



Asia-Pacific Network for Global Change Research

# Optimization Strategies for the Management of Change in Coastal Zones and Inland Waters Caused by Salinity Intrusion

## Final report for APN project 2005-17-NSG-Costa

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# **Optimization Strategies for the Management of Change in Coastal Zones and Inland Waters Caused by Salinity Intrusion**

**2005-17-NSG-Costa**

**Final Report submitted to APN**

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## **Overview of project work and outcomes**

### **Non-technical summary**

Changes in coastal zones and adjacent waters, caused by extraction of water and resulting salinity intrusion has been a problem and is an emerging problem in many countries, and is the case in certain locations of all the participating countries. As managing such changes and related quality degradation of water necessitates tools and information here initially preliminary data as well as information was collected and analyzed. The proponent and the Indian counterpart met with other stakeholders in India and the project was discussed. Thereafter the proponent organized a workshop at the Galadari Hotel, Colombo, Sri Lanka on the 5<sup>th</sup> and 6<sup>th</sup> of October 2005, where the collaborators as well as other stakeholders came together at the workshop to develop a strategy to identify the scope of the problem, the desired tools and solutions and the methodology of detail investigation.

Thereby a draft detail research proposal to investigate this issue was developed. This proposal was then finalized and submitted to APN. The workshop / proposal had inputs from all the participating countries, the International Water Management Institute, LOICZ South Asia node, and the ESSP - Global Water Project. In addition it had much input from many Scientist, policy makers and engineers in numerous countries involved in this area.

### **Objectives**

The main objectives of the project were:

1. Identify the scope of the problem.
2. Conducting a workshop in order that stakeholders could come together to, develop a research methodology / proposal to identify multiple objectives optimal strategies for the effective management of change that occur in coastal zones and inland waters.

### **Amount received for each year supported and number of years supported**

Total award 16,000 US Dollars for the year 2005.

Number of years supported – one.

Amount spent / received 13,672US\$.

### **Participating Countries**

New Zealand, Australia, India, Sri Lanka and Japan

## **Work undertaken**

1. Information / data collection in each site.
2. Establishing contact and meeting with stakeholders.
3. Organizing of workshop in Sri Lanka to develop research proposal
4. Conducting of workshop with the participation / input of all collaborators, international agencies such as IWMI, LOICZ – South Asia node and policy makers.
5. Finalization of proposal and submission of proposal to APN.

## **Results**

1. A research proposal was developed to identify a universally applicable generalized model for forecasting salinity intrusion as well as managing changes in coastal zones and inland waters caused due to salinity intrusion.
2. The profile and awareness of continuous change in coastal zones and inland waters, and related issues were increased.
3. Links with policy makers and stakeholders were established.
4. International understanding was enhanced.
5. An international team was developed.
6. A conference paper was developed.

## **Relevance to APN scientific research framework and objectives**

In recent times, the unmanaged extraction of ground water together with other effects like global warming, sea level rise, and tsunami after effects have resulted in continuous change within fresh water bodies in coastal zones. Changes in catchments characteristics also interact with socio economic changes. This project intended develop a research proposal that will investigate these changes and explore ways of managing the resource / human interactions.

This project falls in to theme 4 of the APN Science agenda - Use of resources / water, and pathways for sustainable development. The project also lied across several other themes as it has elements of, Theme 2 Ecosystems (Extent, causes and impacts of land use change, assessment and enhancement of land use sustainability) and, Theme 5 Cross cutting and science policy linkage (as it related to Global change and water, science policy interfacing relating to global change and, sustainable management of coastal zones).

## **Self-evaluation**

The project was extremely successful. It proceeded very much as planed and budgeted. There were neither slippages nor variations. All project objectives and more were met.

## **Potential for further work**

1. The long term and short-term effect of salinity intrusion on coastal zones and adjacent inland waters must be investigated.
2. Simple and easy to use optimization model, that would yield optimization strategies and best practices for the management of change in coastal zones and inland waters caused due to salinity intrusion needs to be developed and this information disseminated to policy makers.

