Policy perspectives on agricultural water management and associated technologies suitable for different agro-climatic zones of West Bengal, India

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Agriculturally, West Bengal is one of the major productive states in India. It has made significant contributions to the gross state value added through agriculture and allied sectors, and water management is the most vital component to ensure stability and sustainability in agricultural production systems. There is increasing uncertainty in availability, or site-specific excess of water due to climate change. These call for strategic management of this important natural resource to achieve one of the Sustainable Development Goals (SDG No. 6) set by the United Nations, i.e. ensuring availability and sustainability in water management, and also providing sanitation to all by 2030. This eastern Indian state has six distinct agro-climatic zones (ACZs) based on its varied physiography, land, soil, weather, cropping pattern, vegetation and other characteristic features. Both water scarcity and water excess are intricately associated with the agricultural activities in the state, which demand integrated approach in the management of water resources and their efficient utilization. Here we elucidate the agricultural importance, distinctive features and constraints of six ACZs, provide an account of the water supply and demand, potential options to increase water-use efficiency, suitable technologies and zone-wise policy perspectives on water management in agriculture and allied sectors in West Bengal.

Keywords: Agricultural technology, agro-climatic zones, policy, water management, water-use efficiency.

IN 2015, all member countries of the United Nations (UN) had adopted 17 global goals, i.e. Sustainable Development Goals (SDGs) and called for urgent action. Among these goals, SDG No. 6 deals with water-related – issues ensuring its availability and sustainable management, including increasing efficiency of water use in agriculture and allied activities, reducing the gap between demand and actual withdrawal of freshwater, integrated management of water resources, restoring water-based ecosystems and above all reducing the sufferings of people due to water-related problems by 2030 (ref. 1). Water scarcity is a major concern as it affects about 40% of the world's population, and projection indicates its further rise in the future. One estimate by the UN mentions that about 1.7 billion people are living in different river basins, wherein water withdrawals exceed the recharge. Globally, about 70% of freshwater withdrawal is used for irrigation purposes; this water is abstracted from different water bodies like reservoirs, rivers, aquifers, lakes, etc. India is a member nation of the UN. The country has multiple problems related to water scarcity, excess and water-related disasters. Therefore, effective plans and policies should be framed by each Indian state to address the issues of water management in agriculture and allied sectors.

West Bengal, an eastern Indian state, has unique geographical features. It is located between 21°31′–27°41′N lat. and 85°91′–89°93′E long. The snow-capped peaks and the Himalaya in the north greatly influence the weather conditions of the North Bengal districts. The Tropic of Cancer runs across the middle of the state. The extreme south touches the Bay of Bengal (BoB). Profuse clouds with moisture-laden winds from the BoB bring early showers in the state and heavy rainfall during monsoon. The southern districts lie mostly within the equatorial region. The Sunderbans ('sundar ban' in Bengali, meaning beautiful forest) is a mangrove forest area in the delta of the southern region. The state shares its boundary with

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Sikkim and Bhutan in the north, Odisha in the south, Jharkhand and Bihar in the west and Assam in the north-east (Figure 1). There is an extensive network of rivers, tanks, reservoirs, canals and other water bodies. Majority of the land area consists of detritus and alluvial plains.

West Bengal with its diverse climate, mostly fertile soil, water and human resources has contributed significantly (8.21%) to the national value in agriculture and allied sectors, with only 3.7% of the net sown area in the country[2]. The share of West Bengal's gross value added (GVA) from agriculture, including crop and livestock sectors, accounts for 20.97% of the state's total GVA[2]. Agriculturally, the state is leading in its production of rice and jute, and considerable contribution to the production of total foodgrains, potato, pulses, oilseeds, horticultural crops, tea, milk, fish, egg and meat in the country (Table 1).

West Bengal – salient features and specificity of agro-climatic zones

Table 2 shows the salient features of the West Bengal with respect to its area under cultivation, water availability, irrigated area, etc. Overall, net irrigated area is about 64% of the net sown area, with cropping intensity of 188.5%. The surface and groundwater availability in total exceeds water demand, but its efficient management is necessary to bring more areas under irrigation for most of the crops. It is only 31.9% and 51.1% under pulses and rice respectively. The area under micro-irrigation (drip and sprinkler) is about 67,000 ha (Table 2), which is only 0.59% of the country's total micro-irrigated area, i.e. 11.42 m ha as on March 2019. As far as weather conditions are concerned, there exist variations in rainfall, temperature, relative humidity and altitude in different agro-climatic zones (ACZs). Farming systems and agricultural practices are influenced by seasonal variations of weather conditions, physiography and soil in the state.

