RESEARCH ARTICLE

Efficacy of coastal reservoirs to address India's water shortage by impounding excess river flood waters near the coast

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Abstract: India is a sub-continent where presently 320 million people remain in the water-starved parts of the country and according to the UN, this number is expected to increase to 840 million in the year 2050. There is a severe demand-supply mismatch. Though there has been no significant change in India's rainfall pattern, the number of areas under drought in India is increasing every year. Increase in population is one of the reasons for water scarcity but the inefficient management of the received precipitation stands as the major cause. Though extreme rainfall events are significantly increasing, there is a spatial non-uniformity in the rainfall events that occur. This makes it difficult to pre-plan large scale water storage at different locations. Out of the 4,000 billion m^3 of freshwater available from precipitation per annum, major portion run off into the sea. The solution to India's water problem is to conserve the abundant monsoon water bounty, store it in coastal reservoirs, and use this water in areas which have occasional inadequate rainfall or are known to be drought-prone or in those times of the year when water supplies become scarce. It is estimated that about 4,400 thousand million cubic feet of rainwater just simply drains into the sea. This paper focuses on the concept of Coastal Reservoir. This basically means building a storage structure near the mouth of river. In this way, the amount of water that is wasted as run-off can be stored. The construction of a coastal reservoir does not involve many risk factors and disadvantages like relocation which would occur in an inland dam construction. The paper also presents the concept of Sarovarmala - a chain of coastal reservoirs which is an innovative concept that has the potential to ensure water availability to India throughout the year.
Keywords: coastal reservoirs, flood water, India's water resources, storage per capita

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1 Introduction

Demand for water keeps on increasing day by day. However, average rainfall has remained constant and it is plentiful. In India, it is about 4,000 billion m^3. But most of India's rainfall comes over a 4-month period starting from June to September. India also experiences years of excess monsoons and floods, followed by below average or late monsoons with droughts. Despite abundant rains in July to September, some regions face a shortage of drinking water, while some other parts of the country receive excessive rains resulting in floods. This geographical and time variance in the availability of natural water versus the year-round demand for irrigation, drinking and industrial water creates a demand-supply gap that keeps worsening with rising population. It is estimated that about 4,400 TMC ft of river flood water from west flowing rivers alone drains into the Arabian Sea. From this, it is very clear that India is not water-starved but storage-starved.

The solution to India's water problem is to conserve the abundant monsoon water bounty, store it in coastal reservoirs, and use this water in areas which have occasional inadequate rainfall or are known to be drought-prone or in those times of the year when water supplies become scarce. Per capita storage of water in India for domestic purpose is too small when compared with developed countries. It is wise to invest in storage of this excess flood water (which is reasonably diluted and cleaner) in the coastal reservoirs close to the places where rivers join the sea.

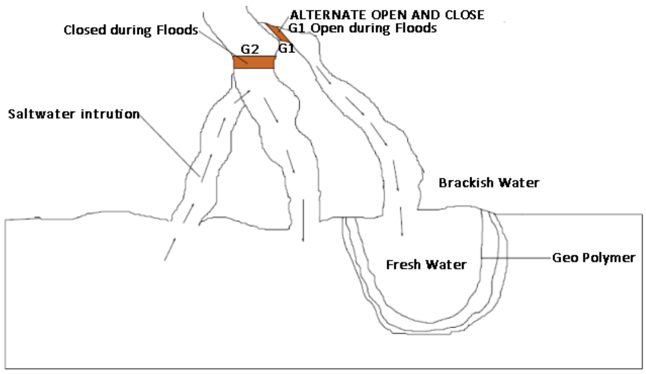

Figure 1. Schematic of a coastal reservoir that enables storage of freshwater during river floods.

The currently available solutions are unable to satisfy people's increasing need for water. As far as rain water is concerned, one area receives too much rain in the wet seasons thereby causing floods and excess rainwater discharge into the sea, while receiving a shortage of rain fall in dry seasons. Hence, the solution lies in utilizing or conserving the abundant monsoon water which runs off to the ocean.

There is a need for a method for developing a sustainable water source for managing rain water. There is further a need for storing flood water in sea based reservoirs by building impermeable sea walls and interlinking these reservoirs for transfer of water from one place to another. The primary objective of the present paper is to present a method for developing a sustainable water source for managing rain water. And highlight the potential of coastal reservoirs for storing flood water.

