Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 2	pp. 589-594	2016

Review Research Paper

Comprehensive Water Resource Management in Coastal Ecosystem of Odisha: A Critical Review

Ranu Rani Sethi*†, R. C. Srivastava*, Madhumita Das*, P. S. B. Anand*, Jugal Kishore Tripathy**
*ICAR-Indian Institute of Water Management, Bhubaneswar, India
**Aul Embankment Division, Department of Water Resources, Govt. of Odisha, India
†Corresponding author: Ranu Rani Sethi

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 21-04-2015
Accepted: 24-06-2015

Key Words:
Water management
Coastal ecosystems
Technological options

ABSTRACT

Most of the coastal ecosystems face double whammy problems in terms of excess water congestion during the monsoon period and non availability of freshwater during the post monsoon period. Ingression of saline water due to high tide is a challenge to humanity, in general, and agriculture, freshwater resource, fisheries and aquaculture in particular. Eastern part of India is highly populated with plenty of natural resources. But due to lack/poor irrigation infrastructure, maximum freshwater flows to the sea. Hence, this ecosystem requires adequate attention to develop and refine appropriate technological options to facilitate more freshwater availability throughout the year and check the saline water ingression in order to increase the overall land and water productivity of the area. Geographic, engineering, socioeconomic and environmental factors which are closely associated with the water management issues have been reviewed for proper water management options in the coastal ecosystem.

INTRODUCTION

Coastal ecosystems are the areas where land and water are joined together which is very sensitive to changes in the environment. The dynamic processes that occur within the coastal zones produce diverse and productive ecosystems which have been of great importance historically for human population (Kay & Alder 1999). These areas equate to only 8% of the world's surface area, but provide 25% of global productivity (Brown et al. 2002). Coastal water resources management integrates surface-groundwater-seawater interactions, which are associated with hydro geological, ecological, and environmental problems. The combined effects of increasing population in coastal areas, and rising sea level caused by global warming are further stress on freshwater supplies in coastal aquifers worldwide. The Intergovernmental Panel on Climate Change (IPCC 2001) predicts that by 2100, global warming will lead to a sea-level rise of between 110 and 880 mm, and it is generally understood that sea-level rise is expected to result in the inland migration of the mixing zone between fresh and saline water (FAO 1997).

Odisha, located in the eastern part of India is the most vulnerable site for climate change scenarios, but simultaneously it is one of the agriculturally potential states which are blessed with plenty of natural resources. But while comparing the overall productivity of the State, it is very low as compared to the national average. There is an ample scope to increase the crop productivity through proper technological interventions mainly in the irrigation sector. In this review paper an attempt has been made to identify different issues like geographic, engineering, socio-economic and environmental factors associated in coastal ecosystem for developing suitable planning on water management.

GEOGRAPHICAL ISSUES

Geographical issues are associated with the location of the coastal areas and major threat is the sea water level rise, which leads to increased saline water heads at the ocean boundary, and enhanced sea water intrusion in logical consequence. In order to tackle the problems related to sea water intrusion, field studies alone are very difficult to manage. Hence, mathematical simulation modelling can act as a tool to tackle the issue more effectively. Through numerical simulations, Sherif & Singh (1999) noted that a 500-mm rise in the Mediterranean Sea level will cause additional intrusion of 9.0 km in the Nile Delta Aquifer in Egypt, but the same rise in sea water level in the Bay of Bengal will only cause an additional increase in seawater intrusion of 0.4 km, which shows a vast difference in result. There are many researches in coastal areas which are concentrated on the interaction between surface water, groundwater and seawater. However, a part from this has concentrated on saltwater intrusion (Calvache & Bosch 1994). Li & Jiao (2003) noted that research on tide induced coastal groundwater-level fluctuation has played an active and crucial role in improving understanding of the interaction between groundwater and seawater. Salinity is the most important factor affecting the distribution of estuarine organisms. It is an essential element in determining estuarine habitat and directly affects the distribution, abundance and composition of biological resources. The seasonal time scale has been reported to be responsible for most of the net changes in salinity, due to seasonal differences in freshwater discharge and prevailing wind speed/direction. Tropical storms and high volume releases from control structures can eliminate vertical stratification and suppress tidal influences (Orlando et al. 1994). Besides natural forces such as tides, currents and wind, anthropogenic influences can greatly alter salinity variability.