There are six ACZs in West Bengal: northern hill zone, Terai–Teesta alluvial, Gangetic alluvial, Vindhyan alluvial,

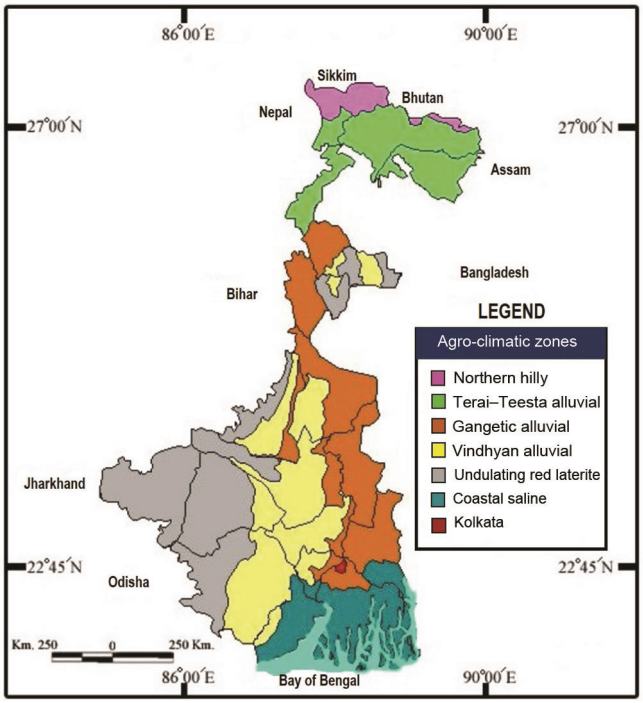

Figure 1. Map showing six different agro-climatic zones of West Bengal, India (source: ref. 33).

Table 1. Production of major crops, fish and livestock sector, and West Bengal's contribution to the all-India production (2018–19)

Production of crops and allied sectors	India (mt)	West Bengal (mt)	West Bengal's contribution to all-India production (%)
Total foodgrains	284.95	18.30	6.42
Rice	116.42	16.05	13.79
Total pulses	23.40	0.48	2.05
Total oilseeds	32.26	1.16	3.60
Jute and mesta	9.77	7.69	78.71
Horticultural crops	313.85	34.32	10.94
Potato	53.03	13.78	25.99
Tea	1.33	0.38	28.57
Milk	187.70	5.61	2.99
Fish	13.42	1.77	13.19
Meat	8.11	0.83	10.23
Egg (billion nos)	103.30	8.61	8.33

Source: Refs 2 and 34.

Table 2. Salient features of West Bengal on agricultural land, irrigated area and cropping intensity

Salient features/description	Value[#]
Total geographical area	88.75 lakh ha
Arable land/agricultural land/cultivable land/ culturable land	56.48 lakh ha
Net sown area	52.43 lakh ha
Total cropped area	98.81 lakh ha
Fallow lands, including current fallow	3.50 lakh ha
Cropping intensity	188.5%
Net irrigated area	33.52 lakh ha
Water availability (BCM)	
Surface water	132.905
Groundwater	27.580
Total	160.485
Water demand during 2015–16	90.54 billion m^3
Irrigated area under rice	51.1%
Irrigated area under pulses	31.9%
Irrigated area under total food grains	53.2%
Irrigated area for total area under all crops	64.0%
Irrigation potential under AIBP-all major and medium irrigation projects up to March 2019	1.475 lakh ha
Area under micro-irrigation as on March 2019 (ha)	
Drip irrigation	964
Sprinkler irrigation	65,723
Total	66,687

[#]Pertaining to the period 2015–16 (latest available). Data source: Ref. 2.
AIBP, Augmented irrigation benefit programme.

undulating red laterite and coastal saline zone (Figure 1). Each zone has its characteristic features and soil-related problems, which have been discussed in detail in the following sections.

Northern hill zone

This zone includes the districts of Darjeeling (except Siliguri sub-division), Kalimpong and the northern fringe of Jalpaiguri with a total area of 2.428 lakh ha. The zone extends from the top 3700 m down to the foothills at 60 m altitude, and is mostly under forest area intercepted by terraced land available for cultivation with plantation and field crops. The average rainfall varies between 2500 and 3500 mm. The temperature during winter is considerably low; it often reaches around 0°C in higher altitudes; bright sunshine hour is also considerably low due to cloudy weather. Soils are known as brown forest soil and mostly coarse in texture. These soils are porous and shallow in depth with poor water-holding capacity. Soil reaction is moderate to strongly acidic (pH 4.2–5.8); organic matter content though high is not well-decomposed, and the rate of mineralization is very low due to low temperature. Available soil P and K contents are medium to low. Soils are generally low in Ca and Mg and also low in micronutrients.

Due to peculiar physiographic conditions of the zone, about 30% of the land is available for cultivation and the scope of extending the same is limited. On the other hand, due to uncontrolled deforestation, there has been widespread soil erosion resulting in landslides every year, affecting general agriculture of the hills to a considerable extent. The coarse-textured soils of the hills are highly susceptible to erosion due to heavy rainfall and steep slopes. In spite of moderately good fertility status of the soils, crop performance is poor due to shallow soil depth, high acidity, low temperature and insufficient sunshine hours.

