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Multipurpose Freshwater Coastal Reservoirs and Their Role in Mitigating Climate Change

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Abstract*: A coastal reservoir (CR) is a freshwater reservoir to store river water in the sea area adjacent to the sea coast by replacing seawater. A CR is formed by constructing a long oceanic dike to impound surplus water that is flowing to the sea from a river basin. Freshwater from the CR is pumped throughout the year into a series of embankment canals to reach upland areas for meeting agricultural, industrial, municipal, etc water needs along with the required base flows and environmental flows in river basins. The embankment canals also create pumped storage hydropower (PSHP) potential to meet the energy storage requirements for harnessing variable power resources like solar, wind, etc which are economical, clean, renewable, and carbon neutral. The oceanic dike also creates a mega-scale ultra-deep sea harbor along with a coastal highway and railroad. CRs are cheaper to construct compared to land-based reservoirs wherever the cost of submerged land and immovable property acquisition and rehabilitation of the affected population is very high. They also serve multipurpose utilities such as deep-sea harbor, road transport, rail transport, land reclamation, PSHP energy storage, rejuvenation of over-exploited rivers, etc without appreciable overall environmental damage. CR projects are feasible in every continent except Antarctica as there are few mighty rivers with huge surplus water discharges to the sea and also the existence of vast desert/semi-desert areas which can be converted into productive agricultural lands or forest lands with water supplied from the CRs. Greening the desert or semi-desert lands into lush green farms or forest lands would enhance the soil carbon storage and also provide food grains and biomass. The available biomass can be used as feedstock to produce carbon-neutral biofuels to replace fossil fuels which are contributing to global warming. Few feasible CR projects are listed in the paper that can harness nearly 9,000 billion cubic meters (bcm) of water annually and contribute to achieving a carbon-neutral world. To explain the concept of the freshwater CRs and the associated embankment canals, a CR project to utilize the surplus waters of the Brahmaputra, Ganga, and Meghna rivers is considered as a case study in some detail in this paper. The project would create a 360 bcm capacity CR to harness nearly 1,200 bcm of water throughout the year regardless of monsoon vagaries for meeting various water needs in all major river basins between the Ganga and Krishna rivers.

Keywords: Ganges, Brahmaputra and Meghna Rivers, Oceanic Dike, Pumped Storage Hydropower, Topsoil Carbon.

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I. INTRODUCTION

The unabated release of greenhouse gases (GHG) into the atmosphere by human activity is warming the planet Earth, rising the sea level, and contributing to ocean acidification. The global surface temperature was 0.95 to 1.20° C higher in 2011–2020 than in 1850–1900. The global mean sea level increased by nearly 0.20 m between 1901 and 2018 [1]. The long-term temperature goal by the end of the 21st century, as per the Glasgow Climate Pact (COP26), is to keep the rise in mean global temperature well below 2.0° C above the pre-industrial levels [2]. It is planned to reduce anthropogenic GHG emissions by reducing fossil fuel consumption and sequestrating carbon from the air into the soil or underground caverns. Limiting the global surface temperature rise well below 2.0° C would have disastrous effects on the living standards of the people provided alternate carbon-neutral renewable energy sources like biomass, wind, solar, hydropower, etc are not developed adequately and economically [3]. However, wind and solar are intermittent and variable energy sources that cannot be relied upon for meeting uninterrupted and continuous electricity supply without building up energy storage capacity in the form of pumped storage hydropower (PSHP) plants or battery energy storage systems (BESS).

The yearly average water resources available from the global rivers are nearly 37,000 billion cubic meters (bcm) out of which nearly 11% is harnessed so far for various uses, particularly for irrigation [4]. In addition to river water, groundwater is also extracted in an unsustainable manner where there is a shortage in surface water availability. The total cultivated land (both temporary and permanent crops) is 15.56 million km^2 in 2019 which is nearly equal to the total global desert land area (excluding frigid deserts) [5,6]. Wherever freshwater resources are sparse due to climatic conditions, water stress under high and critical classifications is increasing globally [5]. Water stress is defined as the ratio of total freshwater withdrawn by all major sectors (agricultural, industrial and municipal) to total renewable freshwater resources, after considering environmental flow requirements. There are mighty rivers with surplus water on all continents and also vast desert/semi-desert lands suffering from water shortage [5]. Nearly 89% of global surface water resources from the rivers are going to waste in the sea. There is plenty of scope to utilize another 25% of global surface water sources (9,200 bcm/year) to convert substantial desert and semi-desert lands into rich agricultural and forest lands by envisaging multipurpose CR projects.

Agricultural wetlands and cultivated forest lands sequester more carbon from the air to the soil in the form of topsoil organic matter compared to desert and semi-desert lands [7,8]. The enhanced biomass production from agricultural wetlands and forest lands can also be used to replace the fossil fuels like coal, natural gas, and crude oil [9]. These water resources are adequate to convert nearly 40% of global desert lands (nearly 6 million km^2) into productive wet agricultural and forest lands in addition to supplying deficit water to the global cultivated lands which are subjected to water stress. These water projects can also serve for energy storage /PSHP purposes economically to supply round-the-clock power from lower-cost, renewable, and carbon-neutral power sources like solar and wind power which are essential for attaining a carbon-neutral global economy [10]. A few feasible Coastal Reservoir (CR) projects worldwide with brief details are listed below which have the total potential to use nearly 25% of global surface water available in the rivers.

Fig. 1: Outline of the oceanic dike in the Bay of Bengal sea

1 A freshwater CR is feasible to harness nearly 1,050 bcm of flood water of the Ganga, Brahmaputra, and Meghna rivers system for the purpose of irrigation, carbon or energy forests, rejuvenation of Indian rivers, energy storage/PSHP, etc in India and Bangladesh. A CR is created by constructing 600 kilometers (km) long oceanic dike in the Bay of Bengal Sea to impound the water joining the sea from Ganga, Brahmaputra, and Meghna rivers system. (refer to Fig. 1) From the CR, two independent embankment canals are routed to the uplands located in the northwest and southwest parts of India which are suffering from water stress (refer to Fig. 7). This project is considered a case study in this paper to explain the concept of freshwater CRs and associated embankment canals. The project could be named the “East to West Water Transfer (EWWT) Project” as it transfers water from the east coast (Bay of Bengal) towards the northwest and southwest of India.

2 Water transfer from Fly, Kikori, Purari, etc rivers of the Papua New Guinea island to Northern Australia is feasible by blocking the shallow depth (< 20 m) of Torres Strait between southern Papua New Guinea and the northern tip of Australia by a freshwater CR. For navigation purposes, a freshwater navigation channel (22 m water depth, water level 2 m above mean sea level, and 500 m wide with locks at the entry points to the sea) is proposed to cross the CR which is blocking the Torres Strait. Two barrages are also envisaged to transfer freshwater by gravity from the northern part to the southern part of the CR via the navigation canal (refer to Fig. 2). The divided CR into two parts by the navigational canal is also connected by tunnels for water transport from the northern part to the southern part when the water level in the northern part is below sea level. Nearly 400 bcm of water can be used by lifting water from the CR via multipurpose embankment canals by 500 m height to reach the vast arid and drylands of Australia including the water deficit Murray Darling River basin to convert the area into rich agriculture or forest lands.