## **Publications**

A conference paper was developed and sent for publication in proceedings and presentation at the 15<sup>th</sup> Congress of the International Association for Hydraulic Research – Asia Pacific Division (IAHR-APD August 2006) – (Being reviewed - Pending)

## **References**

1. De Costa. S., Porter. M., and Jones. A., 2003: Comparative analysis of salinity intrusion-Case of the Waiwhetu aquifer New Zealand and the Bundaberg aquifer Australia, Proceedings of the 30<sup>th</sup> Congress of the IAHR, Theme B, pp.565-572.
2. De Costa. S., Kojiri. T. and Porter. M., 2004: Salinity Intrusion – Its characteristics and impact, - Cases of the Asia Pacific Region, Proceedings of the 14<sup>th</sup> Congress of the International Association for Hydraulic Research – APD.
3. Ishikawa. T., Tsuruta. Y., Nishida, S., and Narita, M., 2001: Salt water behaviour near exit of lake Ogawara, relation to breeding *Cubicula Japonica*, Proceedings of 29<sup>th</sup> IAHR Cong., Vol. 2.
4. Kurupparachchi. D., 1995: Impact of irrigated agriculture on ground water resources of Sri Lanka, Proceedings of the Sri Lanka Association of the Advancement of Science, pp.49-66.
5. De Costa. S., Kojiri. T. and Porter. M., 2005: A study on salinity intrusion phenomena and its impact on the environment - Proceedings of the 31<sup>st</sup> Congress of the International Association for Hydraulic Research, Vol. 1, pp.313-318.
6. Joint START/ LOICZ / IGBP-SL workshop, Proceedings of the South Asian regional workshop on Estuarine modeling and coastal zone management, 1999.

## **Acknowledgments**

The authors sincerely thank APN, not only for the financial support but also for their kind and efficient support and assistance given throughout the project. In addition the authors wish to thank each of the collaborating institutes for all the support.

## **Technical Report**

## Preface

Changes in coastal zones caused by, salinity intrusion is, or would be a problem in many countries. Managing such changes necessitates many tools. A workshop at Galadari Hotel, Colombo, Sri Lanka was held on 5<sup>th</sup> and 6<sup>th</sup> October 2005, in which collaborators and other stakeholders came together to develop a strategy to identify the scope of problem, the desired tools and methodology of detail investigation. Here a research proposal to investigate this issue was developed, and submitted to APN. The workshop had inputs from all collaborators, IWMI, LOICZ South Asia node, ESSP - Global Water Project and many Scientist, policy makers and Engineers from this area.

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## **1.0 Introduction**

Due to the increasing need for fresh water, surface and ground water are being extensively used worldwide. In coastal zones unmanaged extraction of water gives rise to quality change in water bodies for the worse mainly caused by salinity intrusion. Further, global warming, sea level rise, and tsunami after effects etc., have also resulted in continuous change within fresh water bodies in coastal zones. Such changes to water bodies are occurring in coastal zones around the globe.

With increasing population and rapid development in technology the rate of change to water bodies and catchments round the globe have increased alarmingly making the phenomena and issue global change in nature.

Changes in water bodies directly relate to changes in catchments characteristics, which also interact with socio economic changes as clearly demonstrated in Bundaberg Australia. Such changes to water bodies are occurring in coastal zones around the globe and if catchments and socio economic dimensions round the globe are not yet affected they at least have the potential to get affected soon.

Some specific sites with potential issues are as follows,

### ***a. New Zealand – Wellington***

The Waiwhetu aquifer is located beneath the city of Wellington is a major source of water. Greater Wellington extracts 40% of its water requirements from ground water aquifers. We analyzed the water quality at three well locations to establish the degree of intrusion, which has already occurred in this aquifer. Past trends indicate change from fresh into the medium saline category by the year 2025. Analyses suggested that there is considerable dependency as well as stress on the aquifer and it has the potential to degenerate in quality unless properly managed.

