

Improving Water Productivity Helps Provide Food Security in Drylands

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Abstract: The article discusses background of water use in agriculture in the dry areas; the past, present and future projections of water scarcity in the dry regions. It highlights some of the latest debates, principles and terminologies used in the field of agricultural water management. And, finally discusses an ongoing project in the Indira Gandhi Nahar Pariyojana where these principles are being applied to improve the field- and irrigation scheme-scale water productivity of the farming systems.

Key words: Water scarcity, agricultural water management, blue and green water, IGNP.

Most of the 852 million poor people in the world live in the developing countries of Asia and Africa, more so in drylands/rainfed areas. These rainfed areas are hotbeds of poverty, malnutrition, water scarcity, severe land degradation and poor physical and social infrastructure. Though rainfed agriculture constitutes 80% of global agriculture and plays a crucial role in achieving food security, increasing water scarcity and climate change threaten to affect rainfed areas and their peoples owing to their vulnerability to drought during the crop-growing season. Current farmers' yields in rainfed areas are two to five-fold lower than achievable potential yields and that current rainwater-use efficiency is only 35-45% in most rainfed areas. Water used for food production in rainfed areas is almost three-fold higher than that used in irrigated systems.

An insight into the inventories of natural resources in rainfed regions shows a grim picture of water scarcity, fragile environments, drought and land degradation due to soil erosion by wind and water, low rainwater-use efficiency (35-45%), high population pressure, poverty, low investments in water-use efficiency (WUE) measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003a, b; Rockström *et al.*, 2007). These rainfed areas are prone to severe land degradation. Drought and land degradation are interlinked in a cause and effect relationship, and the two combined are the main causes of poverty in farm households.

This unholy nexus between drought, poverty and land degradation has to be broken to meet the Millennium Development Goal of halving the number of food-insecure poor by 2015. Reduction in the producing capacity of land due to wind and water erosion of soil, loss of soil humus, depletion of soil nutrients, secondary salinization, diminution and deterioration of vegetation cover as well as loss of biodiversity is referred to as land degradation. A global assessment of the extent and form of land degradation showed that 57% of the total area of drylands occurring in two major Asian countries, namely China (178.9 Mha) and India (108.6 Mha), are degraded (UNEP, 1997).

Increasing the productivity of water in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security. The argument for this statement is simple: by growing more food with less water, more water will be available for other sectors and human uses. Increasing productivity of water is particularly important where water is a scarce resource. Physical scarcity, when there is no additional water in a river basin to develop for further use, is common in an increasing number of either dry or intensively developed basins (IWMI, 2000). In these cases, it is likely that increasingly less water will be available for agriculture and that, to sustain production, increases in water productivity will be necessary. There are other important situations of scarcity. Economic scarcity describes a situation where there is

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water remaining in nature to be tapped for productive uses, but there is extreme difficulty in developing the infrastructure for this water for economic, political or environmental reasons (IWMI, 2000). A third common situation occurs when water and infrastructure are available and cultivation techniques are known and yet people do not have ready access to water. For example, a lack of water is often not the cause of a head-tail problem. As another example, poor people are excluded from infrastructural development and do not have equal access to the benefits available from a project. This management-induced scarcity has a variety of causes, including poor infrastructural development and maintenance but, often, it finds its roots in inappropriate or ill-functioning policies and institutions.

Water and Land Management during Last 50 years

The agricultural productivity has seen a rapid growth since the late 1950s due to new crop varieties, fertilizer use and expansion in irrigated agriculture. The world food production outstripped the population growth. However, there are regions of food insecurity. Of the 6.5 billion population today, about 850 million people face food insecurity. About 60% of them live in South Asia and sub-Saharan Africa. According to Molden (2007) and IFAD (2010), the number of food-insecure people in sub-Saharan Africa nearly doubled from 125 million in 1980 to 240 million in 2010. Food and crop demand is estimated to double in the next 50 years.

Since the late 1960s, agricultural land use has expanded by 20-25%, which has contributed to approximately 30% of the overall grain production growth during the period (FAO, 2002; Ramankutty *et al.*, 2002). The remaining yield outputs originated from intensification through yield increases per unit land area. However, the regional variation is large, as is the difference between irrigated and rainfed agriculture. In developing countries rainfed grain yields are on average 1.5 t ha^{-1} , compared with 3.1 t ha^{-1} for irrigated yields (Rosegrant *et al.*, 2002), and increase in production from rainfed agriculture has mainly originated from land expansion.

Trends are clearly different for different regions. With 99% rainfed production of main

cereals such as maize, millet and sorghum, the cultivated cereal area in sub-Saharan Africa has doubled since 1960, while the yield per unit of land has been nearly stagnant for these staple crops (FAOSTAT, 2005). In South Asia, there has been a major shift away from more drought-tolerant, low-yielding crops such as sorghum and millet, while wheat and maize has approximately doubled in area since 1961 (FAOSTAT, 2005). During the same period, the yield per unit of land for maize and wheat has more than doubled. For predominantly rainfed systems, maize crops per unit of land have nearly tripled and wheat more than doubled during the same time period.