2 Current Water Solutions

There are different kinds of water supply options in the world. For example, groundwater, on-land reservoir, desalination of seawater, reuse of wastewater, diversion of water from a remote source. Each of these has its own characteristics. The primary renewable source of freshwater is rainfall. Rainwater, surface water, subsurface flow, ground water and sea water are other sources of water available for water supply options. Following are the different options:

1. More inland reservoirs - Very few large dams after the year 2000; more and more people have realized the problems of large dam construction on land. Silting process reduces storage - 75% of silt will be left on land. Further, India is the third largest dam building nation in the world with more than 6,000 dams (large dams).
2. Interlinking of rivers - to optimize the surface water.
3. Ground water.
4. Desalination plants.
5. Wastewater reuse facilities.
6. Coastal (sea based) reservoirs.

As the available fresh water sources are very less throughout the world, there is a stress upon the available sources and conservation structures. The focus of desalination and other techniques is increasing. However, for a developing country like India, it is very difficult to make a huge investment in projects like desalination, which requires a high maintenance cost.

Desalination is not environmentally viable and it affects marine environment where waste water is released. The coastal cities are normally more urbanized, and more and more urbanization is concentrated along the coasts. There is a rapid migration of people because of the job opportunities. There would be a rapid increase in population and the demand for water would increase exponentially. Presently, the solution for this issue would be a coastal reservoir, i.e. a reservoir in the sea to store a portion of the river flood waters which is joining the ocean in the monsoon periods and use it during the drought periods.

3 Coastal Reservoir to Store Flood Water

Coastal reservoir is a unique structure constructed at an estuary or gulf, bay or in the sea (point where a river meets a sea) to store the portion of excess water at flood time. This sea wall or dike structure may run for kilometers together in the coast line. Coastal reservoir has many advantages, such as no land acquisition problems, no land submergence and forest submergence like in inland reservoirs. They are already put to work in countries like the Netherlands, Singapore, China, India, South Korea, Hong Kong, United Kingdom, etc and proven to be beneficial. They are designed with gates so that the excess flood water which is more than the capacity of the reservoir can be discharged into the sea. Even inlets and outlets are controlled so that only good-quality water enters the reservoir with very little stagnation of water. One can adopt very innovative designs with smart sensor networks to operate the coastal reservoirs efficiently.

Figure 1 shows a typical schematic of a coastal reservoir which enables storing of fresh water during river floods. The fresh water reservoir includes an impermeable sea wall for containing the fresh water and preventing a mixing of the fresh water with the sea water. The sea wall is located on the sea bed having three-sided structure to prevent ingress of sea water into the fresh water/river course. By keeping out seawater, the construction of sea wall along with one or two barrages (with sluice gates) close to the mouth of river forms the fresh water reservoir in the ocean. Sea based reservoir is a part of the river watershed which is formed by the convergence of the rivers and allows fresh water and salts to join the ocean. The reservoir will be shallow waters and have an average depth of 10 to 20 m with a maximum depth of about 30 m. When it rains heavily during low-tide, the sea reservoir outflow crest gates will be lowered to release the excess rain water from the reservoir into the sea. If heavy rain falls during high-tide, the outflow crest gates remain closed and large reservoir can be designed so as to absorb the flood water shocks and release water out to sea only during low tides. The method further includes interlinking of these reservoirs at different locations across different rivers through underwater subsurface pipes for transferring water from one reservoir to another in shallow sea water (herein, we called this as Sarovar Mala; Sarovar means freshwater pond in Sanskrit and mala means necklace around the land)[1].

4 Scenario in India

India is a peninsula surrounded by ocean on three sides, enjoys a lot of monsoon rainfall because of its physical features. Indian peninsula receives an average annual rainfall of 4,000 BCM and this number has not changed much in the last 100 years. However, due to climate change, very intense rainfall events are causing floods in many regions in India. In some other areas, average annual rainfall is 300-650 mm, but it is very un-

Table 1. Comparison of sea based reservoir vs land based reservoir.