ENGINEERING MEASURES

Many engineering measures like stabilizing coastal dunes, seawalls to absorb shock of the waves, reduce erosion of the shore; breakwaters and Groynes to protect coast from high energy waves, encourage build up of beach; Gabions to weaken wave energy, reduce coastal erosion has been standardized for protection of coastal ecosystem. But hardly very less work has been taken up for developing structures for water management issues in the coastal areas. Increased amounts of impervious surface may alter hydrodynamic processes and add to salinity variability (Lerberg 1997). Another significant problem relating to salinity alteration results from increased use of groundwater resources that can influence the balance between the fresh and saltwater boundary in aquifers. The freshwater in aquifers occurs as a lens over more dense seawater. The fresh and saline water layers are in a state of balance with the recharge rate and flow of groundwater into the ocean. When the water table is lowered by pumping, the cone of depression is reflected in a rise of the boundary between fresh and salt water (Dunne & Leopold 1978).

Bobba (2002) conducted numerical simulations of salt water intrusion into the Godavari delta, India, where simulations were used to demonstrate an apparent risk of mixing salt water with freshwater due to sea-level rise, but it is very difficult to delineate the effects of vertical infiltration of seawater into the aquifer vs. seawater intrusion in terms of lateral migration of the sea-freshwater interface. Hence, there is an urgent need that a simple method should be developed to assess the risk of seawater intrusion for the purpose of managing fresh groundwater resources in coastal areas. The development of a seawater intrusion hazard index could be modelled after the Coastal Vulnerability Index (CVI) to Sea-Level Rise (Thieler & Hammer-Klose 1999, 2000a,b) which is used to assess risk of property damage, and would allow regulators to rapidly assess the risk of seawater intrusion at various locations. Mathematical models are often three-dimensional, which require a detail and costly geological investigation to provide accurate results for calibration (Bredehoeft 2009). Computationally intensive optimization techniques have been developed to try to deal with heterogeneity numerically, but due to the nature of uncertainty in the subsurface, there is no substitute for thorough geological investigation (Bredehoeft 2009). The result is that even with almost unlimited computing power; too much is unknown about the subsurface to build accurate regional scale models to assess the vulnerability of a single well to salt water intrusion (Sanford & Pope 2009, 2010).

Groundwater flow modelling has been undertaken in an area of 10500 ha within the regional unconfined aquifer system of a coastal plain of southern Australia, in the vicinity of the town of Cooke Plains, to predict the impact of various land management options (including recharge reduction and discharge enhancement) on the extent of land salinization caused by shallow saline water tables. Sensitivity analysis was performed to assess the influence of mesh size, boundary conditions, and aquifer parameters, and particularly rates of recharge and evaporative discharge, on groundwater levels. The results showed that continuing current annual crop-pasture rotations will result in water table rises of approximately 0.2 m in 20 years (significant in this setting), with a further 50 ha of land salinized. A reduction in the rates of groundwater recharge through the establishment of high water-use perennial pastures (e.g. lucerne) showed the most promise for controlling groundwater levels. Enhanced groundwater discharge such as pumping from a windmill was found to be non-viable due to the relatively high aquifer transmissivity and specific yield. The modelling approach has enabled a relatively small area within a regional aquifer system to be modelled for a finite time (20 years) and has shown that the extension of the boundaries of the model would not have altered the predicted outcomes. Modelling has demonstrated that dryland salinization can be controlled by reducing groundwater recharge over substantial tracts of land, and is not dependent on recharge reduction over an extensive area up-gradient, at least over the next 20 years (Pavelic et al. 1997). The increased volume of runoff, combined with the "flashiness" of discharge events, can result in straighter stream channels (Arnold & Gibbons 1996). With increase in impervious coverage, the velocity and volume of surface runoff increases with a corresponding decrease in infiltration. Decreasing infiltration reduces groundwater recharge and lowers the water table. Physical and ecological changes associated with imperviousness were discussed by Schueler (1994).