World food demand, and thus the consumption of agricultural water, will continue to increase during the coming decades, even though the rate of population growth is declining. With a growing population, rising incomes, and changes in diets, food demand may grow by 70% to 90% by 2050. Without improvements in the efficiency of agricultural water use, crop water consumption would have to grow by the same order of magnitude. Competition between water for food production and water for other sectors will intensify, but food production will remain the largest water user worldwide. Because of urbanization, demand for water in domestic and industrial sectors is expected to grow by a factor of 2.2 by 2050. With the increasing scarcity of water, reuse of urban wastewater will become more important in water-short areas. Crop production for energy generation also is increasing in several areas, with potentially substantial implications for land and water use in agriculture. While major trade-offs will occur between all water using sectors, the trade-offs will be particularly pronounced between agriculture and the environment, the two largest water-demanding sectors. Climate change will further increase pressures on water resources management.

Food: A national security issue

In the 1950s and 1960s agricultural policy in many developing countries favored import substitution, with food security equated with national food self-sufficiency. Farm lobbies were strong, and protecting agriculture was considered necessary for ensuring national food security. Subsidized water and irrigation

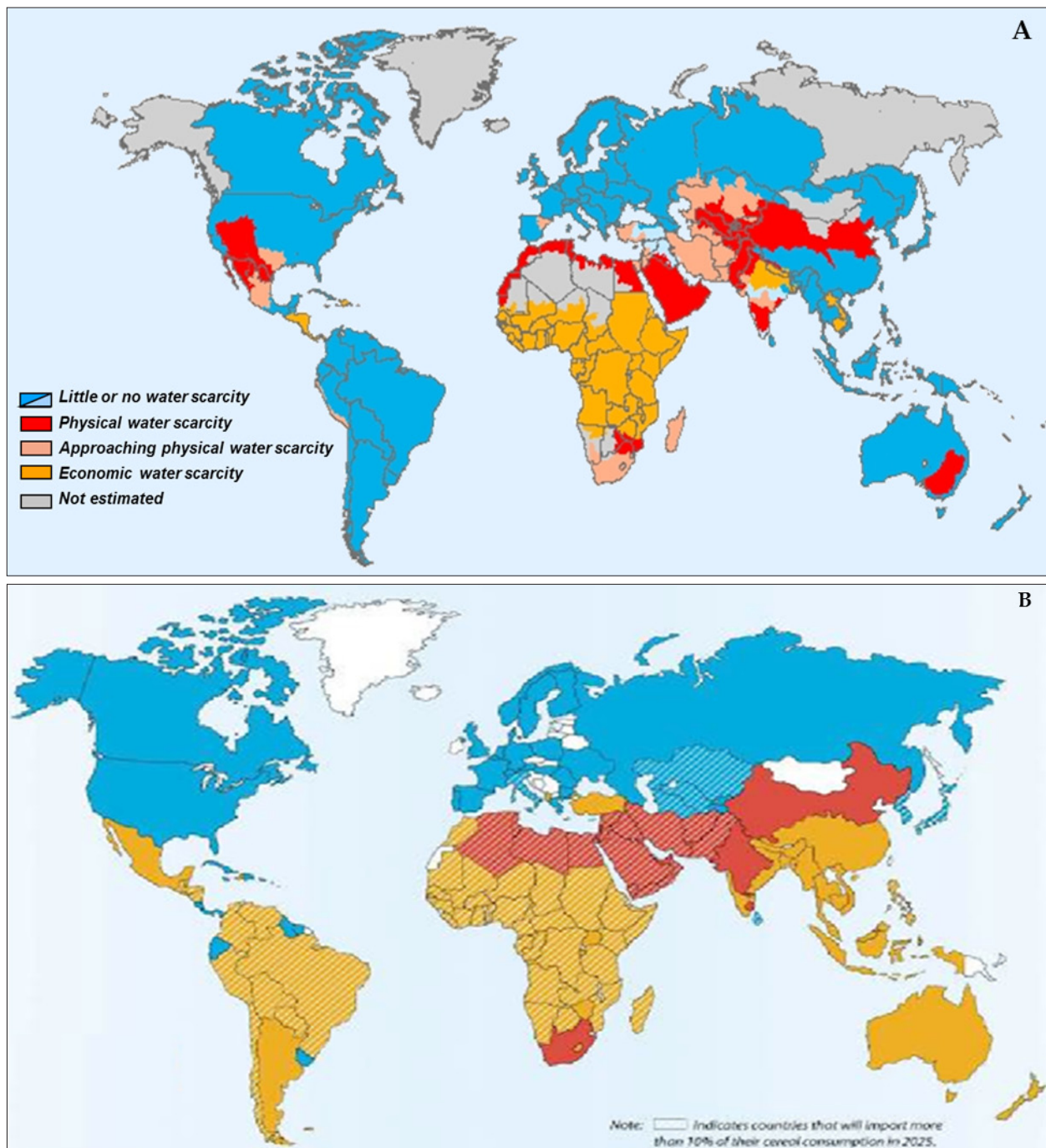


Fig. 1. Maps of (A) present and (B) projected water scarcity prepared by International Water Management Institute (IWMI) in 2000 (Source: IWMI, 2000).