Terai–Teesta alluvial zone

This zone consists of the Siliguri sub-division of Darjeeling district, Jalpaiguri, Alipurduar, Coochbehar and North Dinajpur (Figure 1). It covers an area of about 2.149 lakh ha. Alluvium has been formed by deposits brought down from the Himalayan range by the rivers Teesta, Mahananda, Torsa, Jaldhaka and others. Annual rainfall is in the range 2000–3500 mm. Heavy rainfall often cause floods; about 20% of the land in this zone is chronically flood-affected and inundated annually. Sometimes floods occur 2–3 times in the same rainy season. In many areas, coarse sands are deposited on the cultivated lands making those almost barren for the next few years. Soils are mostly sandy to sandy loam, porous and greyish black. They are moderate to strongly acidic (pH 4–6) as a consequence of leaching of bases due to heavy rainfall. Organic matter content is medium to high and sometimes raw humus-type. Available soil P and K is low to medium; P-fixation capacity is high. Considerable area is affected by Al toxicity, especially in strong acid soils. Ca and Mg and some of the important micro-nutrients are deficient.

Apart from these constraints, there are a number of other problems such as soil erosion due to heavy rainfall and frequent flash floods. This has been aggravated by indiscriminate falling trees in the forest areas of the northern Terai region near the foothills. As the monsoon showers start from March, double cropping is common even under rainfed conditions from March to December. The productivity of the soil is generally low, but there is ample scope for improving the same by soil amelioration with dolomite. The period from November to February is dry and cool.

Gangetic alluvial (new alluvial zone)

This is a non-saline alluvial region mostly in the northern and eastern parts of the River Ganga, comprising districts of South Dinajpur, Malda, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Hooghly, Howrah, East Burdwan and parts of Birbhum. It covers an area of about 15.304 lakh ha. Average rainfall varies between 1300 and 1600 mm; air temperature ranges from 26°C to 38°C in summer and 10°C to 26°C during winter. The topography is mostly flat. Soils are mostly neutral, and greyish in colour. In medium and lowland situations, the soils are heavy with a high percentage of clay. The fertility status of the soil is medium with respect to N and P, and rich in K and Ca. Zn is low and sometimes near the critical level in the high-pH calcareous soils of Nadia and Murshidabad. The area experiences floods during the rainy season due to inflow of water and excess run-off. About 10% of the area suffers from such calamity. Drainage and flood control works are as important as the development of irrigation.

The area is suitable for cultivation of all kinds of field and horticultural crops. Plantation crops are mango, litchi and mulberry. There is immense possibility to grow coconuts and a range of tropical and subtropical fruit crops in the region.

Vindhyan alluvial (old alluvial zone)

This zone is centrally located comprising the western part of Murshidabad and Hooghly, South Dinajpur, eastern part of Birbhum and Bankura, East Midnapur, central part of Burdwan and the northern part of Howrah (Figure 1). The soils are formed by deposits brought down mostly from the rivers Mayurakshi, Ajoy, Damodar, Darkeswar, Kangshabati and others originating from the eastern fringe

of the Vindhyan range. Total area is about 17.537 lakh ha under this zone. Average annual rainfall varies between 1300 mm and 1500 mm. The mean temperature varies from about 37°C (maximum) in summer to about 11°C (minimum) during winter. Maximum temperature, however, in some places, goes above 40°C. The land has flat to rolling topography. Fields are generally bunded in uplands and medium lands. The soils are light, medium and heavy in texture, with the uplands being lighter and medium and lowlands being heavier. Soil is acidic to neutral (pH 5–7); acid soils respond to liming. It is low to medium in organic matter and available P, while available K is low to high, and is highly responsive to applied fertilizers.

About 10% of the area is subject to floods, caused by impeded drainage and river overflows during the rainy season. High humidity, high temperature and cloudy weather conditions during *kharif* season favour pest and disease infestation. Rice is the major crop; other important crops are potato, jute, sugarcane, pulses, oilseeds and vegetables. One of the best potato belts in the whole India is located in this zone. There is immense scope for further increase in area under multiple cropping by the development of irrigation as well as drainage infrastructure accompanied by conjunctive use of both surface and groundwater.

Lateritic, red and gravelly undulating zone

This zone has laterite, red, gravelly and alluvial soils which occur in the districts of South Dinajpur, Malda, Birbhum, West Burdwan, Purulia, Bankura, West Midnapur, Jhargram Birbhum, Burdwan, Bankura, Purulia and Midnapur. There are also some pockets of red soils in the districts of Malda and west Dinajpur (Figure 1). Total area of this zone is approximately 24.842 lakh ha. Soils are highly coarse-textured and well-drained. Fe concretions are dispersed on the surface and honeycomb structures of oxides of Fe and Al are present in the subsurface or exposed in some eroded areas. The gravelly soils are mostly present in the Purulia district and parts of other western districts. The topography is undulating with numerous rivers and rivulets either passing through or originating in this tract; undulated areas with ridges and valleys represent the eastern fringe of the Vindhyan ranges, and are characterized by the presence of low hills like Ajodhya, Susunia and others. About 50–60% of the area is under highlands (locally known as tard or baid), 20–30% on medium land situation (locally kanaly) and 10–20% are on lowland situations (locally bahal). Upland soils are coarse-textured and may be strongly acidic (pH 4–5), poor in organic matter, available P, K and lime. Soils in the lowlands are fertile, whereas uplands are mostly deficient in available nutrients. Upland soils are highly susceptible to erosion.