SOCIOECONOMIC FACTORS

The rapid expansion in groundwater abstraction over the past 30 to 40 years has supported new agricultural and socioeconomic development in regions where alternative surface water resources are insufficient, uncertain or too costly. Over-abstraction leads to groundwater depletion, loss of habitats and deteriorating water quality. In 9 out of 11 countries where coastal over exploitation was reported to exist, salt water intrusion is the consequence. The exploitation of coastal aquifers always produces a lowering of the water table levels, balanced by sea level in the coastal strip. When extracted volumes are greater than the recharge, even on a local basis, salinization process begins in aquifer as the seawater flows under the land. In light of this, management of coastal aquifers is conditioned by the need to determine the maximum permissible penetration limit for each particular aquifer.

ENVIRONMENTAL FACTORS

Salinity changes in the scale of tidal creeks occur in response to runoff events. Lerberg (1997) examined water quality in the tidal creeks of the Charleston Harbour estuary and found that salinity varied within creeks, among creeks, and among watershed classes. He found that tidal creeks were much more dynamic than most large estuaries and experienced salinity fluctuations greater than 6 ppt over a tidal cycle. Lerberg (1997) also found that the variance in salinity, as represented by the salinity range, was greater in creeks surrounding suburban, urban and industrial land uses, than those that were forested upland creeks. These changes in salinity variance were related to increased amounts of impervious surface at the anthropogenically impacted sites. Increased amount of impervious surface alters hydrodynamic processes, especially the rate at which runoff from rainfall events reaches receiving waters. Extreme and highly variable fluctuations in the salinity pattern are an indicator of hydrodynamic changes to tidal creeks resulting from watershed development. Saltwater encroachment can occur in the coastal environment from salt water displacing or mixing with freshwater in an aquifer (Todd 1980). Encroachment of salt water can be caused during drought conditions or through over pumping of freshwater from an aquifer. Several methods can be employed to control saltwater encroachment including modification of pumping patterns, artificial recharge, extraction barriers, subsurface barriers, and saline scavenger wells (Todd 1980). A number of areas have been forced to deal with salinization of their ground water because of saltwater encroachment. Based on reductions in the differences in loads and concentrations between upstream and downstream sites, there is less potential to reduce nutrients and sediment, once these materials are in stream flow, than when water is moving to streams through a riparian buffer. A downstream pond that received inputs from both the north and south basins had significantly lower concentrations of most nutrients and sediments than either of the upstream sampling sites (Lowrance et al. 2007). A changing groundwater table can affect the flow regime between surface water and groundwater. Quantitative approaches are required to understand how such changes influence the flow regime. A comparison of lakes and rivers reveals that the latter are less likely to disconnect in response to a decrease of the regional groundwater table (Brunner et al. 2009).