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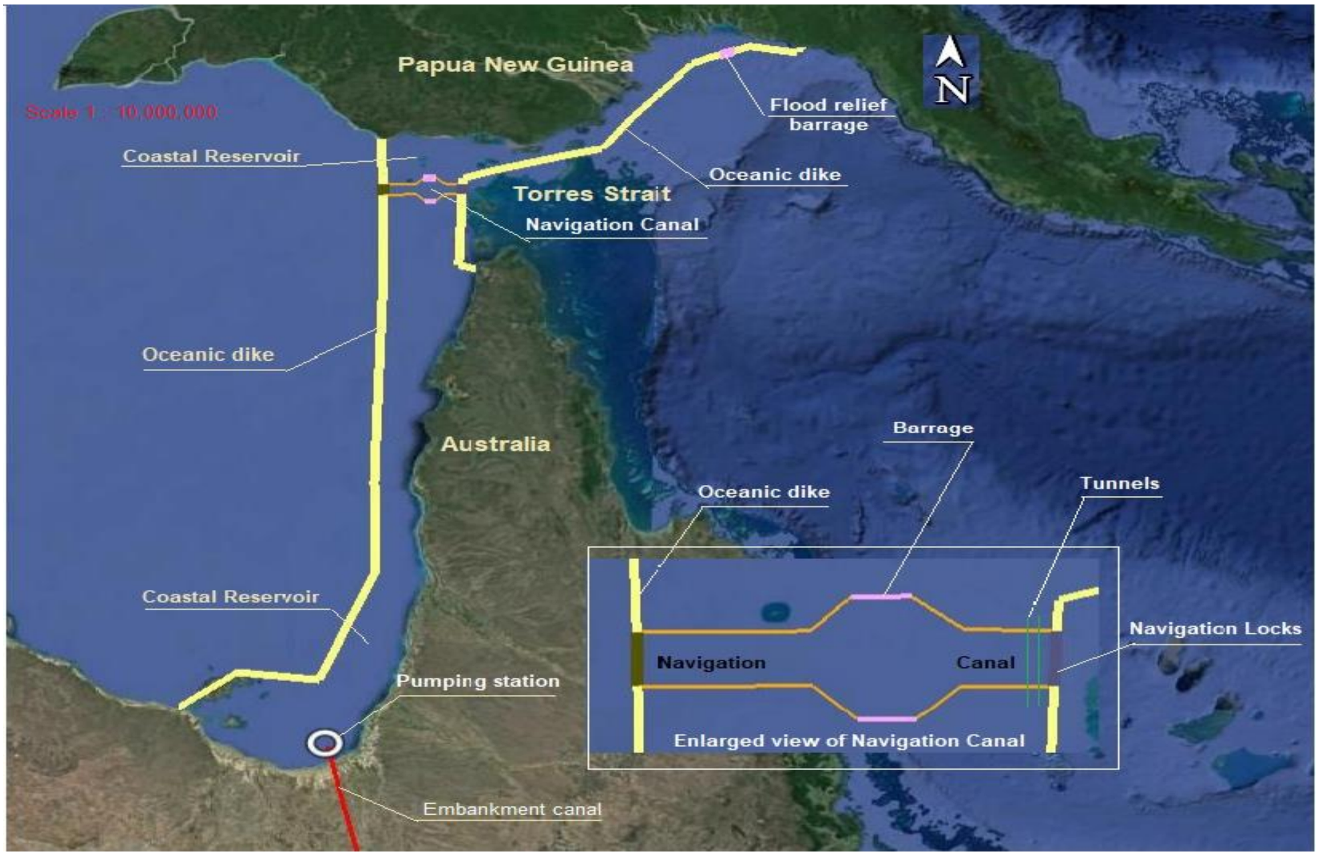

Fig. 2: Coastal reservoir between Australia and Papua New Guinea

3 Nearly 1,000 bcm water of Yangtze River can be put to use by diverting the river water to a CR located on the left side of its river mouth (refer to Fig. 3). Water from the Yangtze River is diverted into the CR via its northern delta branch by constructing a barrage across the Yangtze River. The diversion barrage will also have navigation locks for shipping needs. Excessive flood water is sent directly to the sea through the other delta branches of the river. Embankment canals originating from the CR would pass along the dividing ridge between Yangtze/Huai and Yellow/Huang He River basins to reach the highlands of the Yellow River basin and further to extend up to Inner Mongolia and Xinjiang regions. Water is lifted by 1,500 m height by the PSHP stations via cascading embankment canals to convert vast desert lands into rich agriculture or forest lands.

The main embankment canal is also interconnected with the Yangtze River by a branch embankment canal along with its PSHP stations to receive the water released from the Three Gorges Dam into the downstream Yangtze River. During the nighttime, PSHP stations will generate hydropower from the water released by the Three Gorges Dam while flowing to the CR via embankment canals. During the daytime, the water released from the dam is received by the main embankment canal and pumped further to the uplands by the PSHP stations. Thus, Yangtze River floods downstream of the Three Gorges Dam can be eliminated by diverting floodwaters to the embankment canals.

4 Nearly 900 bcm of water available at the river mouths (located in Russia) of the Lena and Amur rivers can be transferred to desert lands of Mongolia and China (inner Mongolia and Xinjiang regions) to transform into rich agriculture or forest lands by envisaging CRs at the river mouths along with embankment canals. The embankment canals also create huge PSHP potential for energy storage.

5 Nearly 1,000 bcm of water available at the river mouths of Yenisei and Ob rivers (located in Russia) can be transferred to desert lands of Kazakhstan, Uzbekistan, and Turkmenistan to convert into rich agriculture or forest lands by envisaging CRs at the river mouths along with embankment canals. The embankment canals also create vast PSHP potential for energy storage.

6 Nearly 1,600 bcm of water available at the river mouths of Congo, Niger, and Nazareth/Ogowe rivers can be transferred to the desert lands of Chad, Niger, Mali, Mauritania, Algeria, Libya, Sudan, Egypt, etc. The CR is nearly 1,900 km long covering the river mouths of the Congo and Niger rivers. The embankment canals, originating from the CR, pass through Cameroon and Nigeria to reach the edge of the Sahara Desert in Chad and further extended to reach most of the Sahara Desert area for converting into rich agriculture or forest lands.

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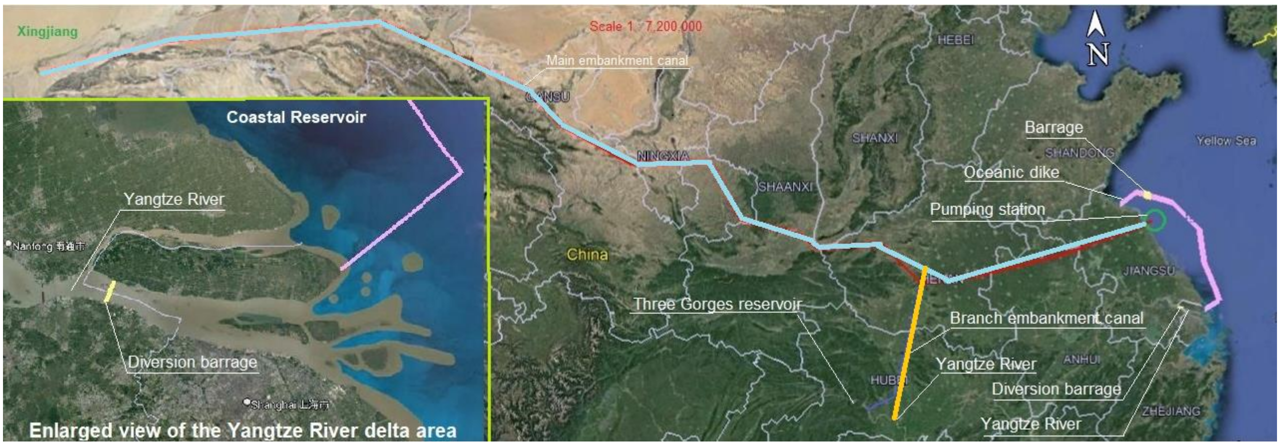

Fig. 3: Freshwater coastal reservoir to harness Yangtze River waters

7 Nearly 140 bcm of water available at the river mouth (located in Mozambique) of the Zambezi river can be transferred to the desert lands of Tanzania and Somalia. The embankment canals, originating from the CR, pump water up to 500 m height for converting desert lands into rich agricultural lands.

8 Nearly 1,100 bcm of water available in the Mississippi and Saint Lawrence rivers can be transferred to the water deficit western and southern parts of the USA and the northern part of Mexico for converting sparsely vegetated areas into rich agriculture or forest lands. A 250 km long CR is constructed up to 20 m water depth along the sea coastline of Canada to impound the water flowing from the Saint Lawrence/ Great Lakes river basin. Water from the CR is pumped via embankment canals into Lake Ontario, Lake Huron, and Lake Superior. The Niagara Falls, a renowned tourist attraction site, operations are not disturbed without reducing its water flow but the released water downstream is pumped back from Lake Ontario to Lake Huron. The water levels of the Great Lakes would remain in their natural fluctuations range as most of the needed water storage is provided by the CR. Navigation on the Great Lakes is also not affected.

An embankment canal emanating from Lake Superior will transfer water to the western part of the USA covering sparsely vegetated areas up to 1500 m elevation. Another embankment canal from Lake Michigan crosses the Mississippi River near Saint Lewis to transfer water (including the water available in the Missouri River) to the uplands located in the southern part of the USA and the northern part of Mexico. Another embankment canal originating from the Mississippi River after the confluence of the Arkansas River will supply water to the arid lands of Texas state. The embankment canals also create huge PSHP potential for energy storage.