Annual rainfall ranges from 1100 to 1300 mm, about 80% of which occurs during June to September, i.e. in the monsoon period. Even within this short period, rainfall may be unevenly distributed. The monsoon may commence early or late and may also retreat early. There is 20–30% probability of dry spells or rainfall breaks occurring within the season. Rice acreage is more than 90% of the area, and is subjected to erratic monsoon. It is the quantum of rainfall received during the transplantation, vegetative and reproductive stages of the crop and not the total rainfall that determines the type of harvest of the major rice crop. Partial or even total crop failure happens in rainfed conditions; drying up of water is a common phenomenon during dry and hot weather.

Coastal saline zone

This zone consists of the southern parts of North 24 Parganas, South 24 Parganas, Howrah, East Midnapur, and covers an area of 14.569 lakh ha. It also includes numerous islands of the Sundarbans. The area is criss-crossed by a large number of rivers, rivulets and natural cricks which are highly active due to tidal actions. Rainfall is also fairly heavy, and varies between 1500 mm and 1800 mm, mostly occurring during the monsoon. Inundation of saline water is common in the southern part of the coastal tracts. Soils are alluvial and generally saline with sporadic patches of saline alkali, non-saline alkali and acid saline. In general, pH varies from 6.5 to 8.5, but pH around 4 is also observed in some blocks, indicating the presence of acid sulphate soil with deep black colour. Soils are of fine texture, mostly silty clay, rich in Mg, K and organic matter in different stages of decomposition. Due to predominance of Mg, soils become hard and dry and get deflocculated when wet, resulting in impeded drainage condition.

This is primarily a mono-cropped area, with rice being the only field crop grown with monsoon rainfall. Improvement of drainage facilities and simultaneous land shaping with surface irrigation infrastructure will enable the farmers to grow modern varieties of rice during monsoon; crops like chillies, watermelon, sunflower, safflower, groundnut, sugarbeet and vegetables are grown with residual soil moisture during post-monsoon.

Water availability, water demand and water gap

Figure 2 and Table 3 depict surface and groundwater resources in different river basins and different districts of West Bengal. The rivers and basins have been conveniently grouped under four types based on origin of the rivers and terrain of their flow. These are: Himalayan and northern fan rivers, Plateau and western fan rivers, Ganga delta rivers, and coastal rivers and creeks. All rivers receive plenty of water during monsoon. Total water availability was about 160.35 billion cubic metre (BCM) according to the latest available data of 2015 (Table 3); out of which,