infrastructure, marketing boards, tariffs, and input subsidies were viewed as necessary measures to promote food self-sufficiency and minimize the risk of famines (Molden *et al.*, 2001; Kikuchi *et al.*, 2001; Barker and Molles, 2004). The role of trade in domestic food supply was - and for most developing countries still is - modest. Expanded international food trade

can have significant impacts on national water demands. Allan (1998) coined the term "virtual water" to denote the water used to produce imported crops. By importing agricultural commodities, a country "saves" the amount of water it would have required to produce those commodities domestically. For example, Egypt, a highly water - stressed country, imported 8

million metric tons of grain from the United States in 2000. Producing that grain in Egypt would have required about 8.5 billion cubic meters of irrigation water - about one-sixth of Egypt's annual releases from Lake Nasser. Japan, a land-scarce country and the world's largest grain importer, would require an additional 30 billion cubic meters of irrigation water and rainfall to produce its food imports (de Fraiture *et al.*, 2004). Globally, cereal trade has a moderating impact on the demand for irrigation water, as four of the five major grain exporters (United States, Canada, France, and Argentina) produce grain in highly productive rainfed conditions. Without cereal trade global demand for irrigation water in 1995 would have been 11% higher (de Fraiture *et al.*, 2004; Oki *et al.*, 2003).

A key question for planners is how to improve food security and livelihoods for the most vulnerable people. Around 70% of the poor in sub-Saharan Africa and South Asia live in rural areas, with few options except to work in agriculture. For the near-to-medium term, the challenge will be to transform the agricultural economy in these regions from a source of poverty to an engine for economic growth. Hunger alleviation will require no less than a new green revolution during the next 30 years, particularly in sub-Saharan Africa. As stated by Conway (1997), the challenge is to achieve a green-green revolution, which compared with the first green revolution that lifted large parts of Asia out of an imminent hunger crisis in the 1960s and 1970s, will have to be founded on principles of environmental sustainability.

Water requirement for food security

Water productivity improvement can provide two pathways to poverty alleviation. First, targeted water interventions can enable poor and marginalized people to gain access to water and use it more effectively. Second, across-the-board increases in water productivity may benefit poor people through multiplier effects on food security, employment, and income.

Target techniques range from a combination of agronomic and water management practices to raise grain yields in high-potential areas, to strategies to increase the value per unit of scarce water, to strategies to reduce

vulnerability to drought, polluted water, or loss of water allocations. Most water productivity interventions can be tailored to benefit the poor. For example, efforts to reduce the cost of drip irrigation have made it affordable for smallholders (Postel *et al.*, 2001). Poverty alleviation efforts may drive water productivity gains in areas where access to water is difficult - in economically water-scarce areas. Interventions targeted to the rural poor can help them get the most out of limited water supplies. Examples include treadle pumps providing low-cost access, drip lines reducing the amount of water needed, and water bags for storage. With access to a little water and some precision technologies small-scale farmers can produce high-value crops such as vegetables and fruits. Microcredit and private commercial investments can help people use water. Access to markets is essential. Improvements in water productivity that indirectly increase food security and generate employment opportunities and income through multiplier effects can also reduce poverty.

As suggested by Falkenmark and Rockström (2004), there is a third green dimension to a new agricultural revolution, since the focus will have to be on upgrading rainfed agriculture, which entails increasing the use of the portion of rainfall that infiltrates the soil and is accessible by plants to generate vapor flow in support of biomass growth. This triply green revolution will require huge quantities of freshwater as vapor flow from the soil, through plants to the atmosphere. It raises the question of what eradicating hunger will in fact imply for water-resources planning and management.