9 Nearly 300 bcm of water available in the Atrato and Magdalena rivers can be impounded by a CR on the Atlantic sea coastline of Columbia. CR water is pumped to 110 m height via embankment canals (nearly 500 km long) and transferred to the San Juan River which is draining into the Pacific Ocean. Another 1200 km long CR is constructed along the sea coast of Columbia, Ecuador, and Peru to transfer water from Atrato, Magdalena, San Juan, etc rivers (nearly 400 bcm) for use in Peru. An embankment canal from the southern end of this CR would pump water to the low and midlands of Peru which are arid and desert lands. This water transfer project can also be used as a navigation canal between the Pacific Ocean and the Atlantic Ocean similar to Panama Canal. Peru would supply continuous power derived from its solar power plants and the PSHP stations to Ecuador and Columbia in return for the supplied water.

10 The Pará River or Santa Mario River Channel and Tocantins river waters (750 bcm/year) of Brazil can be impounded in a CR covering the river mouth of Tocantins. Through the Santa Mario River Channel, Amazon River water (290 bcm) flows naturally into the estuary of the Tocantins River [11]. During the lean flow season, it is also possible to divert more water into the Santa Mario River Channel from the Amazon River by constructing a weir/barrage across its southern delta channel called Baia Do Vieira Grande. Nearly 750 bcm of water from the CR can be pumped via embankment canals to reach the uplands up to 600 m elevations in the Araguaia sub-basin of the Tocantins and the Sao Francisco river basin for irrigation, energy plantations, etc uses [12]. The PSHP stations located on the embankment canals are also used for energy storage purposes.

11 The southern part of Argentina is arid desert land (Patagonia desert) which needs water for converting into rich agricultural or forest land. Water available in Paraná and Uruguay rivers can be impounded in a CR located on the gulf of Rio De La Plata up to 20 m water depth. The water from the CR is pumped via embankment canals to the uplands up to 1,500 m elevation located in the southern part of Argentina for various water uses (850 bcm/year) and energy storage.

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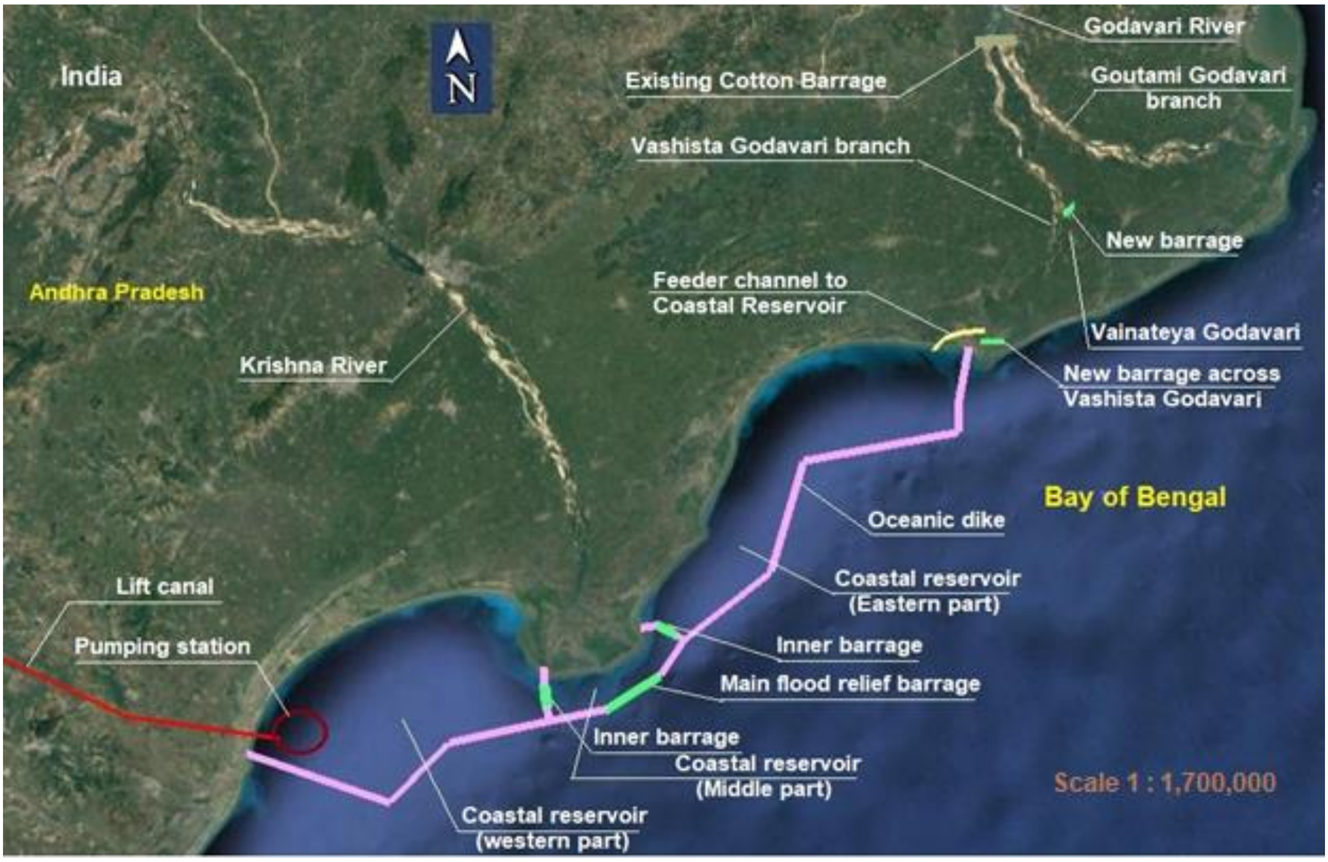

Fig. 4: Freshwater coastal reservoir to harness Godavari River floodwaters

12 Flood water of Godavari River, located in India, is impounded in a 29 bcm water storage capacity CR located on the Bay of Bengal Sea [13]. Water is supplied from the CR to the water deficit Rayalaseema region of Andhra Pradesh state and adjacent Tamil Nadu state. One barrage across the Vashista Godavari branch and another barrage across the Vainateya Godavari branch are constructed to divert Godavari water through a feeder channel to the proposed CR (ref Fig. 4). Nearly 50 bcm/year of Godavari River water can be used from the CR. The adjacent Krishna River mouth is also forming part of the CR and the water available at its estuary is not of good quality for irrigation purposes as the river water is overexploited. So a provision is made to avoid mixing with the Godavari water by sending Krishna water directly to the sea during the non-monsoon period. Two inner barrages are planned to divide the CR into three parts. When the eastern part of the CR is nearly filled up during the monsoon season, the inner barrage will release water into the central part and further transfer water to the western part of the CR through the other inner barrage. During the non-monsoon period, the inner barrages are kept closed and Krishna water is allowed to flow to the sea through the main flood relief barrage. The eastern and western parts of the CR are also interconnected by tunnels to transfer water during the non-monsoon period.

13 Floodwaters of the Indian rivers Narmada and Sabarmati are impounded in a CR located on the Gulf of Khambhat of the Arabian Sea. This project is called the 'Kalpasar Project'. Water from the CR is pumped into the water deficit Saurashtra region of Gujarat located on the other side of the Gulf of Khambhat [14]. Nearly 20 bcm/year of water can be harnessed for agriculture, industrial, municipal, and carbon or energy forests in the Gujarat state of India.

II. METHODS

A typical schematic of a coastal reservoir (CR) is shown in Fig. 5. CR enables storing of river water in the sea area. The freshwater reservoir is formed by an oceanic dike. The oceanic dike is located on the sea bed having a three-sided structure to prevent the ingress of seawater into the freshwater CR. As the oceanic dike is fully enclosing the river mouth, a gated barrage is constructed to discharge the excess floodwater to the open sea from the CR. A freshwater CR is created by separating sea area up to 20 meters (m) of water depth. Oceanic dike is constructed from the sea bed up to 12 m above the local mean sea level (asl). The oceanic dike is envisaged in the form of two parallel bunds with a 1,000 m wide gap in between. The landside inner bund stores the river water and its freshwater level varies as the water is extracted for various uses from 20 m below mean sea level to local high tide level (maximum reservoir level) with full reservoir level (FRL) at ± 0.00 m asl. The gap between the inner bund and the seaside outer bund is also filled with river water and always maintained at 2 m asl by pumping fresh water from the CR.

This is required to completely prevent any seawater seepage into the freshwater CR whose water level is below sea level normally [15]. Seawater (40,000 ppm total dissolved salt content) seepage equal to one percentage (1%) of the CR storage capacity can make the stored freshwater unfit for any use. So, reverse seepage of fresh water from the outer bund to the sea is incorporated by maintaining the water level at 2 m asl in the water body located between the twin bunds [16]. Freshwater from the outside of the inner bund can only seep into the CR which will not contaminate the stored freshwater.