COASTAL WATER MANAGEMENT IN INDIA

In India, the coastal zone is defined as an area from the territorial waters limit (12 nautical miles) including its sea bed upto the landward boundary of the local self government abutting the sea coast (CRZ 2011). India with its 7,500-km coastline in 9 coastal states holds about 49% of the country's population. The coastal state has a population density ranging from more than 2000 people per sq. km in Kerala to more than 600 people per sq. km against the national average density of 300 people per sq. km. The population load increases agricultural activities at the same pace. But the majority of the coastal soils are waterlogged, saline to saline-sodic, low in carbon content and poor in productivity. Few studies revealed that subsurface drainage improved the fertility status of the soil. Sustained operation of subsurface drainage system could maintain a favourable salt balance in the topsoil layer (0-30 cm) enhancing microbial activity and consequently nitrification. As a result, the nitrite concentration in soil water at field capacity was within the permissible limit of 0.9 mg/L in the rhizosphere. There was, however, a higher amount of nitrite accumulation in the area with impeded drainage (Singh et al. 2007). A number of projects have been taken up in coastal saline hazard areas utilizing the minor creeks and channels for storing the freshwater for irrigation and side by side injecting the freshwater into saline water bearing shallow aquifers so that the salinity of water can be reduced and make it useful for irrigation and other purpose. Improvement of irrigation facilities, renovation of the creek system and sluice -check weirs have been constructed to regulate seawater ingress and to impound the freshwater in the creeks through tidal influx. A proper sluice arrangement was made at the end of each creek. During full moon and new moon days sluice gate is opened for entry of freshwater into the creeks and once the creek gets filled up, the sluice gate is closed. The freshwater, thus impounded is being used for irrigation through indigenous devices. In Odisha, seven pilot schemes in parts of Bhadrak, Kendrapara and Puri districts were taken up under schemes of "Arresting Salinity Ingress and Ground Water Recharge" by Central Groundwater Board, Bhubaneswar, Odisha. It was observed that creeks and sub creeks are required to be desilted frequently, suitable outlet should be provided to increase irrigation intensity, sluice gates are required to be maintained properly and should be strengthened, inflow and outflow of fresh/tide water should be monitored properly (CGWB web site). A study conducted in the Sunderban coastal ecosystem of West Bengal, which is famous for mangrove forests, aquatic resources, rich biodiversity and indigenous traditional knowledge of the local people. But this area is now under the adverse impact of climate change. Most of the water management technologies were practiced by the community as a whole. The technique like land shaping was related to soil management and irrigation to solve the increasing problem of soil salinity due to climate change. The different practice like ail cultivation, dhibi cultivation, circle cultivation and then digging of soil through spade were related to cultivation practice and soil management. (Sarkar & Padaria 2011). Intensive rice cultivation in a coastal groundwater basin in Balasore district of Odisha province (eastern India) during the monsoon and winter seasons has resulted in extensive pumping of groundwater by a network of shallow, mini-deep and deep tubewells. Particularly, shallow tubewell owners using centrifugal pumps are unable to lift groundwater during winter seasons due to the rapid drawdown of groundwater table below suction lift caused by mini-deep and deep tubewell owners. The seawater intrusion front is also progressing inland at an alarming rate. To develop a long-term sustainable land and water management strategies for the aforementioned issues in humid regions, the district administration realized the need for crop planning and water resources management policies in deterministic and stochastic regimes. As non-structural measure, the deterministic linear programming and chance-constrained linear programming models were developed to allocate available land and water resources optimally on seasonal basis so as to maximize the net annual return from the study area, considering net irrigation water requirement of crops as stochastic variable. Sensitivity analysis of the models has been carried out by varying three ranges of cropping scenarios (20, 40 and 50% deviation from the existing cropping pattern) and combinations of surface water and groundwater at various risk levels (10, 20, 30 and 40%). The total groundwater available and withdrawal in the region are 655.87×103 and 255.03×103 km^3, respectively. The study reveals that 40% deviation of the existing cropping pattern is the optimal that satisfies the minimum food requirement and maintain geo-hydrological balance of the basin. The sensitivity analysis of conjunctive use of surface water and groundwater shows that 20% surface water and 30% groundwater availability as the optimum water allocation level. The proposed cropping and water resources allocation policies of the developed models were found to be socio-economically acceptable that maintained the balance of the entire system, considering all the constraints and restrictions imposed (Sethi et al. 2006).

Geo-morphological changes of a tidal inlet are governed by complex interactions of tidal currents, waves and sediments. Tidal inlet(s) of the Chilika lagoon on the east coast of India and its geo-morphological changes is linked to the contemporary phase of lagoon transformation such as sedimentation (from riverine discharge, land drainage and decay of macrophytes), choking of the outer channel, northward shifting, closing and opening of inlet(s). These transformations are responsible for decrease in salinity, depth and weak lagoon-sea interaction, which in turn are responsible for decline in water area, increase in vegetated area (macrophyte growth) and decrease in fish productivity. The present study investigates the past and present geo-morphological changes of Chilika inlet(s) using historical data, satellite data, field observations and numerical modelling techniques. A numerical model was used to simulate the hydrodynamic conditions and salinity distribution in the lagoon for one inlet and multiple inlets and the results are calibrated with observations. The study suggests that tidal inlet(s) and its geo-morphological changes have significant impacts on ebb and flood currents at the inlet(s), salinity distribution in the lagoon, sediment and water exchange between the lagoon and sea (Panda et al. 2013).

Similarly, coastal lands around the Bay of Bengal in Central Godavari Delta are mainly agricultural fields with paddy crops throughout the year. Canals of Godavari River are the main source of water for irrigation. Geophysical and geochemical investigations were carried out in the study area to decipher subsurface geologic formation and assessing seawater intrusion. Electrical resistivity tomographic surveys carried out in the watershed-indicated low resistivity formation in the upstream area due to the presence of thick marine clays up to a thickness of 20-25 m from the surface. Secondly, the lowering of resistivity may be due to the encroachment of seawater in to freshwater zones and infiltration during tidal fluctuation through mainly the Pikaleru drain, and to some extent through Kannvaram and Vasalatippa drains in the downstream area. Groundwater quality analyses were made for major ions revealed the brackish nature of groundwater water at shallow depth. The in situ salinity of groundwater is around 5,000 mg/L and there is no groundwater withdrawal for irrigation or drinking purpose in this area except Cairn energy pumping wells which is used for injecting brackish water into the oil wells for easy exploration of oil. Chemical analyses of groundwater samples have indicated the range of salt concentrations and correlation of geophysical and borehole litholog data in the study area, predicting seawater-contaminated zones and influence of in situ salinity in the upstream of the study area. The article suggested further studies and research work that can lead to sustainable exploitation/use and management of groundwater resources in coastal areas. (Gurunadha Rao et al. 2011).