Item	Sea based reservoir	On land reservoir
Dam Site	Sea (Inside/outside river mouth)	Valley (limited area)
Water level	At sea level	Above sea level
Pressure	Low pressure along with wave surges	High water pressures
Catchment area	Entire Catchment of the river course	Partial catchment
Seepage	By density difference (Slow)	By head difference (fast)
Pollutant	Land based and sea water	Land based
Land acquisition	Nil	High
Environmental damage	Nil (no forest damage, no displacement of people, etc.)	Very high (difficult to build dams nowadays)
Water supply	By pumping	Mainly by gravity
Construction cost	Low	High

reliable and the southwest monsoon accounts for most of the precipitation. Different regions receive different amounts of rainfall, varying from 20 cm to over 800 cm. Despite that, we have a massive network of both perennial and non-perennial rivers that form a network within the country. India also has various water storing and conservation structures. India is the third largest dam building country in the world after USA and China. India has built more than 6,200 dams which are taller than 15 m and the majority of them ($>$ 80%) are earthen dams. Various storage structures lie at conflicting spots and hinder the socioeconomic condition of the people whenever there is a problem. Even these structures act as hotspots in both national and international borders. Inter-state water disputes have only increased in the recent times. As per the government of India information, there are 8 major inter-state water disputes in the country.

Due to various climatic factors, the total rainfall that should be received throughout the year is just received in 30-40 days. This would result in torrential rainfall and flash floods during monsoon. This precipitation water ultimately would mix in the ocean without any use during the time of need. Close to 80% of the total precipitation received over Indian peninsula joins the ocean in just 3 to 4 months every year. Because of the lack of the storage structures within the country (even with more than 5,000 large dams), we have a burning need of more storage structures to cater to water demands during times of drought. Even though land based reservoirs like dams have various advantages, they also have their own disadvantages. Land acquisition, clearing of forest areas, loss of bio-diversity, submergence of lands and forests, diversion works during construction etc are some of them.

5 Benefits of Coastal Reservoir

Table 1 shows the comparison of sea based reservoirs to the land based reservoirs. There are many advantages of the sea based reservoirs when compared with any conventional land based reservoirs [2].

Listed below are the advantages of coastal reservoirs:

1. No harm to any of the river basins and no alteration to the river course (no temporary diversions as well).
2. No disturbance to any forest cover and no submergence of land.
3. No physical displacement of people and their villages/-towns.
4. Agriculture activities can be augmented.
5. Coastal erosion can be minimized.
6. Ground water recharge due to fresh water in estuarine areas.
7. Intrusion of saline water into wells will reduce.
8. Freshwater dredging will provide sand for construction.
9. Earthquake resistant sea walls.
10. Solar panels on the sea wall - solar energy.
11. Tidal energy at the wall.
12. Roadways over the sea wall, Fresh water Fishing, Navigation and Tourism.
13. Real estate opportunities.
14. Length and width of sea wall - serve as a deep-water fishing harbour - benefit the fishing community.
15. Increase in industrial, recreational and fisheries activities around this fresh water.

Table 2 shows the existing coastal reservoirs in the world along with the purpose [3].

Table 2. Existing sea based reservoirs around the world.

Country	Name	Purpose
Netherlands	Afsluitdijk in the Ijsselmeer, 1932	Flood control
India	Thanneermukkom Bund, 1974	Agriculture
South Korea	1. Sihwa, 1994	Tidal energy
	2. Saemanguem, 2010	Land reclamation and fresh water
Hong Kong	1. Shek Pik, 1968 2. Plover Cove 3. High land	Fresh water
China	1. Qingcaosha, 2011 2. Chenhang, 1992 3. Baogang, 1985	Fresh water
Singapore	Marina Barrage, 2008	Fresh water
United Kingdom	Cardiff Bay Barrage, 1987	Fresh water lake

note: Under Planning Stage: 1. Pluit Reservoir Revitalization Project, Jakarta, Indonesia; 2. Kalpasar Project, Gulf of Khambhat, Indian Water Project, Gujarat; 3. Sydney and other coastal cities, Australia; 4. New York, USA.

Table 3. Cost of water and cost of construction.

	Cost per kilolitre of water in Indian Rupees (Rs)	Cost of construction / Billion Cubic Meters (in Indian Rupees)
Sea based reservoirs	Rs 2-10 (sea level)	Rs 20,000 Million / BCM
Inland reservoirs	Rs 30-100 (above the sea level)	Rs 100,000 Millions / BCM
Desalination	Rs 60-80 (sea level)	Rs 80,000 Millions / BCM

Table 3 gives the cost of water and cost of construction using coastal reservoirs in comparison to desalination, inland reservoirs, water recycling (from waste water). Cost of water per 1,000 liters (1 m^3 or Kilo liters) and cost of construction for storing 1 Billion Cubic Meter (BCM) of water has been estimated considering the costs of labor, materials and execution in India. Cost of water has been estimated at the location of coastal reservoir without considering the cost of pumping.