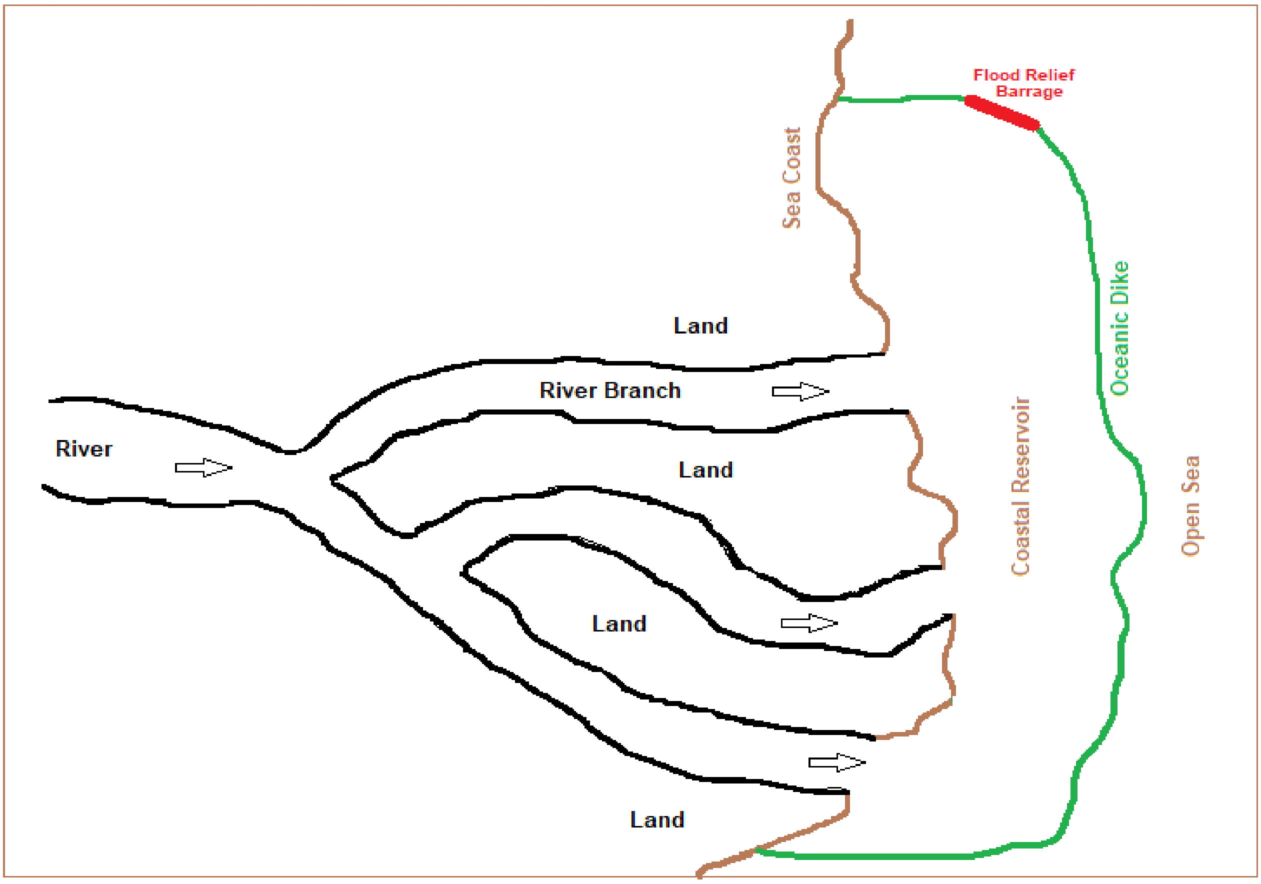

Fig. 5: Schematic of the coastal reservoir formed by an oceanic dike

The 1,000 m wide water body, with 22 m water depth at 2 m asl, in between the two bunds is envisaged for use as a deep-sea harbor by providing outlets to the sea through navigation locks. The top of the inner bund (50 m wide) would serve as a road and rail access to the adjacent deep-sea harbor in addition to serving as a coastal highway and railroad.

The proposed CR (Fig. 1 and Fig. 7) of the EWWT Project is located on the seacoast of Odisha and West Bengal states in India and the seacoast of Bangladesh. The western end of the oceanic dike is located near the north of Baitarni river mouth and the eastern end of the oceanic dike is located near Kutubjom Union town in southeastern Bangladesh stretching nearly 600 km in length. The CR is of 60 km average width, 10 m average depth, and 360 bcm gross storage capacity at 0.00 m asl FRL. The operation of the existing Chettogram/Chittagong harbor is unaffected by constructing an 85 km long earth dike on the sea bed at 5 m water depth (5.00 m below sea level along the sea coast in the area of the CR) to provide a minimum 3,000 m wide corridor for access to the sea from Chittagong harbor. Access to the Chittagong harbor from the open sea will be via gated locks of the deep-sea harbor. Also, a barrage is envisaged to pass the floodwaters to the sea (Fig. 1) from the rivers of southeastern Bangladesh. The occurrence of waves (surge plus tide) with a height of about 10 m is approximately once in 20 years [17]. The probable maximum flood (PMF) (less than once in 1,000 years) is not exceeding 165,000 cubic meters per second (cumecs) for all rivers (Meghna, Ganga, Brahmaputra, etc rivers) which are draining into the CR. Two barrages, one each in India and Bangladesh areas, would be provided to discharge the PMF with the backwater level in the Ganga and Meghna rivers not exceeding 2 m asl. The area of the CR is nearly 36,000 km^2. The 70 bcm surcharge storage capacity available above the FRL of the CR itself can accommodate the PMF for nearly 5 days. In addition, there is an adequate pumping capacity to discharge PMF to the sea through an embankment canal. The CR will have at least 700 years of operating life when the average annual sediment carried by the rivers is around 0.5 bcm.

III. RESULTS AND DISCUSSION

The average water availability in a water year from the CR is 1,050 bcm [18]. The monthly water flows from Ganga and Brahmaputra rivers are given in Table 1. The water already harnessed/utilized from the Ganga River after 1973 is not accounted for/deducted in the data given and the inflows to the sea from the downstream areas (Bangladesh and Meghna River catchment area) are not included.

The additional water inflow from the rivers draining into the CR from Bangladesh and India (West Bengal, Meghalaya, Assam, Odisha, Jharkhand, etc.) would be nearly 150 bcm. The planned embankment canals in the Ganga basin will also intercept/capture/harness nearly 50 bcm before flowing into the proposed CR. Also, substantial groundwater seepage takes place into the sea/CR throughout the year. Rainwater falling directly on the CR area is adequate to meet the seepage, evaporation, and harbor flushing water losses from the CR. After considering these factors, total water availability in the CR presently in an average water year is estimated same at 1,050 bcm as per the observed/gauged data earlier.

Nearly 400,000 MW solar PV and 400,000 MW wind & hydropower are required to supply electricity for pumping the available Brahmaputra and Ganga floodwaters from the CR by 435 m average head @ 147,731 cumecs (5,215,000 cusecs) flow. The peak wind season is from May to September every year coinciding with the high water inflows into the CR during the monsoon season. Water pumping from the reservoir (refer to Table 2) is decided by the power available from the 800,000 MW power plants in a month and the remaining water is stored in the 360 bcm capacity CR. Total power consumption in a year is 1,575 billion kilowatt hours (kWh). One kWh is consumed to pump one cubic metres (m^3) of water by 290 m height @ 80% pumping efficiency. Nearly 800,000 MW in pumping mode or 520,000 MW in turbine mode of Pumped Storage Hydro Power (PSHP) capacity is installed at multiple locations for pumping water to the uplands via a series of embankment canals. When not used for pumping water, these units also work for PSHP purposes to store the daytime surplus power and generate power during nighttime from the stored energy on a daily/weekly basis. The reservoir (360 bcm storage) is filled up from July to October months with the floodwater flows and nearly 430 bcm is also used/pumped for irrigation and upstream storage during these four months (refer to Table 2).