Solutions based on Water Resource Management

Blue water and green water solutions

The conventional water-resource planning and management focus is on liquid water, or blue water. It served the needs of engineers who were involved in water supply and infrastructure projects quite well. However, the blue water that has dominated the water perceptions in the past only represents one-third of the real freshwater resource, the rainfall over the continents. Most rain flows back to the atmosphere as a vapor flow, dominated by consumptive water use by the vegetation. When analyzing food production, we therefore

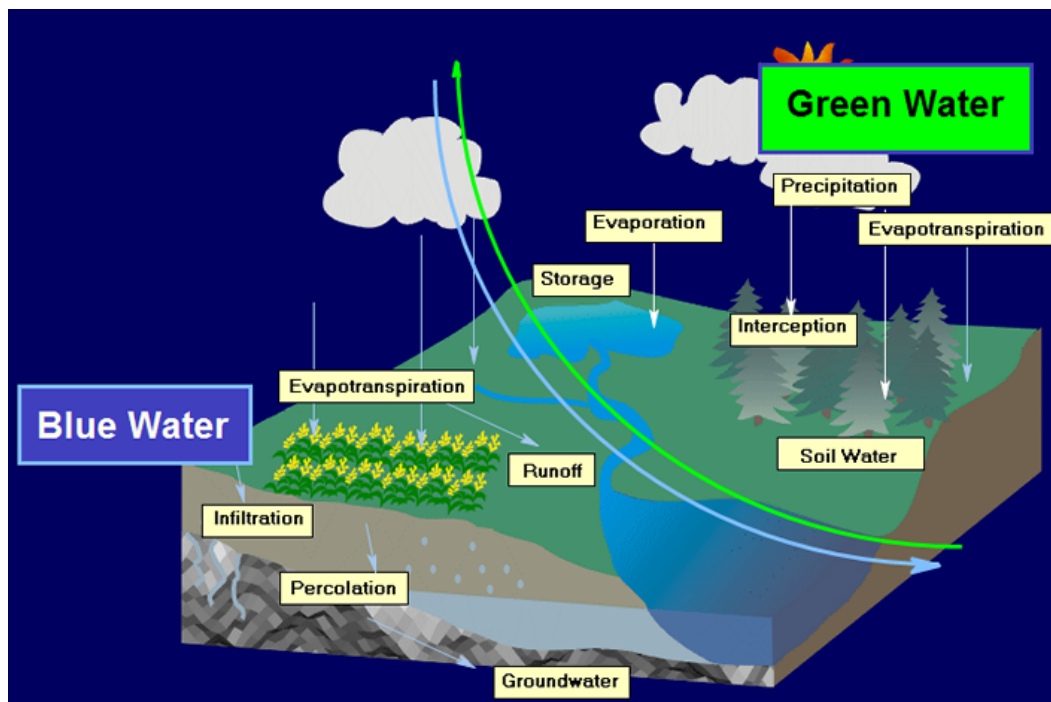


Fig. 2. Blue and green water cycle (source: virtual water, University of British Columbia, 2012).

need to incorporate a second form of water resource, the rainfall that naturally infiltrates into the soil and that is on its way back to the atmosphere. Figure 2 illustrates the new concept, distinguishing between two types of water resources—the blue water resource in aquifers, lakes, and dams, and the green water resource as moisture in the soil—and two complementary water flows—the liquid blue water flow through rivers and aquifers and the green vapor water flow back to the atmosphere.

Blue water represents about 35% and green water amounts to 65% of total precipitation mass. These proportions obviously vary with climate types. Whereas in a humid tropical forest with annual precipitations of 3600 mm, 50% is evapotranspired in the form of green water and there remains 1800 mm of blue water available, a semi-arid tropical savannah receiving 600 mm in annual precipitations evaporates about 500 mm of green water, which only leaves some 100 mm of blue water available.

Globally, about 80% of agricultural evapotranspiration is directly from green water, with the rest from blue water sources (Fig. 3). There is considerable variation between regions. Irrigation is relatively

important in Asia and North Africa, while rainfed agriculture dominates in sub-Saharan Africa. The implications of green and blue water use are quite different. Increased evapotranspiration from blue water sources reduces stream flow and groundwater levels. Increased evapotranspiration from green water sources is usually due to expansion of agricultural land area, a terrestrial impact, but has less impact on blue water flows. Still, any change in land use can affect river flows. In South Africa, recognition of the effects of “streamflow-reducing activities” has led to initiatives to control commercial forestry and to remove invasive tree species in order to reduce evapotranspiration and increase river flow (Hope, 2006). Global blue water withdrawals are estimated at 3830 cubic kilometers, 2664 cubic kilometers (70%) of which are for agriculture, including losses. The net evapotranspiration from irrigation is 1570 cubic kilometers, while the remainder of the 7130 cubic kilometers used is directly from rain. About 1000 cubic kilometers (25%-30%) of the 3,830 cubic kilometers withdrawn originate from groundwater, mostly for drinking purposes and irrigation. Groundwater levels are declining in areas of China, India, Mexico, Egypt, and other parts of North Africa, where dependence on groundwater for agriculture and population