The suitability of the widely used existing solution for calculating groundwater mound due to artificial recharge from rectangular areas is examined for its applicability to unconfined aquifers, and this solution has been found applicable only to confined aquifers. The solution applicable for confined aquifers is derived and shown equivalent to the existing solutions. A computationally simple function is proposed for accurately approximating the integral appearing in this or existing solutions. A procedure involving analytical approximation is outlined for using this solution for unconfined aquifers. A method to calculate ground- water mound height in unconfined aquifers due to arbitrarily varying temporal recharge (percolation) is also proposed (Singh 2012).

In Odisha, as per coastal regulatory zone act, out of 6 coastal districts, 1036 villages consisting of 3,150,576 populations are located within 0-15 km away from the coast line. Water quality in coastal areas showed that pH ranges from 6.9 to upto 10 and electrical conductivity ranges from as low as 171 μS/cm to as high as 7940 μS/cm. As such the analysis of water samples reveal that the water is in general of potable nature and fit for irrigation purpose. But pockets of saline water exist. The lower part of the command area, particularly in the Ersama, Kujang block of Jagatsinghpur district and Mahakalpara Block of Kendrapara district, has been affected by quality problem of higher electrical conductivity. It is reported as the after effect of Super Cyclone in 1999, when seawater has entered into the phreatic aquifer system and in absence of proper natural flushing out mechanism is yet to be stabilized. Moreover, it has also rendered vast patched of agricultural land into a barren one (Pati et al. 2012). The major problem that exists in irrigation command is more water at head reach and limited water at tail reach. Due to large variations and unequal supply of irrigation water, productivity remains a major constraint in most of the command area. To improve WP, a study was conducted in distributory no. 5 (CCA 753.92 ha) of Pattmundai Canal (Mahanadi Delta-I) in Cuttack district of Odisha. To provide irrigation in winter season, shallow bore well and open wells were constructed on participatory mode (50:50 basis) by involving group of farmers. Different crops were grown by using groundwater during winter season and assessed water productivity and other important parameters at project site and of total command area. The result reveals that the water productivity of the experimental area was quite higher than the water productivity of the selected command area. This was due to better irrigation management practices followed through ground water use. Similarly, due to a good amount of ground water available at shallow depth, particularly in coastal belt of Orissa, there is ample opportunity to grow three crops in a year and improve water use efficiency/ water productivity of the irrigation project (Singhandhupe et al. 2009). Management of water below the canal outlets offers the greatest scope for increased production and productivity in the irrigation commands. A review paper presents major issues and options available for on-farm water resources management in canal commands of one of the eastern most state of the country (Odisha) with an aim to fine-tune the activities that are, at present, undertaken for resource optimization. The traditional management systems of the area, on-farm-development measures taken through the centrally sponsored Command Area Development and Water Management (CADWM) programme and farmers' involvement in the process of distribution and utilization of irrigation water are presented in the paper (Panigrahi 2009). A multi cropping technology has been developed in deep waterlogged areas located in Alisha and Churali villages of Satyabadi block and Talajanga village of Puri. The technology is being successfully implemented in several coastal districts of Odisha which has increased the agricultural income of the farmers to 200 per cent. It has enormous potential in coastal Odisha as 85,000 hectare land suffers from the problem of waterlogging rendering such huge area under productive (Kar et al. 2010).