Embankment canals are best suited for pumping water from the CR to reach the uplands (up to 600 m asl elevation) for meeting the irrigation, industrial, municipal, etc requirements. An embankment canal is formed by building two parallel Earth cum Rock Fill (ECRF) dams/bunds extending 20 to 50 m high from the local ground level. The two parallel bunds are separated by 3,000 meters distance at full supply level (FSL) and water is fed to the above-ground channel formed in between the two bunds. A series of cascading embankment canals are used to transport water to distant uplands. Each embankment canal is generally 200 km long. The top of the bund level of an embankment canal is the same from starting point to the endpoint to facilitate bidirectional water flow. As the maximum pumping rate from embankment canal to embankment canal is of the order of 180,000 cumecs (6,354,000 cusecs), it would be exorbitantly costly to construct below-ground level canals or pipelines. For very high water flow requirements, constructing above-ground embankment canals is the cheapest method to transport water over long distances. The cost of an embankment canal is nearly independent of its water flow capacity (cumecs) and only land requirement increases proportionately as its width is increasing. Soil/earth is excavated from the embankment canal area to the required extent for the construction of ECRF bunds and further soil digging/excavation is not required. The water surface gradient is less than 1:35,000 and the maximum level drop in a canal is 10 m. Thus 10 m water depth at design water flow is used for transporting water. Another 10 m water depth is used for the buffer water storage required for the operational requirement of PSHP units. For a 200 km long embankment canal, the buffer water storage volume is nearly 6 bcm which can be used by the PSHP units daily. At the end of the canal, the bund height (from the local ground level) below its FSL reduces to 20 m from the 50 m at its starting point. From the lower level embankment canal, water is pumped into another higher level embankment canal with at least a 30 m variation in FSL levels by installing PSHP/pumping stations. By constructing a series of embankment canals and associated PSHP/pumping stations, water is transported from the CR to the required distance and elevation (up to 2,500 km distance to reach Sutlej and Krishna river basins). Further from every embankment canal, water is either pumped to uplands by installing pumping stations or fed by gravity to low-lying areas for the needs of irrigation, etc throughout the year. Water drawn from the embankment canals is also stored in the existing/new reservoirs in various river basins during the monsoon season if they are not filled up fully with the monsoon inflows from their catchment areas.

Generally, the embankment canals are routed along the dividing line/ridge between two watersheds or river basins to minimize the embankment canals requirement to cross the major natural streams. Depending on topography constraints, many times it is not feasible to align the embankment canals accordingly. However full-proof measures would be incorporated to address these problems with minimum water submergence outside the embankment canals. The level difference from an embankment canal to a connecting embankment canal need not be limited to 30 m (minimum) and water can be pumped to higher elevations even by 200 m in a single lift taking advantage of the steep natural/terrain gradient available without increasing the embankment canal bunds height (i.e. 50 to 20 m high at FSL). It is also possible that an embankment canal is connected to an existing reservoir located across a river or tributary to feed water at its full reservoir level (FRL) or draw water from the reservoir. It is also possible that an existing reservoir is bifurcated into two reservoirs by an embankment canal while crossing the reservoir.

Table 1: Monthly water flow data of Ganga and Brahmaputra rivers

Month	Ganga River flow at Farakka, India (Data from January 1949 to December 1973) [19] The river point catchment area is 935,000 km^2				Brahmaputra River flow at Bahadurabad, Bangladesh (Data from January 1962 to March 1992) [20] The river point catchment area is 636,130 km^2				Total monthly flows
	Maximum m^3/sec	Minimum m^3/sec	Average m^3/sec	Average bcm/month	Maximum m^3/sec	Minimum m^3/sec	Average m^3/sec	Average bcm/month	Average bcm
April	2176	1228	1751	4.54	11423	6270	8409.5	21.80	26.34
May	2981	1359	1984.5	5.32	27795	7530	15530	41.59	46.91
June	10199	1181	4314.4	11.18	44855	18119	31817	82.47	94.27
July	33922	12090	20793	55.69	59325	31900	49111	131.5	187.23
August	65072	19042	43030	115.3	55861	30354	45017	120.6	235.82
September	52121	19331	36899	95.65	53006	30500	42937	111.3	206.94
October	31053	7131	17593	47.12	45183	15000	28686	76.83	123.95
November	10719	3831	6836.7	17.72	18400	8624	12248	31.75	49.47
December	5399	3042	3984.5	10.67	9459	5040	7212.6	19.32	29.99
January	4224	2265	2827.0	7.57	7013	3880	5075.2	13.59	21.16
February	3508	1685	2419.0	5.90	5558	3314	4160	10.15	16.05
March	2641	1411	2014.4	5.39	6906	3390	4928.5	13.20	18.59
Annual	65072	1181	12037	379.6	59325	3314	21261	670.5	1050.00

Many obstructions/interferences surface when cross-country embankment canals are routed/aligned. These are existing overhead transmission lines, water canals, roads, railway lines, natural streams/drains/rivers, sewage drains/lines, underground or above-ground water/petroleum products/crude oil/natural gas pipelines, buried communication cables, etc. Roads and railway lines are made to cross the embankment canals through underpass tunnels [21]. In addition, the non-overflow dams constructed between the two embankment canals can also be used for road/rail transport requirements. Overhead high voltage (HV) power lines are rerouted above the embankment canals with sufficient headroom to clear navigational transport needs if any. HV power lines can also cross the embankment canals as underwater submerged HV cables laid on the bed of embankment canals or gas-insulated HV bus ducts/cables laid in underpass tunnels. When a surface water canal is interfering with an embankment canal, the water canal is terminated and the isolated downstream part of the canal is fed by gravity from the embankment canal. When a sewage open drain/ pipe is interfering with an embankment canal, the sewage line is terminated near the embankment canal and a sewage treatment plant is installed nearby and the treated water is pumped into the embankment canal. Underground or above-ground water/petroleum products/crude oil/natural gas pipelines, buried communication cables, etc that are interfering with the embankment canal will be rerouted in underpass tunnels to cross the embankment canals.

Table 2: Operating hours of the PSHP, solar PV, and wind/hydropower plants for water pumping

Billion cubic meters (bcm)	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
Water inflows (bcm/month)	187.2	235.8	206.9	123.9	49.4	29.9	21.1	16.0	18.5	26.3	46.9	94.2
Water pumping planned (bcm/month)	163.2	149.0	77.0	35.0	49.4	54.5	71.1	74.6	82.6	88.0	99.0	112.7
Month-end storage (bcm)	24.0	110.8	240.7	329.6	329.6	305	255	196	132	70.6	18.5	0
Power (billion kWh/month) consumed @1.5 kWh/m^3	245	223	115	53	74	82	107	111	123	133	149	169
Full load power generation hours in a day by the solar power plants (400,000 MW$_{AC}$ capacity) 1,971 hr/year or 5.4 hr/day operation.	3.5	3.6	3.6	3.8	4.0	4.0	6.0	9.0	9.0	8.0	6.0	5.2
Full load power generation hours in a day by the wind /hydropower plants (400,000 MW) 2,079 hr/year or 5.7 hr/day operation.	16.5	14.4	6.0	2.5	2.1	2.5	2.6	3.0	2.9	3.3	4.5	9.0
Pumping hours/day for the 800,000 MW pumping capacity. (2,022 hr/year or an average 5.53 hr/day)	9.9	9.0	4.8	3.1	3.1	3.3	4.3	6.0	6.0	5.5	5.3	7.1

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When an embankment canal has to cross a natural stream/tributary/river, the following solutions are possible (Fig. 6) depending on the stream bed level and the FSL of the embankment canal. When the bed level of a natural stream is above the FSL of the embankment canal, the second bund of the embankment canal is not required.

If the stream bed level is less than 20 m below the FSL of the embankment canal or the submergence area of the valley is not exceeding 10 km^2, additional natural stream area will be submerged for routing the embankment canal provided the area is not densely populated or the associated land acquisition and rehabilitation costs are within the acceptable norms. In this case also, there is no requirement for a second bund at the river crossing location.

When an embankment canal has to cross a stream, whose bed level is more than 20 meters below the FSL of the embankment canal, 50% of the probable maximum flood (PMF) flows will be diverted downstream by constructing an underpass tunnel/s beneath the embankment canal. However, when the stream/ tributary is experiencing PMF flows, the additional flows (50% of PMF) are pumped into the embankment canal by envisaging a PSHP plant. A suitable capacity balancing reservoir will also be constructed at the outer side of the embankment canal to run the PSHP plant for at least six hours/day (in turbine mode) in the evening hours to meet the peak power demand. Also on the downstream side of the stream, after crossing the embankment canal through the underpass tunnel, another PSHP plant of equal capacity with an associated reservoir is incorporated to pump the floodwater into the embankment canal. The main purpose of the downstream side PSHP plant is to generate power by releasing water from the embankment canal to the downstream barrage/stream in case there is a power supply failure for the upstream PSHP plant pumping operation when the river/stream is flooding more than the capacity of the underpass tunnel/s. Thus a foolproof arrangement is made to pass the PMF without causing excessive flooding/submergence of land. Additionally, these PSHP plants operate to pump surplus river water (after sparing the downstream needs) into the embankment canal during the monsoon season. During the dry season, these PSHP plants release water from the embankment canal by working in turbine mode to the stream/river for supplying downstream water requirements. Additionally, these PSHP plants operate daily to store the surplus electricity available during the daytime and generate electricity for at least six hours in the evening hours to meet the evening peak power demand. Thus these PSHP plants (nearly 100,000 MW pumping capacity) would be a profitable investment by storing/consuming the cheaper power available during the daytime and generating/selling costly power in the evening peak hours.