### ***b. Australia – Bundaberg***

Bundaberg is a regional centre on the coast of Queensland, 360 km north of the state capital, Brisbane. The Bundaberg aquifer provides a major water supply for domestic consumption and irrigation. It is known to have suffered saline intrusion from the sea over many years, exacerbated by over pumping for irrigation purposes. The State Government has constructed an extensive surface irrigation scheme to reduce the pressure on the aquifer, and pumping of groundwater is now regulated by license. These have affected the agriculture and socio economic trends in this coastal zone. There is a need to identify, the long-term behaviour of the aquifer and the link between management of the catchments socio economic activities to management of the aquifer.

### ***c. India – Goa and Andhra Pradesh***

Aquifer in the State of Goa located in the west coast of India, south of Mumbai underlying the coastal regions of North Goa is vulnerable to salt water intrusion. One of the main usages of groundwater is for large-scale paddy cultivation. There are points of heavy to very heavy pumping in the coastal area for commercial uses also. This has not only affected the lowering of the groundwater levels but also induced seawater intrusion leading to groundwater quality deterioration.

In the state of Andhra Pradesh, saltwater intrusion is widespread in the Delta regions of coastal Andhra Pradesh. Cities/towns affected by deteriorating groundwater quality due to increase in salinity are Vijayawada, Guntur, Tenali, Machilipatnam, Nizampatnam and south regions of the Krishna River. Regions surrounding Kakinada and Rajamundri in the East Godavari District of the Godavari River delta are affected by saltwater intrusion in the pumped sandy unconfined aquifers underlying these areas. Groundwater in this region is utilized for domestic and especially agricultural purposes. As the demand and usage for groundwater is heavy in these areas, these aquifers are very much vulnerable to widespread intrusion of saltwater, with the potential to render these unconfined sandy aquifers saline.

### ***d. Sri Lanka - Colombo, Kalpitiya, Hambantota and Jaffna***

Aquatic systems in the coastal zone of Sri Lanka have been severely affected by the changes in the salinity intrusion patterns. Such changes have affected the rich bio diversity, low lying agriculture and in general leading to overall environmental degradation. Kalpitiya a coastal zone of Sri Lanka is a region of high agricultural activity. It has been observed in wells that there is a high salinity content. The ground water system in the Jaffna peninsula, which is also another coastal zone, is very susceptible to salinity intrusion because of its arid nature.

### ***e. Japan- Gono River, Izena Island,***

The Gono river in the Shimane prefecture, demonstrates that the fresh - saline water interface between adjacent subsurface aquifer systems was positively correlated with the movement of the fresh-saline water interface in the surface river system. This finding establishes the connection between surface and groundwater systems and implies that utmost care must be taken in any intervention of the overall hydro geological system.

Another study done in the western part of Fukouka city demonstrated that salinity intrusion in coastal aquifers was highly sensitive to direct recharge of rainwater and irrigation water in the catchments lowlands but remained low in the high lands. Surface development work such as construction on low lands would result in reduced seepage and so heavily impact on salinity intrusion in coastal aquifers. In addition, systems used to irrigate and drain water in low lands were found to express varying sensitivities to salinity intrusion. The impact of such activity on high lands is much less. Therefore, the location of, surface development work, including irrigation and drainage systems, as well as the works themselves play a major role in controlling salinity intrusion.

The aquifer system on Izena island in northern Okinawa prefecture is the main source of water for domestic and agricultural consumption. It has to be exploited to support the needs of the island and it is imperative that the water quality be maintained. Current management practice results in the formation of large cones of depression due to continuous abstraction. Even though large percentage of the fresh water flow passes through the system in to the ocean, the reverse gradient at the cones of depression causes the saline - fresh water interface to migrate and it is gradually contaminating the aquifer.