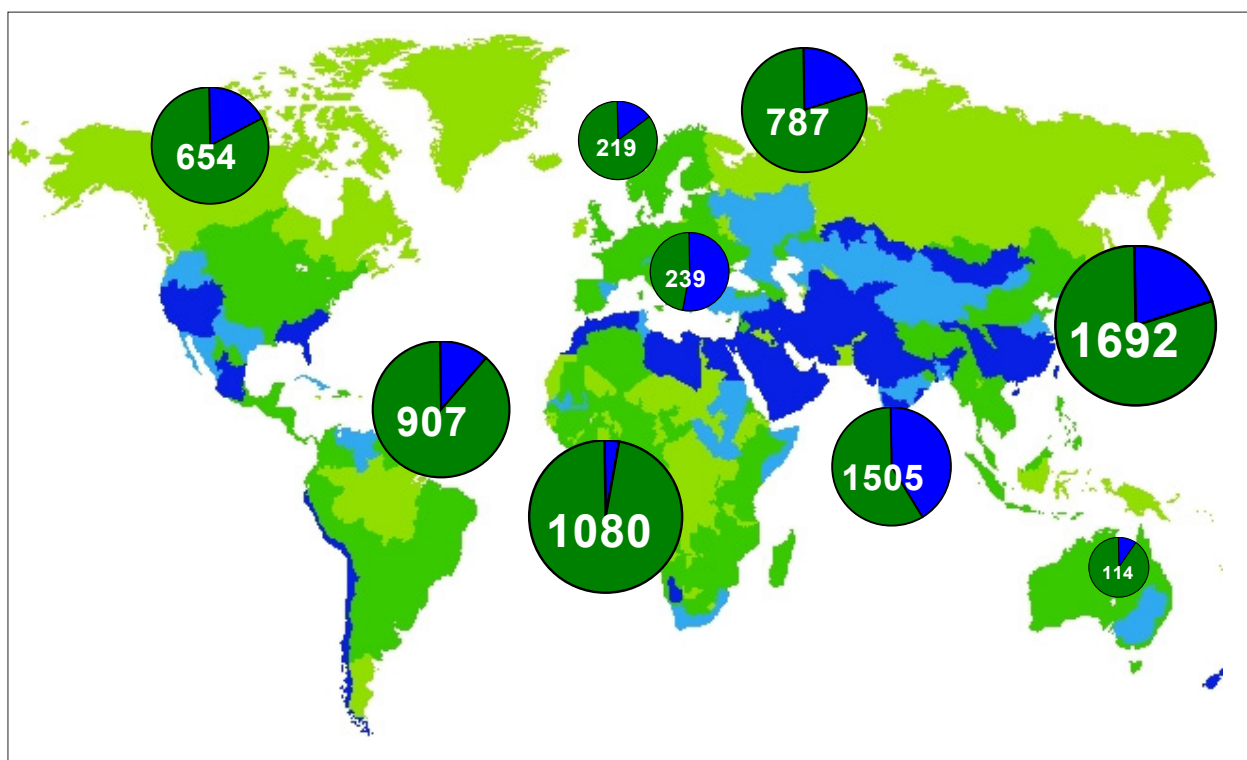


Fig. 3. Dependence on green and blue water (2000). Areas in green: Agriculture mainly under rainfed; areas in blue: Agriculture mainly under irrigation; circles depict total crop depletion.

demands are high. Demand for water for industrial and municipal uses, including for energy generation, is growing relative to demand for agriculture. As competition for water from these other sectors intensifies, agriculture can expect to receive a decreasing share of developed freshwater resources.

There is a range of agricultural water management options between purely rainfed and purely irrigated agriculture (Fig. 4). When proposing solutions, farming systems that rely fully on rainfall, those that use supplemental irrigation in combination with rainfall, and those that rely fully on abstracting and transporting surface water or groundwater directly to the fields (irrigation) need to be considered. These systems are categorized based on the relative reliance on green water sources (soil moisture) or blue water sources (groundwater, rivers, and lakes). Field conservation practices tend to conserve rain water on the field, while both groundwater and surface water irrigation have critical blue water components. Toward the middle of the continuum-supplemental irrigation, water harvesting, and groundwater irrigation - is where some of the most

interesting, but perhaps less explored solutions are found. These sources of water can be small or large scale, serving one or several people. Agricultural drainage (removal of water to create a favorable environment for agricultural production) is considered important for increasing productivity and sustainability for both rainfed and irrigated systems.

More crop per drop

Consideration of scales helps to untangle the 'which crop/which drop' problem. Water use and management in agriculture cross many scales: crops, fields, farms, delivery systems, basins, nations and the globe. Working with crops, we think of physiological processes: photosynthesis, nutrient uptake and water stress. At a field scale, processes of interest are different: nutrient application, water conserving soil-tillage practices, bunding of rice-fields, etc. When water is distributed in an irrigation system, important processes include allocation, distribution, conflict resolution and drainage. At the basin scale, allocation and distribution are again important, but to a variety of uses and users of water. At the national and international