6 Coastal Reservoirs in India

6.1 Thanneermukkom Bund

Theneermokkum Bund (Figure 2) was constructed in 1974 as a part of Kuttanad low land development scheme and creation of fresh water reservoir in the coastal area of Kerala. Thaneermukkom salt water barrier/bund is considered the largest mud regulator in the country and is in operation since 1976. It divides the Vembanad Lake into fresh water lake fed by the rivers draining into the lake and brackish water lake fed by ocean currents into low lands of Kuttanadu. The Four major rivers of Kerala, the Pamba, Meenachil, Achankovil and Manimala flow into the region before they confluence into the Arabian Sea. It also has a major portion of the largest lake in Kerala "the Vembanad Lake". Lake is fed by ten rivers of which the above four major rivers form the main part. The region receives a good amount of annual rainfall which is above 3,000 mm and these four rivers bring a large quantity of water into the lake before joining sea. By constructing the salt water barrier, a coastal reservoir having fresh water has been created for increasing agricultural activities in the area in addition to land development. However, there are reports of environmental and ecological damage such as rampant propagation of water hyacinth in fresh water and deterioration of brackish water fishing in the area. However, these are related to the wrong operations of the reservoir and not the fully functional plan of Thaneermukkum Bund. The problems faced by fisherman and water hyacinth problems need to be addressed with innovative alternative schemes of operations. In fact, this fresh water reservoir is need of the hour and needs to be restored to its capacity for the supply of drinking water to nearby areas and also supply fresh water for irrigation in the low lands of Kuttandu, which helps farmers.

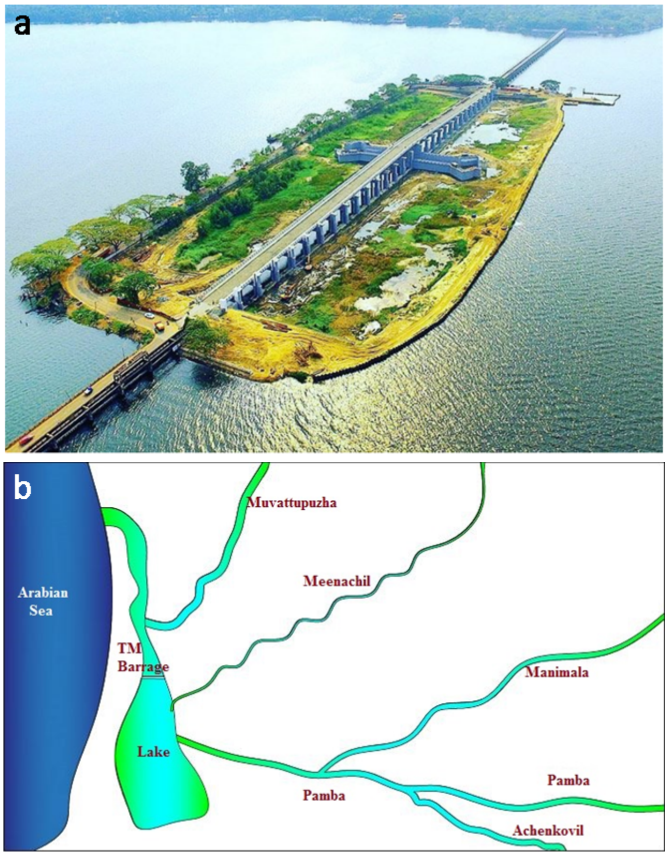

Figure 2. a) Bird eye view of Thanneermukkom Barrage. b) Location of barrage across Vembanadu Lake.