RESEARCH GAPS

Huge investments have been made for the development of water resources through the construction of irrigation projects. But a major chunk of the resources remain unutilized because of lack of management of water resources below the outlet level. On-Farm-Development activities through the CADWM programme have been proved to be the most effective method for reducing inequality in distribution of irrigation water below the outlets and increasing irrigation efficiency. The activities should therefore be extended to all the irrigation projects of the state. As the climatological and geo-morphological situation of the state of Odisha accelerates surface and subsurface flows, the option of having a series of drainage-cum-recycling projects to take the lost water back to the canals or the crop fields at higher elevations is the best option to increase irrigation efficiency and should also be extensively practiced in all canal systems of the state. These programmes can be effectively implemented with involvement of the farmers as a group (Water Users' Association) in the process of operation, management and up-keepment.

SUGGESTED TECHNOLOGICAL INTERVENTIONS

Though many researches has been carried out in coastal areas of India, still there is a lot of potential of productive utilization of land and water resources which could be addressed by increasing the cropping intensity, identifying ways for crop diversification and multiple use of water. But it has been observed that a majority of farmers have marginal land holding i.e., below 1 ha. So it is not feasible to spare any land for construction of small/large water harvesting structures, however there is changes to renovate community based existing water resources infrastructures and develop appropriate technological options for increasing the land and water productivity. It requires monitoring the existing pattern of soil and water salinity status with respect to time. Accordingly based on the hydrologic study and hydraulic aspects, design of irrigation systems could be developed to ensure the availability of freshwater resources, which has the potential to improve farm income and water productivity. Simultaneously water users group should be strengthened to properly maintain and control the water resources infrastructure for livelihood sustainability of farmers of coastal ecosystem.

REFERENCES

Arnold, C. L. and J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association, 62(2): 243-258.

Bobba, A.G. 2002. Numerical modelling of salt-water intrusion due to human activities and sea-level change in the Godavari Delta, India. Hydrological Sciences, 47(S): S67-S80.

Bredehoeft, J. 2009. Maintaining high fluid pressures in older sedimentary basins, Geofluids, 9(3): 179-181

Brunner, P., Simmons, C. T., and Cook, P. G. 2009. Spatial and temporal aspects of the transition from connection to disconnection between rivers, lakes and groundwater. Journal of Hydrology, 376(1-2): 159-169.

Brown, K., Tompkins., E.L. and Adger, N. 2002. Making Waves: Integrating Coastal Conservation and Development. Earthscan Publications Limited, London.

Calvache, M.L.L. and Pulido-Bosch 1994. Modelling the effects of salt-water intrusion dynamics for a coastal karstified block connected to a detrital aquifer. Groundwater, 32(5): 767.

CRZ 2011. Coastal Regulation Zone Notification. Ministry of Environment and Forests CGWB, http://cgwb.gov.in/GroundWater/AR/Orissa.pdf

Dunne, T. and L. Leopold 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

FAO (Food and Agriculture Organization) 1997. Seawater intrusion in coastal aquifers: guidelines for study, monitoring and control. Rome, Italy: FAO Water Reports.

Gurunadha Rao, V. V. S., Tamma Rao, G., Surinaidu, L., Rajesh, R. and Mahesh, J. 2011. Geophysical and geochemical approach for seawater intrusion assessment in the Godavari Delta basin, A.P., India. Water, Air & Soil Pollution, 217(1-4): 503-514.

Intergovernmental Panel on Climate Change (IPCC) 2001. Intergovernmental Panel on Climate Change Third Assessment Report-Climate Change 2001. Synthesis report. http://www.ipcc.ch/pub/reports.html (accessed June 20, 2008).

Kar, G., Sahoo, N., Das, M., Roychoudhury, S. and Kumar, A. 2010. Deep water rice and pond based farming system for enhancing water productivity of seasonal flood prone areas. Research Bulletin No. 48, Directorate of Water Management (Indian Council of Agricultural Research), Chandrasekharpur, Bhubaneswar, India.

Kay, R and Alder, J. 1999. Coastal Planning and Management. E & FN Spon, London.

Lerberg, S. B. 1997. Effects of watershed development on macrobenthic communities in the tidal creeks of the Charleston Harbor estuary. M.S. Thesis. University of Charleston, Charleston, SC.

Li, H. and Jiao, J.J. 2003. Tide-induced seawater-groundwater circulation in a multi-layered coastal leaky aquifer system. J. Hydrology, 274(1-4): 211-224.

