irrigation is deep and of marginal to brackish in quality. Groundwater dams would help to create shallow aquifers of freshwater and provide healthy source of water for domestic, stockwater and agriculture.
- Creation of artificial aquifers in arid lands by constructing dams across non-perennial waterways.

Elements of Strategy

- Integrated approach is essential. Small dams have four components:
  - watershed area feeding inflows to reservoir
  - Reservoir
  - command area
  - left-over farmers of Spate irrigation lost their water rights in dry season and get water only when water flows from the spillway
- Consider four components while planning water entitlements of all farmers considering historic rights of land owners, landless, women and children and livestock.

Elements of Strategy

- Integrated land use covering crops, fruit/forest plants, shrubs, grasses, fisheries and livestock would increase livelihood and adapt to extreme events of droughts and floods expected to be more severe due to climate change.
- Forest plants, shrubs and grasses can survive in droughts and provide fuelwood and pastures
- Roots of forest plants and forage can extract water from deeper depths and can survive in droughts and provide livelihood to farmers and reduces chances of out-migration.
- Range plants and grasses can also tolerate ponding due to extreme floods