6.2 Kalpasar Project

The Gulf of Khambhat Development Project is mainly water resources project involving the creation of fresh water reservoir in the Gulf of Khambhat for meeting demand of irrigation, domestic and industrial water supply. Associated components related to the fresh water reservoir are use of top of the dam across the gulf as a surface transport link, potential development of fisheries, reclamation of saline land around the fresh water reservoir. The Gulf of Khambhat extends about 200 km from north to south and the width varies from 25 km at the inner end to 150 km at the outer mouth, covering an area of around 17,000 km^2, of which only 2,000 km^2 will be enclosed by constructing a dam across the gulf between Bhavnagar and Dahej. Figure 2 shows the Kalpasar project location and detailed plan of Gulf of Khambhat development wherein is a coastal reservoir is envisaged in Gulf of Khambhat and using contour canals to supply water the entire Gujarat Coast. The Kalpasar Project envisages building a dam across the Gulf of Khambat for establishing a huge fresh water reservoir for irrigation, drinking and industrial purposes. A 10 lane road link will also be set up over the dam, greatly reducing the distance between Saurashtra and South Gujarat by 225 km. A state government release said the Rs 55,000 crore (US$ 11.7 billion) project to be completed by 2020, will have a vast fresh water reservoir with gross storage of 16,791 million m^3 of water. The 64 km long dam across the Gulf of Khambhat connects Ghogha in Bhavnagar with Hansot in Bharuch District. The state government of Gujarat has signed an MOU with a Korean consortium to build the first ambitious sea wall project in the Gulf of Khambhat in the first quarter of 2016[4]. Once constructed, it will be one of the large freshwater reservoirs in the sea with highest priority for irrigation and drinking water in the region for Saurashtra and Central Gujarat regions of India.

6.3 Feasibility Study of Coastal Reservoir at Mangaluru from Flood Waters of Netravati River

Author has carried out a detailed feasibility study with a large multidisciplinary team on developing a sustainable water source for Bengaluru and Mangaluru using the coastal reservoir as a storage area for Netravati/Gurupura River flood waters, Karnataka, India. The principal objective of the project was to assess the feasibility of storing fresh water in a reservoir along the coast, by building a sea dike in the Arabian Sea. On one side, the dike will ensure the required quantity of fresh water which flows from the Netravati River to the reservoir, without being drained completely into the sea. On the other side, the sea dike will prevent the sea water from entering the reservoir avoiding salt contamination of the fresh water supply. The study addresses the coastal urban watershed management of Mangaluru city and agricultural land along the river and the coast, in the context of the proposed project of building a sea dike for the creation of a fresh water reservoir impounding river flood waters[5].

It is imperative that a small percentage of runoff of Netravati River is more than sufficient to cater the water requirements of Mangalore and Bangalore. From the data of last few decades, there are hardly any chances of scarcity of water availability in Netravati River. The concept of coastal reservoir emerges as the best solution to meet the future water demands of both Bangalore and Mangalore. The average annual runoff in Netravati River is 388.5 TMC. As per Bangalore Water Supply and Sewerage Board (BWSSB), shortfall in demand in Bangalore in 2051 is 26.16 TMC which is 7% of average annual runoff through Netravati. In 2021, the shortfall in demand is only 8 TMC which is just 2.1% of the runoff. There is hardly any chance of silting of reservoir as the average annual sediment load in Netravati River is 0.04 TMC. The water quality parameters in Netravati and Gurupura Rivers are in tolerable limits for safe drinking water, thus the water can be directly utilized without any major treatment. Benefiting sectors due to coastal reservoir are agriculture, prawn culture and sand dredging. The possible renewable energy generation implies that the system will be self-sufficient in energy to meet the energy demands for pumping, lighting and other requirements. Consultation and inputs from renewable energy developers would strongly support in the planning for cost-effective and sustainable technology installations for renewable energy generation. The coastal reservoir will not affect the built-up area. The land use indicates that built-up area is less, while the vegetation cover is more. Also, due to fresh water reservoir, a reduction of salinity of water is expected after the construction of coastal reservoir, its effects on the vegetation must be pre-assessed and analyzed.

6.4 Sarovar Mala (Garland of Reservoirs for India)

Sarovar Mala (Figure 3) is a concept of linking sea based/coastal reservoirs (Sarovar's in the ocean) at the mouth of rivers (where rivers in Indian Peninsula join the ocean. The main objective is to create a large of fresh water for developmental activities including drinking/agricultural activities and increase water storage per capita in the coastal areas. This is a strategic plan to increase the water storage per capita in India along the Indian coast by storing the excess flood waters from major rivers in southern Indian Peninsula, once these Sarovar's are connected by pipelines in shallow ocean waters along the coast (by using a shallow water spud barge which has side way lowering).