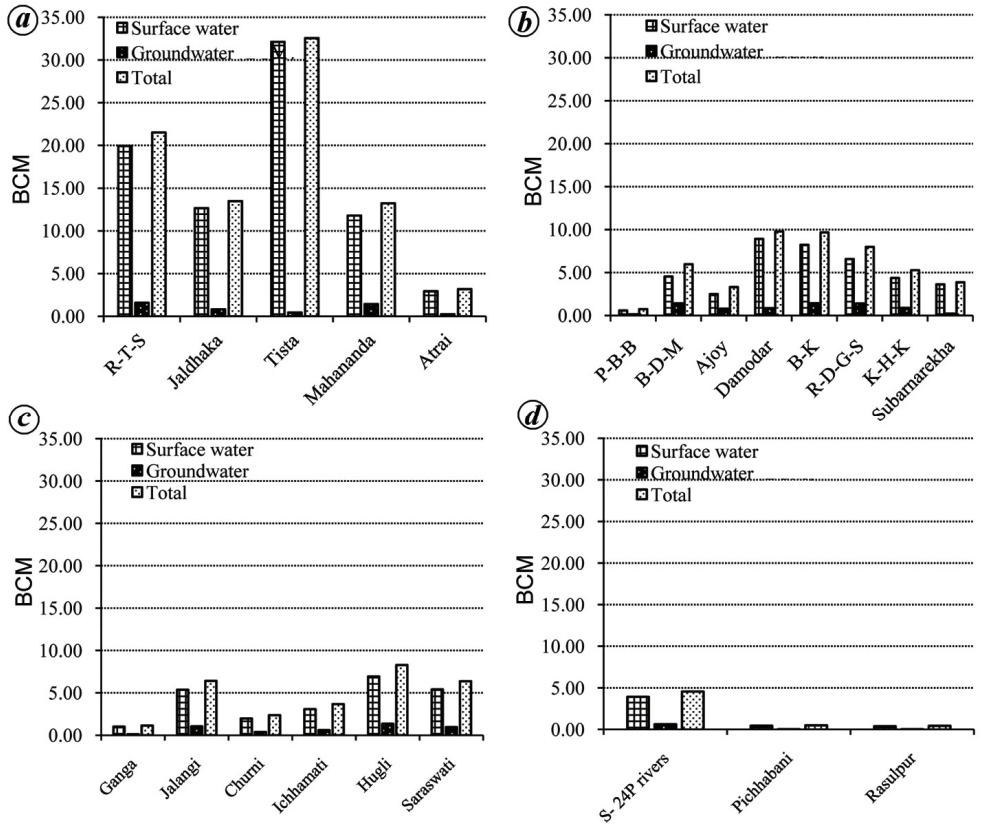

Figure 2. Surface and groundwater resources in West Bengal in different river basins: (***a***) Himalayan and northern fan rivers, (***b***) Plateau and western fan rivers, (***c***) Ganga delta rivers and (***d***) Coastal rivers and creeks. R–T–S, Raidak–Torsa–Sankosh; P–B–B, Pagla–Bansloi–Bagmari; B–D–M, Brahmani–Dwaraka–Mayurakshi; B–K, Banka–Kunti; R–D–G–S, Rupnarayan–Darakeshwar–Gandeswari–Silabati; K–H–K, Kansabati–Haldi–Kaliaghai; S-24P rivers, Sundarban and 24-Paraganas rivers (source: ref. 3).

Table 3. West Bengal: water availability, water demand and water gap

District	Existing water availability during 2015 (BCM)			Water demand (BCM)	Water gap (BCM)
	Surface water	Groundwater	Total		
Darjeeling	20.50	0.47	20.97	2.70	18.27
Coochbehar	14.74	2.10	16.84	4.57	12.27
Alipurduar	14.90	0.00	14.90	2.25	12.65
Jalpaiguri	17.28	2.37	19.65	3.72	15.93
North Dinajpur	5.85	1.62	7.47	4.00	3.47
South Dinajpur	1.79	0.99	2.78	4.24	–1.46
Maldah	4.52	1.31	5.83	5.18	0.65
Murshidabad	5.65	2.19	7.84	8.68	–0.84
Nadia	4.92	1.99	6.91	6.53	0.38
24 Paraganas–North	1.42	1.37	2.79	4.45	–1.66
Burdwan	6.31	3.06	9.37	4.94	4.43
Birbhum	4.23	1.47	5.70	5.08	0.62
Hooghly	5.24	1.50	6.74	5.95	0.79
Howrah	1.86	0.33	2.19	1.98	0.21
Midnapur–West	5.90	3.39	9.29	5.80	3.49
Bankura	5.41	1.95	7.36	4.65	2.71
Purulia	5.06	0.75	5.81	2.90	2.91
Midnapur–East	2.39	0.72	3.11	5.95	–2.84
24 Paraganas-South	4.80	0.00	4.80	6.97	–2.17
Total	132.77	27.58	160.35	90.54	69.81

Source: ref. 35.

surface water was 132.77 BCM and groundwater 27.58 BCM. While total demand was 90.54 BCM, water gap of 69.81 BCM is a positive gap, i.e. availability exceeds demand. The Himalayan and northern fan rivers have more water than the other river basins; consequently, the northern districts, viz. Darjeeling, Coochbehar, Alipurduar and Jalpaiguri have adequate water and higher positive gap. The other river basins and districts show that water availability is comparatively lower; thereby the water-gap is narrow and even negative in some districts. Disparity in the availability exists in different river basins and districts. Water stress occurs in the western and southeastern districts due to low water supply, especially during post-monsoon cropping. There is also a great demand for water for intensive farming and greater concentration of people in the southeast part of the state[3]. The water demand will continue to increase to achieve higher productivity of crops compared to their present level. Farmers will be required to harvest 2–3 crops in a year in an intensive cultivation system from the same piece of land to supply foodgrains, oilseeds, fruits and vegetables to meet the demands of a much larger population in the future.

It is also necessary to deal with natural calamities, viz. erratic monsoon rainfall, floods and droughts in West Bengal, i.e. both water plenty and water scarcity management is the need of the hour, and also in the future to achieve SDG 6. Flood-prone area is about 42.3% of the total geographic area in the state[4]. Frequent floods occur due to heavy downpour and inundation in low-lying basins, and silting in the riverbeds in the Sundarbans, Ganga and Subarnarekha basins. The state has about 3.5 lakh ha wetlands (8.5% of the national wetlands), including 54 natural and 9 man-made wetlands[4]. Strategy and policy should include infrastructure development for marine fisheries so that the wetlands are used for productive purposes to strengthen the economic conditions of farmers and provide environmental benefits in a sustainable manner.