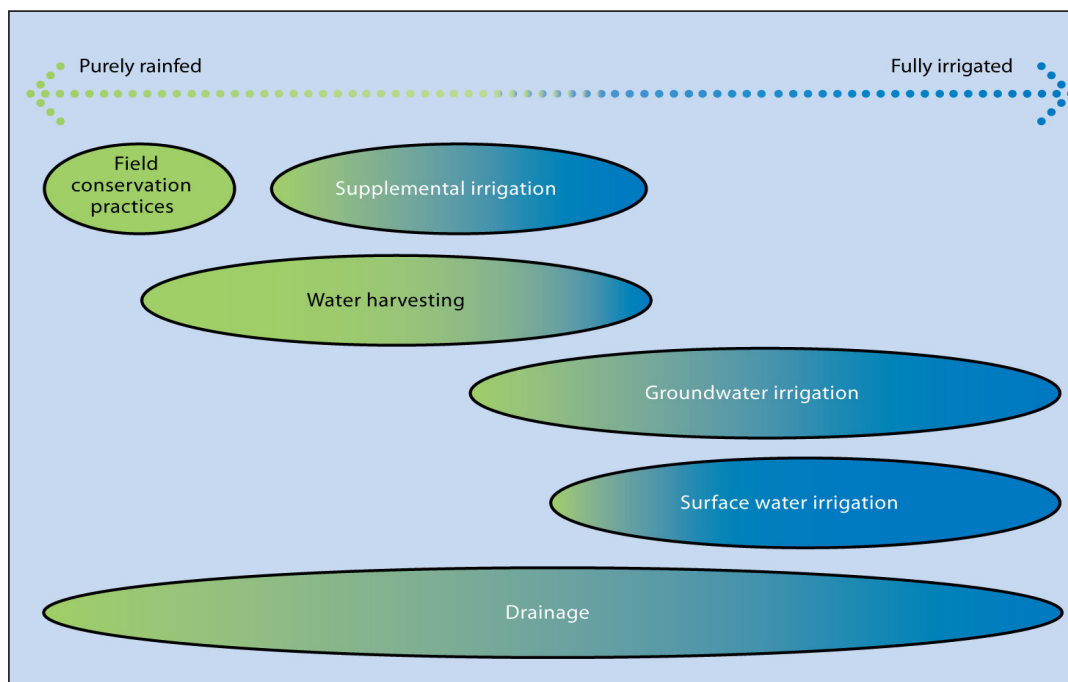


Fig. 4. Agricultural water management: A continuum of practices (Stockholm Environment Institute, 2008).

scale, trade, prices and virtual water all have relevance. Processes between scales are interlinked. For example, basin-scale allocation practices can set a constraint on how much water a farmer receives and the influence on farm water-management practices. Upgrading rainfed agriculture by means of improved on-farm water management can be a means to meet the future food demand.

Realizing the potential of existing rainfed areas reduces the need for new large-scale irrigation development, which can generate adverse environmental impacts. And the cost of upgrading rainfed areas is generally lower than the cost of constructing irrigation schemes, particularly in sub-Saharan Africa. Nevertheless, the potential contribution of rainfed agriculture to world food production is the subject of debate, and forecasts of the relative roles of irrigated and rainfed agriculture vary considerably. Adoption rates of water-harvesting techniques are low, and extending successful local techniques over larger areas has proven difficult in the past. Relying on rainfed agriculture also involves considerable risk. Water-harvesting techniques are useful for bridging short dry spells, and investments in water management are thus a way to decrease risk in rainfed agriculture.

But longer dry spells may lead to crop failure, and rainfed agriculture is generally more risky than fully irrigated agriculture. Upgrading rainfed agriculture through improved water management consists of: *In-situ* soil and water management and water harvesting techniques (conservation agriculture, bunds, terracing, contour cultivation, furrows, land leveling). *Ex-situ* water harvesting for supplemental irrigation (surface microdams, subsurface tanks, farm ponds). These measures are implemented primarily by farmers, without external interventions or detailed engineering analysis. The measures are less technology intensive, more labor intensive and environmentally less disruptive than conventional large-scale irrigation. Some of these measures might be considered as irrigation by some observers. However, it is a continuum of partially irrigated areas between the extremes of areas completely dependent on rainfall and areas that are fully irrigated (Rockström, 2003).

Improving land and water productivity in the Indira Gandhi Nahar Pariyojana

As an example of application of above mentioned concepts in an area of interest to the readers, here we describe a project on improving land and water productivity jointly being implemented by Regional Research

Station, Bikaner of Central Arid Zone Research Institute (CAZRI), and International Center for Agricultural Research in the Dry Areas (ICARDA).