It could be seen that, in all these countries the problem of salinity intrusion in coastal zones and inland waters if it has not manifested itself it is in the process of manifesting itself as a major problem. Therefore it is imperative that the influential parameters, the future degree and behavior of the salinity situation, the catchments / coastal zone characteristics including agriculture and socio economic trends, forecasted and thereby a model developed to yield optimal strategies with multiple objectives that will then give policymakers an important tool and information that will help decision making.

This project intended to bring collaborators from each of the above locations (/ Countries) together and first make a preliminary assessment of the problem and then develop a research proposal at a workshop organized in Sri Lanka, to investigate these changes in detail and explore ways of managing these changes including the resource / human interactions.

This project was in the area of theme 4 of the APN Science agenda - Use of resources / water, and pathways for sustainable development. The project also lied across several other themes as it has elements of, Theme 2 Ecosystems (Extent, causes and impacts of land use change, assessment and enhancement of land use sustainability) and, Theme 5 Cross cutting and science policy linkage (as it related to Global change and water, science policy interfacing relating to global change and, sustainable management of coastal zones).

**The main objectives of the project were:**

1. Identify the scope of the problem.
2. Conducting a workshop in order that stakeholders could come together to, develop a research methodology / proposal, to identify multiple objectives optimal strategies for the effective management of change that occur in coastal zones and inland waters.

## 2.0 Methodology

At present general movement of the saline wedge or the situation of the water body has been studied. Technical solutions of controlling hydraulic gradient etc., are part of the known solutions for issues related to extracting of water in coastal zones and related to salinity problems.

Here, initially preliminary data from each of the above mentioned study areas were collected and a preliminary assessment was made by each collaborator for his / her study location using the currently available methodologies.

The principal investigator then met with the Indian and Sri Lankan collaborators and other stake holders including International agencies such as IWMI, LOICZ – South Asia Node, ESSP Global Water Partnership – South Asia node, and organized a workshop at the Galadari Hotel Colombo, where all collaborators and stake holders could come together and discuss the findings and situation with related Scientist, Engineers, Policy makers and other Social and human dimension scientists / researchers and the International agencies.

The workshop was held on the 5<sup>th</sup> and 6<sup>th</sup> of October 2005, with a participation of 25 persons which included collaborators, International agencies, policy makers, Engineers, Scientist and Social and human dimension researchers. There was active participation by all.

The workshop was structured such that, initially a welcome address and introduction of the project was given and then, an overview which included the significance, scope and objective of the project was presented. Subsequently each collaborator presented his / her findings. The International Water Management Institute presented their perspective on the issue.

Thereafter, there was active discussion by each participant presenting his or her perspective on the issue.

Next the collaborators developed a draft proposal, and this was then fine tuned to meet practical demands, needs and APN requirements.

The final proposal was then submitted to APN by the dead line of 22<sup>nd</sup> October.

In addition to Email, which was extensively used for communication among collaborators, telephone and fax was used as well.

### **Summary of proposed methodology –**

1. Preliminary data / information collection. - Done mainly by collaborator and proponent in each study location
  
2. Preliminary analysis – By collaborators in each study location
  
3. Establishing links with stakeholders – By proponent, using telephone, email, fax and personally meetings
  
4. Organizing of Work shop – By proponent
  
5. Conducting of Work shop
  - a. Identify the scope of the problem.
  - b. Develop a detail research proposal.
  
6. Submission of proposal to APN by the dead line

### **3.0 Results & Discussion**

A brief summary of the out comes were as follows,

1. A research proposal was developed to identify a universally applicable generalized model for forecasting salinity intrusion as well as managing changes in coastal zones and inland waters caused due to salinity intrusion. This proposal was developed at a workshop with the participation / inputs of all collaborators, international agencies such as IWMI, LOICZ – South Asia node, GWP – South Asia and, Engineers, Scientist, Social and Human dimension experts and Policy makers in the area.
2. The profile and awareness of continuous change in coastal zones and inland waters, and related issues were increased through engaging and dialogue with Scientist, researchers and policy makers and highlighting the issues.
3. Links with policy makers and stakeholders were established. They also actively participated in the workshop and presented their views and expectation on the issue.
4. International understanding was enhanced as the collaborators themselves were from five different countries and worked as a team with continuous communication.
5. An international team was developed.
6. A conference paper was developed and it has been submitted to the 15<sup>th</sup> Congress of the International Association for Hydraulic Research – Asia Pacific Division, 2006. (Review pending).