Orlando, S. P., Wendt, P. H., Klein, C. J., Pattillo, M. E., Dennis, K. C. and Ward, G. H. 1994. Salinity characteristics of South Atlantic estuaries. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Panda, U.S, Mohanty, P.K. and Samal, R.N. 2013. Impact of tidal inlet and its geo-morphological changes on lagoon environment: A numerical model study. Estuarine, Coastal and Shelf Science, 116: 29-40.

Panigrahi, D. 2009. On-farm water management options for increasing irrigation efficiency in command areas of Orissa. Odisha Review Paper, pp. 51-57. http://orissa.gov.in/e-magazine/Orissareview/2009/October/engpdf/Pages51-57.pdf

Pati, G.C., Choudhury, A. and Nayak, R.K. 2012. Groundwater management as a possible solution to combat water logging and soil salinity in Mahanadi Delta Stage-I command area, Odisha. In: Proceeding of India Water Week 2012-Water, Energy and Food Security: Call for Solutions, 10-14 April 2012, New Delhi.

Pavelic, P., Narayan, Kumar A. and Peter J. Dillon 1997. Groundwater flow modelling to assist dryland salinity management of a coastal plain of Southern Australia. Soil Research, 35(4): 669-686.

Lowrance, R., Sheridan, J.M., Williams, R.G., Bosch, D.D., Sullivan, D.G., Blanchett, D.R., Hargett, L.M. and Clegg, C.M. 2007. Water quality and hydrology in farm-scale coastal plain watersheds: Effects of agriculture, impoundments, and riparian zones. Journal of Soil and Water Conservation, 62(2): 65-76.

Sanford, W.E. and Pope, J.P. 2010, Current challenges using models to forecast seawater intrusion: Lessons from the eastern shore of Virginia, USA. Hydrogeology Journal, 18(1): 73-93.

Sanford, W.E., Pope, J.P. and Nelms, D.L. 2009. Simulation of groundwater-level and salinity changes in the eastern shore, Virginia. U.S. Geological Survey Scientific Investigations Report, 2009-5066, 125 pp.

Sarkar, Sujit and Padaria, R.N. 2011. Understanding indigenous knowledge system in coastal ecosystem of West Bengal. Journal of Community Mobilization and Sustainable Development, 6(1).

Schueler, T. R. 1994. The importance of imperviousness. Watershed Protection Techniques, 1(3): 137-140.

Sethi, L. N., Panda, S. N., and Nayak, M. K.2006. Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India. Agricultural Water Management, 83(3).

Sherif, M.M., and V.P. Singh. 1999. Effect of climate change on sea water intrusion in coastal aquifers. Hydrological Processes, 13(8): 1277-1287.

Singh, S.K. 2012. Groundwater mound due to artificial recharge from rectangular areas. Journal of Irrigation and Drainage Engineering, 138(5): 476-480.

Singh, Man, Pabbi, S., Bhattacharya, A.K and Singh, A.K. 2007. Nitrite accumulation in coastal clay soil of india under inadequate subsurface drainage. Agricultural Water Management, 91(1-3): 78-85.

Singhandhupe, R.B., Sethi, R.R., Chakravarty, H., James, B. K. and Kumar, A. 2009. Increasing water productivity in canal command of Odisha - A case study in coastal area. In: Proceeding of 60th International Executive Council Meeting & 5th Asian Regional Conference, 6-11 December 2009, New Delhi, India

Thieler, E.R., and Hammar-Klose, E.S. 1999. National assessment of coastal vulnerability to future sea level rise: Preliminary results for the U.S. Atlantic Coast: U.S. Geological Survey, Open-File Report 99-593, 1 sheet, accessed at: http://pubs.usgs.gov/of/1999/of99-593/.

Thieler, E.R., and Hammar-Klose, E.S. 2000a. National assessment of coastal vulnerability to future sea-level rise: Preliminary results for the U.S. Pacific Coast: U.S. Geological Survey, Open-File, Report 00-178, 1 sheet, accessed at: http://pubs.usgs.gov/of/2000/of00-178/.

Thieler, E.R., and Hammar-Klose, E.S. 2000b. National assessment of coastal vulnerability to future sea-level rise: Preliminary results for the U.S. Gulf of Mexico Coast: U.S. Geological Survey, OpenFile Report 00-179, 1 sheet, accessed at: http://pubs.usgs.gov/of/2000/of00-179/.

Todd, D. K. 1980. Ground Water Hydrology. John Wiley and Sons, Inc., New York, NY.