Effective water management and associated technologies

Evidence-based options are available for effective water management in association with other relevant technologies related to land, soil and crop management. Sustainability as a whole will depend on the integration of effective options evolved over time. Water management issues are discussed and some adoptable technologies are suggested. In addition, viable technologies (Table 4) fit to different ACZs. These should be considered for developing an integrated water management policy framework for the state.

There are innumerable perennial streams, locally known as 'Jhora' in the northern hill zone, which can be harnessed and fruitfully used for irrigation. Maize, potato, ginger and vegetables are the main field crops grown on terraced lands. Rice and wheat are also grown at lower altitudes. Tea, orange, peach, apricot, cardamom, etc. are the plantation crops. Soybean and mushroom development may play a major role in improving nutrition of the hill people. Productivity of the soil can be considerably improved by adopting soil conservation measures, afforestation, 'jhora' control and scientific crop management practices. Along with development of agriculture and horticulture, due attention should be paid to the development of floriculture, orchids and animal husbandry.

There is abundant underground water at shallow depths in the Terai–Teesta alluvial zone, which can be tapped for *rabi*-summer irrigation. Along with the underground water development, if the Teesta water is made available for irrigation, a large area can be brought under successful double and triple cropping with adequate soil amelioration, balanced fertilization and scientific water management. Rice, wheat, pulses, oilseeds and other commercial crops are the major crops; tea, arecanut and pineapple are the important plantation crops. Quick drainage, flood relief operations, buffer storage of seeds and food articles are some of the important essential requisites to meet the contingent situations. Sand-laden area should be brought under afforestation programmes.

Groundwater potential is high and aquifer character is mostly unconfined under the Gangetic alluvial zone. Upland soils are lighter in texture containing higher proportions of fine sand and silt, facilitating infiltration and aquifer recharge. With the development of groundwater potential, a vast area under this zone can be brought under multiple cropping and with high-yielding varieties of cereals. The best wheat-growing tract in eastern India is located in this zone. There is a great possibility for extension of area under cultivation of potato and vegetables in the lighter soils. However, adequate storage and marketing facilities are essentially required for this.

There are three major river valley projects in the Vindhyan alluvial zone, viz. Mayurakshi, Damodar and Kangsabati, which supply irrigation water mostly during *kharif* season and partly during *rabi* season. Groundwater is also available for irrigation purpose, though there is further scope for its development. There are numerous tanks and natural reservoirs (locally called as beels) which can be utilized both for irrigation and fisheries.

Under the lateritic, red and gravelly undulating zone, irrigation facilities from Mayurakshi, Kangasbati, Ajoy, Damodar, Silabati and other small projects would facilitate multiple cropping with high yielding wheat, rice and maize. This would pave the way for an increasing water-use efficiency in irrigated areas. Systematic watershed management is necessary. The entire area may be divided into mini- and micro-watersheds with collaborative efforts of line department, viz. agriculture, minor and medium, forestry, fisheries, cooperative and panchayat. Intensive soil and water conservation measures are necessity. Soil amelioration should be practised using lime materials,

Table 4. List of effective water management and associated technologies for different agro-climatic zones of West Bengal