Along with the initiative of the Government of India to modernize India's ports, this fresh water reservoir (Sarovar) will aid the development of coastal areas. With the increased fresh water availability in the coast, the coastlines can be developed to contribute to India's growth. Sarovar Mala provides a good connectivity for non-perennial rivers and will provide a storage plan for fresh water from the excess river flood waters and can develop the industrial clusters and hinterland up to a radius of 100 km, which resulting in Sarovar becoming the drivers of economic activity in coastal areas.

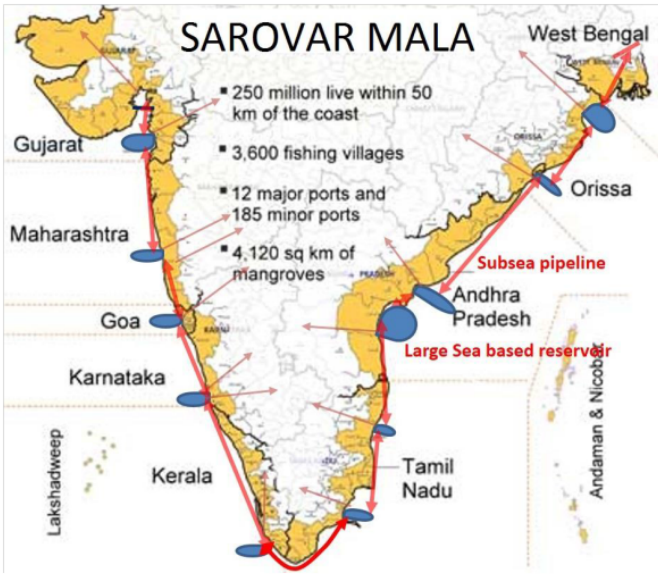

Figure 3. Sarovar Mala, a chain of freshwater reservoirs along the coastal line of India.

7 Concluding Remarks

India receives most of its fresh water during a four-month monsoon period during which time the lakes are filled, rivers experience floods and ground water is recharged. But due to the onset of climate change, the rainfall pattern changed resulting extreme variability of the rainfall is experienced. While some rivers receive huge quantities of rain resulting extreme flooding, other rivers and water bodies are bone dry. Indian population over the decades has increased so much, the density of population and dwindling forest coverage is not allowing the creation of fresh land based reservoirs. The original proposal of interlinking of rivers to overcome the ill effects of variable rainfall in India is practically dead and impossible to implement under the changed circumstances and huge cost of the project. Considering all the above, the solution lies in storing flood water in sea based reservoirs which are of immense value as they do not submerge lands. If heavy rain falls during high-tide, the outflow crest gates remain a closed and large reservoir of about $>$ 100 TMC ft (2.8 BCM) can be designed so as to absorb the flood water shocks and releases water out to sea only during low tides. Even the sand, silts and salts can join the ocean partly through the sea based reservoir. Sea based reservoir can be constructed in shallow waters at appropriate locations close to the mouth of the river along with a barrage at one or two ends. A detailed study is needed even considering salt water intrusion through estuaries, bays and gulfs. By connecting coastal reservoirs around the Indian Peninsula, Sarovar Mala will be a sustainable solution for Indian water requirements specifically in the coastal areas. More species of fish call these ponds home! This reservoir will increase Indias fresh water supply for generations to come and use the rivers flowing into Arabian Sea and Bay of Bengal.

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References

[1] Sitharam T G, 2016, Smart water network to store river flood water in sea based reservoirs and a method of interlinking these reservoirs (Sarovar Mala). India patent no. TEMP/E-1/44294/2016-CHE.

[2] Yang S Q, Liu J L, Lin P Z, *et al*., 2013, Coastal reservoir strategy and its applications, in *Water Resources Planning, Development and Management*, Intech, United States, 95-115. http://ro.uow.edu.au/eispapers/1763/

[3] Yang S Q and Kelly S, 2015, The use of coastal reservoirs and SPP strategy to provide sufficient high quality water to coastal communities. *Journal of Geoscience and Environment Protection*, vol.3(5): 80-92. http://dx.doi.org/10.4236/gep.2015.35010

[4] Kalpasar Government, 2016, The Gulf of Kambhat Development Project, Gujarat, KALPASAR. https://doi.org/10.14453/isngi2013.proc.51

[5] Bangalore Water Supply and Sewerage Board (BWSSB) Report, 2017, Sitharam *et al*., *Coastal reservoir at Mangaluru to impound Netravati River flood waters - A feasibility study in India*, 178.