## 4.0 Conclusions

The main aim of the study being identifying the scope of the problem and conducting a workshop so that stake holders could come together to develop a detail research methodology / proposal, to identify multiple objectives optimal strategies for the effective management of change that occur in coastal zones and inland waters, and this was successfully achieved. The proposal was developed within the set dead line and submitted to APN.

Further, expected out comes such as the following were all achieved.

1. Increasing the profile and awareness of continuous changes in coastal zones and inland waters, and the related issues
2. Establishing links with policy makers and stakeholders
3. Deepen international understanding
4. Development of an international team
5. Development of a Conference paper,

## **5. Future Directions**

1. The long term and short-term effect of salinity intrusion in coastal zones and adjacent inland waters must be investigated.
2. Simple and easy to use optimization model, that would yield optimization strategies and best practices for the management of change in coastal zones and inland waters caused due to salinity intrusion needs to be developed.



## References

1. De Costa. S., Porter. M., and Jones. A., 2003 : Comparative analysis of salinity intrusion-Case of the Waiwhetu aquifer New Zealand and the Bundaberg aquifer Australia, Proceedings of the 30<sup>th</sup> Congress of the IAHR, Theme B, pp.565-572.
2. De Costa. S., Kojiri. T. and Porter. M., 2004 : Salinity Intrusion – Its characteristics and impact, - Cases of the Asia Pacific Region, Proceedings of the 14<sup>th</sup> Congress of the International Association for Hydraulic Research – APD.
3. Ishikawa. T., Tsuruta. Y., Nishida, S., and Narita, M., 2001: Salt water behaviour near exit of lake Ogawara, relation to breeding *Cubicula Japonica*, Proceedings of 29<sup>th</sup> IAHR Cong., Vol. 2.
4. Kuruppuarachchi. D., 1995: Impact of irrigated agriculture on ground water resources of Sri Lanka, Proceedings of the Sri Lanka Association of the Advancement of Science, pp.49-66.
5. De Costa. S., Kojiri. T. and Porter. M., 2005: A study on salinity intrusion phenomena and its impact on the environment - Proceedings of the 31<sup>st</sup> Congress of the International Association for Hydraulic Research, Vol. 1, pp.313-318.
6. Joint START/ LOICZ / IGBP-SL workshop, Proceedings of the South Asian regional workshop on Estuarine modeling and coastal zone management, 1999.

## **Appendix**

1. Workshop program.
2. Workshop participants list
3. Abstract of the paper sent for the 15<sup>th</sup> Congress of IAHR-APD, 2006

## 1. Workshop program

### APN Workshop Program.

#### Salt Water Intrusion Project

##### 5th October 2005

- 9.00 AM - Welcome address & introduction of project.  
By Dr. Shahane Gregory De Costa (Project Leader)
- 9.10 AM - Stakeholder presentations
1. Prof. Samantha Hettiarachchy (University of Moratuwa, Sri Lanka)
  2. Prof. Mark Porter (University of Southern Queensland, Australia)
  3. Dr. Toshio Hamaguchi (Kyoto University Japan)
  4. Prof Bithin Datta (IIT, Kanpur, India)
- 10.30 AM - Tea break
- 11.00 AM - Views of invited representatives.  
Presentation by  
Dr. Karon Vilholth of International Water Management Institute  
Dr. Priyani Amarasinghe IWMI
- 12.30 PM - Lunch
- 1.30 PM - 1<sup>st</sup> Session - Preparation of research proposal (Detail discussion)
- 3.00 PM - Tea break
- 3.30 PM - 2<sup>nd</sup> Session – Preparation of main proposal  
(Development of Project framework)
- 5.00 PM - Close of workshop for day one.