Agro-climatic zones	Area (lakh ha)	Water management and associated technologies
Northern hill zone Darjeeling (except Siliguri sub-division), Kalimpong and the northern fringe of Jalpaiguri	2.428	Harnessing of perennial water streams (locally known as *Jhora*) and adopting scientific crop management; setting up of water line from *Jhora* training and creation of secondary storage of natural water stream[5]. Excavation of rainwater-harvesting structures (reservoirs, farm ponds or tanks, check dams) and construction of community irrigation canal[6]. Micro-irrigation (drip and sprinkler irrigation) with the source from *Jhora* or from rainwater-harvesting structures for crops, viz. maize, potato and other field crops, vegetables, floriculture, orchids, etc. Alternate furrow irrigation for potato and vegetables; mulching for maize and other row crops[7,8]; staggered trenches across slopes for cardamom; mulching of tea with pruned litters; application of well-decomposed forest litter or neem cake for moisture retention in cardamom in case of dry spells, non-availability of irrigation water or soil moisture-deficit period. Irrigation during evening hours and draining out of water in the morning for wheat and other crops against frost damage, if any.
Terai-Teesta alluvial zone Siliguri sub-division of Darjeeling district, Jalpaiguri, Alipurduar, Coochbehar and North Dinajpur	2.149	Tapping of huge shallow groundwater and surface water for irrigation to *rabi*/summer-season crops[9]. Rainwater harvesting structures, viz. farm ponds and integrated farming systems; construction of check-dams to control soil erosion and facilitate storage of rainwater. Draining out of water from crop fields, viz. cabbage, cauliflower, brinjal, chilli, etc. in situations of heavy rainfall in a short span of time leading to waterlogging or flooding. Double transplanting of rice with aged seedlings in upland to medium and lowlands during continuous submergence[10]. In case of insufficient groundwater recharge due to low rainfall, using technologies in shallow tubewell irrigated farming situations, viz. SRI method for rice cultivation; supplemental irrigation through alternate furrows for potato/mustard/maize/vegetables; timely intercultural operation; zero-tillage for wheat; earthing-up of pineapple to provide anchorage. Supplemental irrigation with farm pond-water/other sources; alternate furrow irrigation for potato/mustard/vegetables; irrigation at critical growth stages of crops in case of seasonal dry spells. Direct seeding of rice using drum seeder in medium to highlands; staggered rice nursery[11]; inter-cultivation in jute in case of delayed onset of monsoon or early-season drought. Integrated rice–fish farming in semi-deep water-logging situations[12].
Gangetic alluvial (new alluvial zone) North Dinajpur, Malda, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Hooghly, Howrah, East Burdwan and parts of Birbhum	15.304	Tapping of groundwater (except arsenic-polluted areas) from unconfined aquifer, i.e. huge potential of groundwater utilization development for irrigation of *rabi*/summer-season crops. On-farm water resource development, enhancing surface-based irrigation and integrated farming systems. Irrigation at critical growth stages of crops through farm pond or other resources for post-rainy-season crops[13]. River-lift irrigation for crops grown in fields nearby river beds. Draining out excess water to avoid water congestion due to high rainfall in a short period of time or flooding. SRI method of rice[14], gap-filling with available nursery or by splitting tillers from the surviving hills, effective weed management, life-saving irrigation in early drought situation for rice. Supplemental irrigation, inter-cultural operations to control weeds, open conservation furrows for every three rows in case of mid-season dry spells. Integrated SRI, with a provision of a pond for excess rainwater harvesting for supplemental irrigation, short-term aquaculture in the pond and vegetables at the bund[15], alternate wetting and drying method of rice[16], alternate furrow irrigation or micro-irrigation systems for sugarcane and other post rainy season crops, sugarcane trash mulching, ridge and furrow planting of crops, furrow/sprinkler irrigation under limited water-availability situations, or insufficient groundwater recharge due to low rainfall. Inter-cultivation by harrowing for jute–rice cropping system. Spraying of 2% urea, supplemental irrigation by alternate furrows or micro-irrigation systems, timely weeding for jute–rice, rice–wheat, maize–blackgram, rice–mustard cropping systems for terminal drought conditions.

(*Contd*)

Table 4. (*Contd*)

Agro-climatic zones	Area (lakh ha)	Water management and associated technologies
Vindhyan alluvial (old alluvial zone) Western part of Murshidabad and Hooghly, South Dinajpur, eastern part of Birbhum and Bankura, East Midnapur, central part of Burdwan and northern part of Howrah	17.537	Irrigation through river valley projects and tapping of groundwater (except arsenic-polluted areas) for irrigation of *rabi*/summer-season crops. Minor irrigation infrastructure development, conjunctive use of water utilizing both surface and groundwater resources for multiple cropping. On-farm water resource development, enhancing surface-based irrigation and integrated farming systems, especially in canal commands[17]. River-lift irrigation for crops grown in fields nearby riverbeds. Improvement of drainage system and flood control to avoid water congestion due to high rainfall in a short period of time or flooding. Life-saving irrigation (fertigation), foliar spray with 2% urea to rice in case of normal onset, but early-season drought and mid-season dry spells. SRI and alternate wetting and drying method of rice, gap filling with available nursery or by splitting the tillers from the surviving hills, effective weed management. Draining out excess water to avoid water congestion due to high rainfall in a short period of time or flooding. Drip and sprinkler irrigation to post-rainy season crops[18]. Inter-cultivation at optimum moisture condition to loosen and aerate the soil and control weeds. Paired-row, ridge and furrow system for groundnut[19] and other crops.
Lateritic, red and gravelly undulating zone South Dinajpur, Malda, Birbhum, West Burdwan, Purulia, Bankura, West Midnapur, Jhargram Birbhum, Burdwan, Bankura, Purulia and Midnapur	24.842	Rainwater harvesting in water storage structures, viz. ponds and dugwells, and utilizing the same for supplemental/life-saving irrigation[15]. Conservation and efficient utilization of rainwater in the rainfed, shallow lowland paddy fields[20], optimum dike height in rice fields for water, soil and nutrient conservation[21,22]. Auxiliary/secondary water-storage ponds under canal commands and development of pond-based integrated farming systems[17]. Soil and water conservation through integrated watershed development and management including afforestation. Irrigation through conjunctive use of water utilizing both surface and groundwater resources for multiple cropping[23]. SRI, alternate wetting and drying method for rice cultivation[16,24], dapog nursery method, irrigation during critical growth stages; supplemental irrigation and appropriate crop management, viz. interculture/weeding, gap-filling either with available nursery or by splitting the tillers from surviving hills during dry-spells. Raising of seed bed under transparent plastic cover for vegetables, viz. brinjal, cauliflower, cabbage, tomato, chilli, etc. in case of early season drought due to delayed onset of monsoon. Drip and sprinkler irrigation to post-rainy season crops[25,26]. Sowing of linseed/khesari/lentil as paira crop in case of terminal drought due to early withdrawal of the monsoon. Draining out excess water to avoid water congestion due to high rainfall in a short period of time or flooding. Mulching with crop residues for soil moisture conservation[27]. Preparing mounds for sowing of seeds for cucurbits (cucumber, ridge gourd, bottle gourd, bitter gourd, etc.) in early-season drought situations. Paired-row, ridge and furrow system for groundnut[19] and other crops under limited water availability situations[28].
Coastal saline zone Southern parts of North 24 Parganas, South 24 Parganas, Howrah, East Midnapur	14.569	Land shaping, viz. raised and sunken bed technology[29], ridge and furrow system for agriculture and aquaculture[30]. Storage of excess rainwater in one-fifth excavated land of the total cultivated land of a farmer and raising the adjacent embankment and crop fields. Improvement of drainage systems to avoid water congestion and flooding agricultural fields. Blocking of ingress of saline water by effective regulatory system through construction of embankments, drains and sluices, raising of shorelines of field channels[31], etc. Re-excavation of silted-up creeks and tanks, and sinking of new tanks for impounding rainwater for irrigation facilities to multiple cropping and aquaculture. Gap-filling with available rice nursery or by splitting the tillers from the surviving hills, life-saving irrigation through farm pond water or alternative means (fertigation) in case of early-season drought. Rainwater harvesting in water-storage structures, viz. ponds, and utilizing the same for supplemental or life-saving irrigation to crops[15]. Dapog method of rice nursery, SRI, alternate wetting and drying method[16,24] during *kharif* season. Paired-row, ridge and furrow system for post-rainy season crops[28], zero tillage for wheat, especially under limited water availability situations[32].