The Indira Gandhi Nahar Pariyojana (IGNP) is an enormous multi-purpose irrigation and settlement project, implementation of which started in the late 1960s. The goal was to transport and use over 10^6 billion cubic meter of water annually, withdrawn from the Ravi-Beas River in the north of India, for large-scale irrigation in Rajasthan. The aim of project stage I, commenced in 1974, was to provide water for irrigation of about 553,000 ha area in the north of Rajasthan (India). This had been achieved in 2000. Stage II followed in 1980 and was completed only in the last decade, with the aim to add another 1.41 Mha of semi-arid and range-land/desert area in north-west Rajasthan, south of the stage I area. Therefore, water of the Ravi-Beas River system has been diverted from Harike barrage in Punjab through a 204 km long Indira Gandhi Feeder Canal (no off-takes) into the 445 km long Indira Gandhi Main Canal (IGMC) at Masitawali head works (Fig. 5). The water allowance is $0.0371 \text{ m}^3/\text{sec}$, which is equal to 3.2 mm day^{-1} . The intensity of irrigation was envisaged at 110% with 60% in the winter season (November-April) and 50% in the summer, monsoon season (July-October). At farm level, the water is distributed through a warabandi system. The mean annual (summer) rainfall is 297 mm and the potential evaporation 1500-1600 mm, suggesting water deficits during the whole year including the monsoon months.

Nature of the Problem

Implementation and management of the IGNP had been largely successful. Over the years several million people migrated into the region and were able not only to maintain their own livelihoods, but also to produce food surpluses. However, ever since the inception of the IGNP, challenges-partly natural, partly anthropogenic-arose.

The problems can broadly be divided according to the two stages of the IGNP project:

Partly due to edaphic conditions (sandy-loams or loamy sands in the north and sandy soils the south of Rajasthan), partly because of major differences in irrigation water availability

Stage I	Stage II
Low water productivity	Low land as well as water productivity
Water logging and salinity	Unreliable water supply
Low irrigation efficiency	Yield variability from year-to-year
Wind erosion	Wind erosion
Low nutrient-use efficiency	Low water and nutrient holding capacity of sandy soils

(abundant in the north, scarce in the south), the cropping systems of stage I and stage II command area are quite different. Stage I is characterized by flood or furrow-irrigated cropping systems with rotations such as wheat-cotton-wheat or mustard/chickpea-cluster bean-mustard/chickpea. Part of the croplands has been created by leveling the sand dunes; sand is sometimes spread over the land that get more and more enriched with lighter textured soil due to siltation from sediment-rich irrigation waters, to improve soil physical properties (infiltration, aeration). The stage I area nowadays is intensively cropped. Problems farmers encounter are low water productivity due to poor management of irrigation water, and, in depression areas, water logging and secondary soil salinization. Subsequently, also irrigation and nutrient-use efficiency is low.

Stage II, on the other hand, is characterized by sand dunes which have been stabilized with shrubs and trees (rather than leveling them), and interdunal plains where agriculture is practiced. Given the fact that water is scarce in this area - partly because of the overuse in the stage I area upstream - and prevailing soils are sandy (with infiltration rates too high for rational irrigation by furrows), the government started subsidizing modern irrigation techniques such as (micro-) sprinklers and drip irrigation systems. The idea is to promote efficient management of water by large-scale adoption of pressurized irrigation systems. This, however, requires water storage structures and access to at least moderately reliable source of water, and energy; which may cause problems in areas where these conditions are absent. Moreover, the sandy soils have a low water and nutrient holding/retention capacity. Wind erosion during summertime also at times covers the croplands with sand from neighboring dunes if only poorly stabilized, damaging or burying crops and severely affecting harvest.