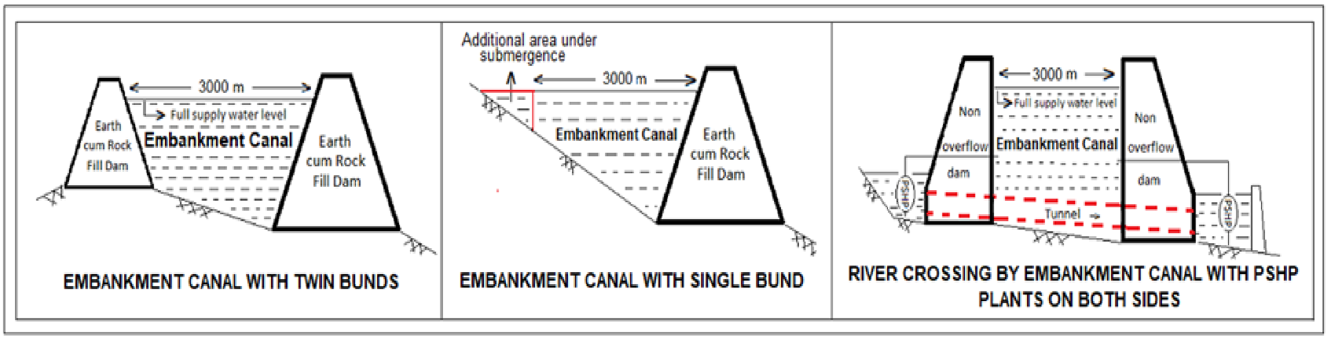

Fig. 6: Types of embankment canals.

Whenever a stretch of a river is not having a confluence of major streams/tributaries on both sides, such a river stretch can be used as an embankment canal by constructing ECRF bunds on both sides of the river. It is not possible, due to economic and terrain topography constraints, to block the major rivers by the embankment canal without substantial area submergence while the river is flooding. Then the embankment canal is terminated to feed by gravity into the river by fixing its FSL equal to the FRL of a new reservoir across the river. Wherever a stream or tributary is having steep gradient, such stream is used as an embankment canal by constructing cascade dams to reach higher elevations while transferring water from a lower-level river basin to a higher-level river basin. (ex: Mahanadi basin to Godavari basin, etc.).

Reliability, availability, and maintainability (RAM) studies would be conducted during the design/engineering phase to ensure the trouble-free working of all the embankment canals throughout the year. Wherever there is the possibility of excess seepage from the bed of embankment canals due to porous soil strata, diaphragm walls would be constructed beneath the ECRF dams up to the hard soil strata. When repair works of an ECRF dam/bund of an embankment canal are to be undertaken, the embankment canal can be fully drained by operating the associated PSHP plants located at both ends within 24 hours. The needed power to pump the water by the upstream PSHP plants can be sourced (if required) from the downstream PSHP plants which are needed to run in turbine mode for draining the embankment canal. When an embankment canal is taken for maintenance, only the upstream embankment canals will not get water from the CR but the upstream and downstream energy storage/PSHP plants, located on other embankment canals, can operate as usual without loss of power capacity or grid disturbance/failure. In fact, upstream PSHP plants can work continuously for energy storage purposes with the available buffer storage in each embankment canal during the daytime as the water pumping for consumptive water uses is not preferred to conserve the available water.

Generally, embankment canals would be taken for repair works lasting for a few weeks when the irrigation water requirement is low or the upstream water storages are comfortable to avoid water shortage in the irrigation systems. The tentative alignment/routing of embankment canals is shown in Fig. 7. Two pump houses are proposed to feed water from the CR into independent streams of embankment canals. Each pump house will have nearly 180,000 cumecs ultimate pumping/PSHP capacity. The Northern Pump House feeds into an embankment canal which is further connected to a series of cascading embankment canals to transport water to Subarnarekha, Damodar, Ganga basin, right bank side of Narmada, Sabarmati, and coastal areas of Gujarat state [22]. A reservoir is planned at FRL/FSL 220 m asl across the Sone River for using the river stretch as an embankment canal. The Southern Pump House feeds into an embankment canal which is further connected to a series of cascading embankment canals and multiple branches to transport water to Bramhani, Baitarni, Mahanadi, left bank side of Narmada, Tapi, Indravati, Sabari, Pranahita, Wardha, Penganga, Godavari, Manjra and Bhima rivers. A reservoir is planned at FSL/FRL 125 m asl across the Mahanadi River for using the river stretch as an embankment canal. The total length of both streams of embankment canals is nearly 5,000 km.

From the embankment canal which is fed by the Southern Pump House, a branch embankment canal is also routed to the open sea. This branch canal is used to drain/pump the saline water from the CR during the CR commissioning phase. It is also used to supply flushing water to the deep sea harbor area. Also, a navigational canal from the Hooghly River to the open sea is constructed along with the Odisha and West Bengal coastline with navigation locks arranged to cross the embankment canals (2 nos). Thus the existing navigation facilities are not abandoned but rerouted. All the industries which are drawing seawater will be supplied with an adequate quantity of fresh water from the nearby navigation canal which is receiving water from the embankment canals.

Fig. 7: Tentative alignment of embankment canals

Water from the CR is pumped to all highlands in every major river basin between Ganga and Krishna rivers to supply water to Odisha, West Bengal, Bihar, Jharkhand, Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, and Telangana states (Fig. 7). With the continuous water supply from the CR, the flood/surplus water would not overflow from the inland barrages or dams when their command area had been increased by 100% at least. Any unused flood water available from these rivers is also pumped into embankment canals which can be around 150 bcm in an average water year. The planned schemes to interlink the Indian rivers will remain unaffected and these schemes also serve as feeder canals drawing water from the proposed embankment canals [23]. To eliminate river floods, the connected embankment canal can also be used to route/divert the floodwaters from the rivers to the CR after generating power from the PSHP plants. The left-side tributaries of the Ganga River and northeast India are surplus in water resources (including replenishable groundwater also) and do not need water imported from other sources for irrigation, etc uses.

However, due to a lack of water storage reservoirs, the flood water generated from the uplands of the Kosi and Gandak river basins (located in Nepal) causes frequent flooding of vast plains in Bihar and Uttar Pradesh states. Flood waters of the Kosi and Gandak rivers can be diverted by constructing embankment canals to the Ganga and Ghaghra rivers respectively to avoid flooding flat low-lying areas. Additionally, hydropower is generated from flood waters by installing PSHP plants. Embankment canals are also used for pumping water from the Ganga River to these river basin areas during non-monsoon months for cultivating multiple crops/plantations throughout the year.

Kosi River flood diversion canal: Kosi barrage (26^{0}31'35" N, 86^{0}56'11" E) is located across the Kosi River where the river is entering India from Nepal. The full pond level is nearly 78 m asl. In Bihar, the Ganga River water level is nearly 25 m msl after the confluence of the Kosi River. The proposal is to construct a 150 km long embankment canal with a full water supply level of 78 m msl from the left bank of the Kosi barrage to the Ganga River along the dividing line of the Kosi basin and the adjacent Mahananda River basin. When Kosi is flooding, water is diverted to the Ganga River via the embankment canal, and also power is generated by a PSHP using a 50 m water head. During the dry season, the water supplied from the coastal reservoir to the Ganga River is pumped by PSHP into the embankment canal to reach the Kosi barrage pond for further distribution through the existing irrigation canals. In addition to the total command area on both sides of the Kosi barrage, an additional area in the Mahananda basin can be irrigated throughout the year by drawing water from the nearby embankment canal. The embankment canal can also be used as a navigation channel to Kosi barrage pond in Nepal from the Ganga River by providing navigation locks and ship lifts.