basic slag and rock phosphate which are available in plenty in the region. Short-duration high yielding variety (HYV) of rice in medium and medium to high lands, and crop diversification in uplands are suggested from rice to arhar, groundnut, maize, sorghum, soybean and finger millet. Short-duration pulses and oilseeds are suitable for growing with residual moisture, and wheat and vegetables are preferred with irrigation in winter.

In the coastal saline zone, numerous silted-up creeks and tanks can be used for aqua-farming. As both deep and shallow tubewells are not economically viable in this zone, excavation of small tanks and simultaneous raising of lowland surface will serve the purpose of multiple cropping and aqua-farming. Cultivation of HYV rice and integrated farming systems approach would be effective by integrating field crops, horticulture, animal husbandry and aqua-farming after land shaping and creating micro-irrigation facilities. Re-excavation of silted-up creeks and tanks, and sinking new tanks would be effective for impounding rainwater for irrigation and aqua-farming. During the dry period, supplementary irrigation would be possible for impounded surplus monsoon rainfall. Improvement of drainage system and flood control would prevent the ingress of saline water by a more effective regulatory system through construction of embankments, drains, sluices, etc. Application of soil amendments is advisable. Plantation crop orchards such as coconut and cashew nut, and horticultural crops such as banana, sapota, etc. are recommended.

Conclusion

West Bengal has all types of land, varied topography, soil and climatic conditions. Production potential is quite high in the agricultural and allied sectors. There exist multiple problems related to water management – water stress, water-logging and salinity as this is a state of both water excess and water scarcity, and ingress of saline water. These call for concerted efforts to achieve the UN's SDG by the year 2030. Sustainable management of water resources would be required to achieve food security and economic prosperity of the state. The holistic approach of integrated water resource management should be implemented for every ACZ of this state. The ultimate stakeholders, i.e. farmers need to be involved in a participatory mode in policy formulations, infrastructure development and efficient water management. It is required to implement existing and already proven technologies of water, soil and crop management. There is a need for considerable increase in water-use efficiency, at least by 20% that has been set by the National Water Mission of the Government of India; the Prime Minister's Krishi Sinchai Yojana must also be effectively implemented. The Government of West Bengal's initiative of 'Jal Dharo Jal Bharo' should be strengthened for rainwater harvesting and efficient utilization of water for irrigation and integrated farming systems with multi-enterprise components, viz. agriculture, horticulture, fisheries and animal husbandry. Waterlogged area management is essential to protect the ecological balance and tap the productive potential of wetlands. Wherever possible, it is essential to replenish as well as extract groundwater to bring more areas under irrigation, by adopting efficient irrigation techniques, viz. micro-irrigation, pipe irrigation or furrow irrigation rather than flooding the fields. Strong policy decisions would be required for the use of electricity, diesel or solar energy as a source of energy for water-lifting pumps, i.e. a judicious use of electricity and diesel would be required. Some solar energy-based pumps should be installed on a pilot scale. Pond-based farming systems approach especially in canal commands would be highly effective for participatory water management and also for a sustainable income generation by the farmers. It is recommended for adoption of zone-specific water management and associated agricultural technologies in West Bengal.

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