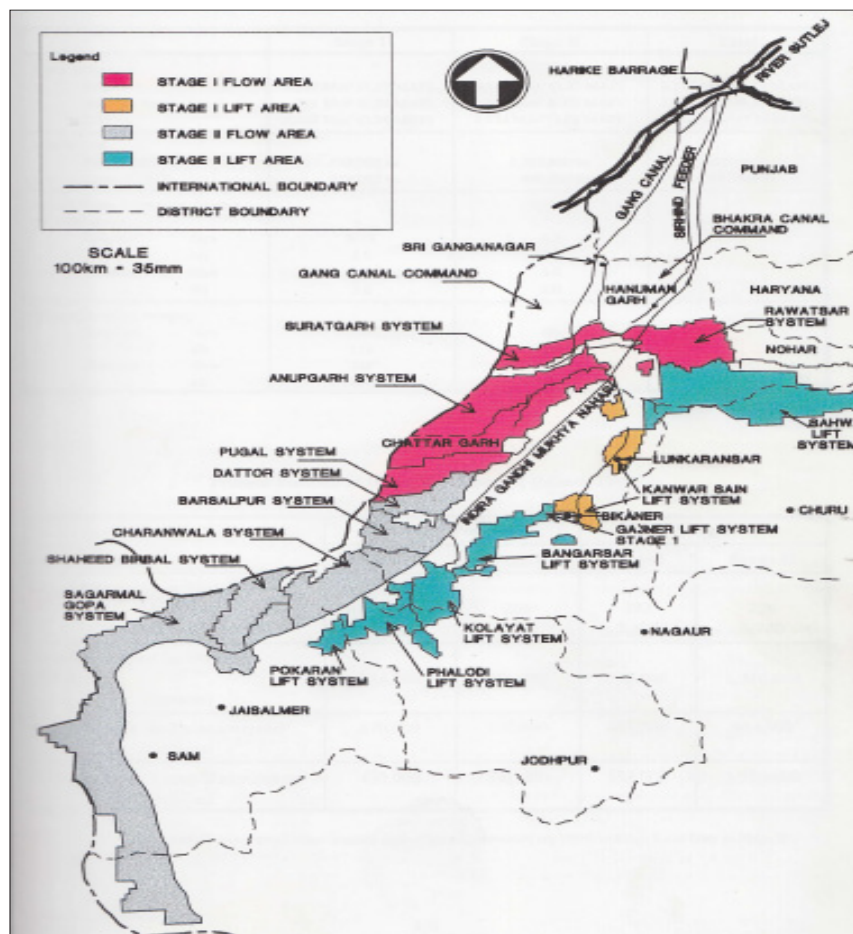


Fig. 5. Layout of Indira Gandhi Nahar Pariyojana (IGNP).

The objective of this study is to improve water and land productivity through better water management, appropriate cropping patterns and optimal cultural practices.

Methodology

The project targets stages I and II command areas of IGNP. Some of the outlined problems require field-level interventions and others are irrigation scheme problems and need to be addressed using interventions at that very scale. Therefore, we apply biophysical simulation models to understand the existing soil-water balance, movement of salts, fluctuations of groundwater, crop growth characteristics, etc. On the one hand, this will be a cropping system model for field-level modeling, and in parallel a scheme-scale model for the assessment of the irrigation and drainage system.

Following this, these models are applied to study the effectiveness of various intervention measures such as supplemental irrigation,

land management, optimization of irrigation scheduling, subsurface drainage and others for solving problems such as low irrigation efficiency, low nutrient-use efficiency, water logging, low land and water productivity, etc.

Expected Outputs

At the field-scale (stage II), the study of inputs and outputs of different crops will help us calculate physical and economic water productivity of different cropping systems. Furthermore, by simulating scenarios under which we change the irrigation scheduling (depth and frequency), fertilizer management, crop rotations, and other management options that are within the control of the farmer, we will be able to develop a matrix of economic and physical water productivity values under different combinations of management practices. These will lead to a set of recommendations on suitable water and crop management options to improve field-scale water productivity (kg/m^3 as well as Rupees/m^3). At the scheme-

scale (stage I), overall physical and economic productivity of the scheme is the objective. So, we target to maximize physical and economic water productivity as well as maintain equity between farmers. Here, we want to reduce the dependence on blue water resource (surface irrigation) without penalizing the productivity and income of the farmers in the scheme. So, we simulate scenarios under which all farmers will be able to maximize their incomes by optimizing the interaction between their inputs (water, fertilizers, pesticides, etc.). Also, we rank the popular cropping systems according to their economic and water productivity values to check which cropping systems maximize income and minimize non-beneficial loss of water. This exercise will lead to a set of recommendations for alternative delivery and drainage options to improve irrigation scheme-scale water productivity (kg/m³ released from the source), reduce groundwater rise and salinity build-up.

Conclusions

In the drylands, precipitation is generally lower than potential evaporation, non-uniform in distribution, resulting in frequent drought periods during the crop growing season, and usually comes in intense bursts, resulting in surface runoff and uncontrolled rill and gully erosion. Precipitation is less than 300 mm, part of which is lost to evaporation and runoff. The amount stored in the root zone is well below crop water requirements. In dry (semi-arid) tropical areas, such as the Sahel zone in Africa, although mean precipitation is relatively higher (500 mm), a larger portion of precipitation is lost to evaporation.

Growing enough food to feed the growing population of the drylands with an ever-shrinking share of water and without adversely affecting the environment is a major challenge for the drylands agriculture sector in the 21st century. Expansion of blue water by increasing irrigated areas through diversion of rivers and aquifers is not an option anymore. So, is expansion of green water usage by increasing rainfed croplands, through conversion of natural areas to arable lands, except in some part of Africa. The only option available to the planners is to improve the water productivity – grow more crop per drop of water. Improving water productivity come at a cost and improving it is a good option provided benefits outweigh

the cost of improving it. Locations where crop productivity and water-use efficiency are very low, it makes sense to promote improving water productivity since it not only leads to higher profits for the farmers, but also spares more water for other users of it such as environment, industry and downstream farmers.

We have to choose if we want to create additional storage structures for water in form of dams, reservoirs, cisterns etc. or if we want to leave it for the environment. If we want to give water to upstream users or downstream, if we want to promote equity or productivity of water, and finally if we want to consume ground water during this generation or leave it for the next.

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