Gandak River flood diversion canal: Gandak barrage (27^{0}26'25" N, 83^{0}54'36" E) is located across the Gandak River where the river is entering India from Nepal. The pond level is nearly 105 m asl. The Gaghra River water level is nearly 63 m msl at 26^{0}15'37" N, 83^{0}44'19" E in Uttar Pradesh upstream of the Gandak River confluence. The proposal is to construct an embankment canal of 150 km in length with a full water supply level of 105 m asl from the right bank of the Gandak barrage to the Gaghra River along the dividing line of the Gandak basin and the adjacent Gaghra River basin. When the Gandak is flooding, water is diverted to the Gaghra River via the embankment canal, and also power is generated by a PSHP using a 42 m water head. During the dry season, the water augmented from the coastal reservoir to the Gaghra River via the nearby Ganga River at 25^{0}36'27" N, 83^{0}40'15" E, is pumped by the PSHP into the embankment canal to reach the Gandak barrage pond. In addition to the total existing command area on both sides of the Gandak barrage, an additional area in the Gaghra basin can be irrigated throughout the year by drawing water (by gravity) from the nearby embankment canal. The embankment canal can also have navigational facilities from the Gaghra River to the Gandak barrage pond in Nepal by providing navigational locks and ship lifts.

PSHP Potential: These embankment canals which are constructed mainly to deliver the ultimate water requirements of India will also cater fully to the electricity storage needs to supply round-the-clock electricity needs of the nation. The PSHP potential of the proposed EWWT Project is adequate to cater to the ultimate power requirements of India and Bangladesh. The ultimate power/electricity requirement of India and Bangladesh would be 16 trillion kWh/year (nearly 1.6 trillion kWh/year in 2020) when the per capita consumption reaches 8,650 kWh/head by the time the combined population of India and Bangladesh is 1.85 billion in the 2060 decade. India and Bangladesh would meet their entire energy requirements from carbon-neutral energy sources like solar, wind, hydro, and biomass by that time. Carbon-neutral transport fuels (road, marine, and aviation) will also be produced at a cheaper cost by using electricity and biomass [24]. Solar/wind/hydropower generation capacity requirement will be nearly 9 million MW by 2060. Solar power generation is possible only during sunshine and wind power generation is possible only when the wind is heavy. It is required to produce sufficient solar and wind power as and when possible to store a major chunk (nearly 40%) of the generated power to meet the nighttime power consumption. The daily PSHP capacity required to generate 40% of the power for 12 hours duration is 1.45 million MW. It is a very difficult task to construct such a huge PSHP or any other energy storage capacity on a standalone basis with tolerable ecological damages and land alienation.

The proposed 5,000 km long embankment canals will have nearly 1,482,500 MW embankment canal to embankment canal-based power generation capacity (refer to Table 3). With an average head of 50 m per PSHP plant, nearly 17.79 billion kWh per day (12 hours' generation in a day) is feasible. All the pumping/PSHP plants would work for pumping water or energy storage to consume the excess solar power generation available during the daytime and generate power to supplement the available (wind, hydro, etc) power generation during the night hours in a concerted manner. All the PSHP units are to be provided preferably with variable speed capability [25] to run at optimum efficiency and also to provide ancillary services for electrical grid management/stability. The installed PSHP capacity (nearly 100,000 MW in pump mode or 64,000 MW in turbine mode) where the embankment canals are crossing the streams/tributaries would also contribute 0.38 billion kWh/day to cater to the nighttime electricity consumption.

The main advantage of creating sufficient PSHP potential, by constructing multipurpose embankment canals, is its very low land footprint (less than 17,500 km^2 or 0.55 % area of India). The present state-of-the-art battery energy storage systems (BESS) installed in outdoor containers require nearly 0.3 acres of land per MWh/day. The land requirement for 18.17 million MWh/day (6.63 trillion kWh/year) is nearly 21,800 km^2 which is more than the total land requirement of the proposed multipurpose EWWT Project. Moreover, BESS incurs more capital costs than PSHP and has a maximum of 6 years of operating life against 40 years for PSHP [26]. After considering lifetime output (kWh), round trip efficiency, operating costs, and the Levelized Cost of Electricity (LCOE), BESS is at least 100% more costly than that of the PSHP [27].

Batteries are made from rare earth metals which are in short supply whereas PSHP is made from metals that are available abundantly without supply constraints. The CR area located in India is 12,000 km^2 (one-third of the total area) out of which nearly 4,000 km^2 can be reclaimed in the future by dredging soil to create a land area without reducing the water holding capacity of the CR. EWWT Project needs nearly 17,500 km^2 land area but creates 29,500 km^2 (1.7 times) of inland freshwater spread area in India which may be used also for locating floating solar power plants. India and Bangladesh can also exploit the offshore wind potential in the proximity of the oceanic dike of CR using it for power transmission purposes [28].

Table 3: PSHP capacity of embankment canals

Parameter	Power generation capacity (MW)	Daily power requirement (billion KWh/day)	Annual power (trillion KWh/year)	Remarks
Total power requirement for pumping and energy storage operation	2,687,000 MW capacity in pumping mode	32.23	11.77	Flow rate 180,000 cumecs/stream, two streams of embankment canals, net head 600 m, 12 hrs/day operation. Pumping efficiency is 80% including all system losses.
Pumping power required for water use	800,000 MW capacity in pumping mode	4.43	1.61	Average net head 435 m, 1050 bcm/year or 2.9 bcm/day, average 5.53 hrs/day operation (refer Table 2).
Electricity consumed by PSHP units for energy storage	1,887,000 MW capacity in pumping mode	27.80	10.16	Difference between the above two rows.
Power generated from energy storage	1,482,500 MW capacity in turbine mode (=17.79 x 10^9 /12 / 1000)	17.79 (= 27.80 x 0.8 x 0.8)	6.49 (= 17.79 x 365 / 1000)	Flow rate 180,000 cumecs/stream, two streams of embankment canals, gross head 600 m, 12 hrs/day operation. Turbine efficiency is 80% including all system losses.
Power generated from energy storage by the 800,000 MW capacity	800,000 MW identified for pumping of water for irrigation, etc uses.	3.31	1.21	Equal to 512,000 MW in turbine mode. 6.47 (=12-5.53) hrs/day operation in turbine mode (refer to Table 2)
Power generated by the PSHP located at stream crossings by embankment canals	64,000 MW capacity in turbine mode	0.38	0.14	100,000 MW in pumping mode. Six hours daily operation on average. Turbine efficiency 80% including all system losses. The embankment canal works as the upper reservoir.
Total power generated by the MW capacity identified for the water use.	900,000 MW in pumping mode or 576,000 MW in turbine mode	3.69	1.36	Sum of above two rows.
Total electricity generated during night time.	1,546,500 (=1,482,500+64,000) MW capacity in turbine mode)	18.17 (= 17.79 + 0.38)	6.63 (= 6.49 + 0.14)	More than 100% of nighttime power (6.4 trillion KWh/year) needs are met from the embankment canals.

The 600 km long CR with 360 bcm (12,700 tmc) storage would cost nearly 133.33 million US$ per km length totaling 80 billion US$ excluding the cost of the water pumping system from the reservoir for various uses. This works out to 6.27 million US$ per tmc (thousand million cubic feet) storage which is cheaper by 5.79 times compared to the cost of the ongoing Polavaram reservoir (195 tmc gross storage capacity) in India which is a union government-sponsored national project. The cost of Polavaram head works including the submerged land acquisition cost and rehabilitation expenditure of the displaced population is exceeding 7.1 billion US$. It works out to be nearly 36.27 million US$ per tmc storage. When the utility of the mega-scale deep-sea harbor associated with the CR is also taken into account, the cost applicable to freshwater storage would reduce further. The freshwater CR can harness nearly 1,050 bcm of water in a year with a water supply cost of less than 0.013 US$ per m^3 whereas the desalination cost for converting seawater into freshwater is more than 0.66 US$ per m^3 (50 times costly) excluding the cost of pumping to uplands in both cases [29, 30].

The entire project including the CR, PSHP/pumping stations (9,00,000 MW), embankment canals, barrages, tunnels, aqueducts, cross-over bridges, distribution canals, associated power plants (400,000 Solar PV and 400,000 wind/hydro), etc would cost nearly 1.65 trillion US$ (INR 123.15 trillion) which works out to US$ 5480 /acre (INR 0.411 million/acre) of irrigated area. Also, 1,483,000 MW PSHP potential created by the embankment canals is equal to nearly US$ 198 billion when monetized. The cost breakup of the total project is shown in Table 4.

The construction of the EWWT Project needs meticulous planning and monitoring to be completed within the optimum schedule as it is a gigantic and complex project.

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Initially, a detailed project report for the entire EWWT Project is to be finalized to assess the total PSHP potential after considering the field data. Workable layout provision is also to be made to achieve ultimate PSHP capacity on each embankment canal in a phased manner as and when required. While adding PSHP units after the commissioning of embankment canals, PSHP housings are constructed as floating caissons and are placed on the concrete rafts or pads before erecting electromechanical equipment. This method does not require dewatering the embankment canals and disrupting the pumping operation.