##### 6<sup>th</sup> October 2005

- 9.00 AM - Preparation of detail project proposal
- 10.30 AM - Tea break
- 11.00 AM - Preparation of detail project proposal.
- 12.30 PM - Lunch break
- 1.30 PM - Preparation of project proposal
- 3.00 PM - Tea break
- 3.30 PM - Finalization of project proposal and,  
Preparation of draft research (/conference) paper, based on the out  
come of the problems and issues discussed at the workshop (Time  
permitting).
- 6.00 PM - Close of workshop for day two.

##### 7<sup>th</sup> October 2005

Discussion and refining of finalized proposal.

\*\* Workshop dinner to be on the 5<sup>th</sup>, 7.30 PM onwards.

## 2. Workshop participants list.

<b>Name</b>	<b>Organization</b>	<b>Contact details</b>
Lakshita Udumulla	Open University of Sri Lanka	<a href="mailto:lakshika0807@hotmail.com">lakshika0807@hotmail.com</a>
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A I K Adhikari	National Water Supply and Drainage Board	
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Visaka Dias	Colombo Municipal Council	<a href="mailto:munici@slt.lk">munici@slt.lk</a>
T Mallawarachchy	Colombo Municipal Council	<a href="mailto:munici@slt.lk">munici@slt.lk</a>
K. Samarasinghe	Colombo Municipal Council	<a href="mailto:munici@slt.lk">munici@slt.lk</a>
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Prof. Hettiarachchy	University of Moratuwa	<a href="mailto:sslh@civil.mrt.ac.lk">sslh@civil.mrt.ac.lk</a>

Plus some others who have not written their names in the attendance list.  
(Late participation)

**Original attendance list – Hard copy attached (No electronic copy).**

**Original attendance list – Hard copy attached (No electronic copy).**

### **3. Abstract of the paper sent for the 15<sup>th</sup> Congress of IAHR-APD, 2006**

## **Towards developing a strategy for managing salt water intrusion in coastal aquifers**

Dr. Gregory Shahane De Costa, Open Polytechnic of New Zealand  
Prof. Bithin Datta, Department of Civil Engineering, I.I.T. Kanpur, India  
Mr. Harikrishna Vennalakanti, Graduate Student, Dept. of Civil Engr., I.I.T. Kanpur, India  
A/ Prof Mark Porter, University of Southern Queensland, Australia  
Prof. Samantha Hettiarachchy, University of Moratuwa, Sri Lanka  
Dr. Hamaguchi, DPRI, Kyoto University, Japan

### **ABSTRACT**

An international research effort is being contemplated for the Asia Pacific region, focussing on the global phenomenon of saltwater intrusion in coastal areas due to natural causes and human intervention. The focus of this joint effort is to link the study areas in different countries and develop a comprehensive methodology with emphasis on practical solution approach. The envisaged total research endeavours to investigate changes in coastal zones caused by salinity intrusion, i.e. both of the catchments socio economic trends as well as the water bodies, and first would, assess and predict the long term salinity intrusion situation, and then, develop a linked simulation model that will actively link the changes in the catchments socio – economic trends to the changes in waters of adjacent coastal zones.

The methodology has two interrelated however, distinct components. The numerical model for simulating density dependent flow and transport in coastal aquifers, and the next component of the proposed study being the development of the regional optimal management strategies to control changes occurring in coastal zones and adjacent waters. Presented here is a brief overview of cases in selected aquifers in the Asia Pacific region, namely in India, New Zealand, Australia, Japan and Sri Lanka, and the first component, the implementation of a numerical model, with an emphasis on Andhra Pradesh, India.