A union government-owned special purpose vehicle (SPV) entity is required to implement and monitor the entire project execution. EWWT Project is to be further divided into economically viable/profitable segments as energy storage/PSHP projects to carry out the execution by private developers on a build, own, operate, and transfer (BOOT) basis after 25 years of operation with contractual provisions to transport water in the embankment canals on chargeable basis at a prefixed price as given in the bid documents. Until the water supply is made available from the CR, the pumping/PSHP plants with associated embankment canals (50% of upstream and downstream embankment canals) will work as 100% energy storage plants by storing the daytime excess power from the solar power plants and generating power during the nighttime. The developers need to quote the fixed levelised cost of electricity (LCOE) at the accepted round trip efficiency to sell electricity during the night time for 25 years. Power required for energy storage and water pumping/conveyance by the PSHP plants will be sourced by the SPV and given to the PSHP developers free of cost. The contract agreement should also have provisions to refer a project development company to National Company Law Tribunal (NCLT) for protecting the stakeholders' interest and changing the project developer in case the project progress/milestones are not achieved in the agreed schedule. Wherever the cost of power generation is high, viability gap funding (VGF) will be offered to the developers to execute all segments of the EWWT Project at the scheduled time. Thus, when an embankment canal is completed along with its PSHP units, it will start earning revenue. Land/property acquisition and compensation to the displaced people are to be done by the union and state governments on behalf of developers.

Table 4: Capital cost break up of East to West Water Transfer Project

Item	Unit rate (US$ million)	Quantity	Cost (US$ billion)	Remarks
Coastal reservoir	133.33 per km	600	80	Twin bunds length. Including other items like barrages, bridges, navigational locks, laydown areas, etc.
PSHP plants	0.4 per MW in Pump mode	900,000	360	Turbine mode 576,000 MW rating. Mainly electro-mechanical and pump house components.
Embankment canals	66.66 per km	5,000	333	
Embankment canal crossings	13.33 per km	5,000	67	Underpass tunnels, overhead bridges, non-overflow dams, etc.
Land cost	7.657 per km^2	17,500	134	Including rehabilitation costs. The land area also includes required government lands.
Feeder and distribution canals, etc.	Lump-sum	-	333	To supply water from embankment canals for irrigation, etc.
Solar PV plants	0.53 per MW	400,000	213	
Wind/hydropower plants	0.8 per MW	400,000	320	
Total			1,840	Including all overheads at prevailing Indian prices in 2021
The monetized value of extra PSHP potential of embankment canals	0.133 per MW	1,483,000 MW	-198	At least 1,483,000 MW PSHP (pump mode) can be installed using embankment canals for meeting the ultimate power requirements from the energy storage. (refer to Table 3)
Net Total Cost			**1,642**	**1.65 trillion US$**.(123.15 trillion INR @ US$ = 75 INR)
Capital cost (US$/acre) for providing irrigation facility	4000 m^3 per acre/year	1,200 bcm	5480	411,000 INR per acre. 150 bcm of water is collected by the embankment canals while crossing various rivers in addition to a 1,050 bcm supply from the coastal reservoir.
Yearly revenue (billion US$) from PSHP operation to offset the operating cost	US$ 0.013 per kWh	1,360 billion kWh/year	18.13	Average 6.47 hours of operation in turbine mode per day of 576,000 MW (refer to Table 3).
Yearly rental income (billion US$) from the deep sea harbor	1.33 US$/ton of goods	1,000 million tonnes	1.33	Excludes other income from shipbuilding, shipbreaking, ship repairs, floating storage, transshipment of merchandise, etc

In addition, solar/wind/hydropower plants required for energy storage/water pumping purpose are offered to independent power producers (IPP) to sell power on LCOE basis to the SPV. The CR execution is also to be offered to the private developers for 25 years of operation on a BOOT basis for the ultra-deep sea harbor with VGF from the government. Ultimately, all the embankment canals are to be constructed and integrated/connected hydraulically to achieve the planned water pumping from the freshwater CR within 15 years.

Unhindered fish migration in both directions is feasible through the navigation locks and barrages to the freshwater CR and further to upstream rivers. Additionally, fish ladders are installed wherever required.

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The local fishermen's livelihood opportunities would be improved since the freshwater in the CR is more productive for fish growth and fishermen can catch the fish with lesser effort. Also, better access to the high seas from the deep sea harbor would enlarge the scope of deep-sea fishing. CRs help to mitigate the fury of nature like tsunamis, cyclones, floods, sea-level rise due to climate change, etc. As the CR water level is normally below sea level, the drainage of irrigated lands adjacent to the reservoir would improve and these lands are also protected from seawater inundation during storm surges, tsunamis, tidal bores, etc. Sea water ingress into the groundwater is also eliminated in the upstream area of the CR. Water supplied/pumped from the CR will build up the groundwater level in vast areas of India and adequate base flows would be available perennially from overflowing aquifers into the streams/tributaries/rivers [31]. Bangladesh would also get continuous freshwater supply from the CR via the Farakka barrage for protecting the freshwater mangroves located in the southwest of the country in addition to minimum environmental flows in the Ganga River [32]. Since the embankment canals also supply the water needed for base flows, salt export water, and minimum environmental flows in the rivers or streams which would flush/dilute the water pollutants to acceptable levels [33, 34, 35]. The embankment canals can also be used to divert river flood water to the CR to prevent flooding of downstream river. The overall net impact of CRs and their embankment canals is environment-friendly.

With the oceanic dikes, coastal lands (above the sea level) which are prone to seawater inundation can be reclaimed and used for agriculture, mangrove forests, industrial, and recreation purposes. Nearly one-third of the CR area can also be reclaimed economically by dredging soil from the shallow water area (up to 8 m depth) to build mega cities/real estate. The water holding capacity of the CR would not reduce by land reclamation as its average water depth increases though the water spread area is reduced. Devastating river floods in the delta plains of the river are drastically reduced as the CR water level is normally below sea level and the empty volume acts as a flood buffer. Most of the microplastics and floating plastic debris are trapped in the CR for recovery without passing into the ocean. As Bangladesh is highly vulnerable to floods and high tides, it will be well protected from storm surges, cyclones, floods, tsunamis, sea-level rise due to climate change, etc by the oceanic dike of the CR extending up to 12 m asl. Bangladesh can build a modern megacity of 7,500 km^2 area (5% area of the country) by land reclamation and the needed soil can be sourced from the shallow depth of the CR [36]. The project area is centrally located and not far from all parts of India. EWWT Project is located mostly in geologically stable and ecologically less sensitive areas to minimize the effect on flora and fauna. There is flexibility in routing/aligning the embankment canals to minimize the ecological damages and displacement of the population. The irrigation potential of the proposed EWWT Project is nearly 1.2 million km^2 which is nearly 66% of the entire arable land of India. All the arable land will be supplied with sufficient water throughout the year for multiple crops/perennial plantations [37, 38]. The additional water utilized in agriculture and forestry will enhance biomass availability and carbon storage in the topsoil. In the future, if there is a reduction in annual water flows into the CR due to adverse effects of climate change then less water will be used for consumptive purposes and more project infrastructure is used for energy storage purposes by the PSHP plants without any economic losses.

IV. CONCLUSION

CO_2 gas concentration in the atmosphere increased from 275 ppm by weight from the preindustrial age (1750 AD) to 413 ppm (nearly 800 billion tonnes of CO_2) by the year 2020 [39]. By converting 6 million km^2 of semidesert and desert lands into agricultural wetlands and cultivated forests with the water supply from the freshwater CRs, the CO_2 gas additionally sequestrated into the topsoil as soil carbon @ 38 tonnes of carbon per hectare is 22.8 billion tonnes of carbon which is equal to 84.5 billion tonnes of CO_2 [7, 8]. It would reduce the CO_2 concentration by 43.62 ppm in the atmosphere which is equal to the rise in global atmospheric CO_2 amount (43.5 ppm) in the last 20 years [39]. The additional carbon-neutral dry biomass produced @ 5 tonnes per hectare is 3.0 billion tons/year which is adequate to produce the required carbon-neutral bio-methanol, bio-ethanol, biodiesel, biogas, bio-hydrogen, etc fuels to replace all the fossil fuels used in hard to abate sectors like aviation transport, marine transport, and organic chemicals production. In all other sectors, carbon-neutral energy sources such as solar, wind, hydro, etc along with PHES would replace fossil fuels [9]. In addition to harnessing the global renewable water resources economically, the role of freshwater CRs is equally instrumental similar to the role of carbon-neutral renewable energy resources in achieving a carbon-neutral world in a sustainable manner to cater to the full energy needs of the global peak population.

DECLARATION

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	I am the sole author of the article.

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