**COASTIN**
**Measuring, Monitoring and Managing Sustainability: The Coastal Dimension**

http://www.teriin.org/teri-wr/coastin/

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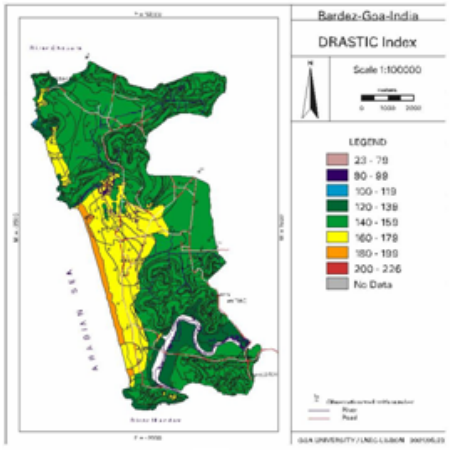
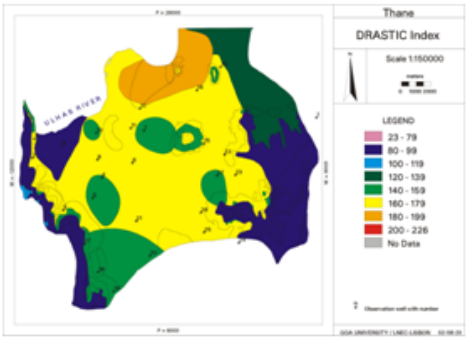
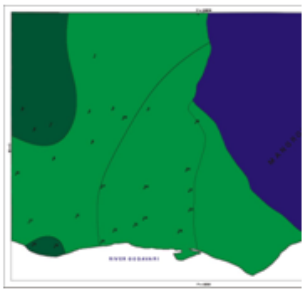
**Responsible Researcher from LNEC**: J.P. Lobo Ferreira

**Objectives**
The main natural resource researched by LNEC in this Project was groundwater in Indian coastal zones. The objectives of LNEC's activity in the Project, besides acting as financial Co-ordinator, was (1) the development of scientific sound criteria for better Management Policy and Optimisation Mathematical Tools, i.e. appropriated management mathematical models and practices towards the optimisation of the existing groundwater resources; and (2) the research of Resources Vulnerability Assessment and Risk Protection, aiming the minimisation of environmental risks to groundwater. This research was developed in close cooperation with The University of Goa. Real world data gathering was a main objective aiming the assessment of the quantitative and qualitative characteristics of the three case-study areas groundwater resources. To increase the access to information on groundwater the programming of a hydrogeological database INVENTOR_India was aimed for the selected coastal zones. The reprogramming of LNEC´s BALSEQ model to Indian climatological and hydrological conditions and the transfer of the new version and the know-how of the model to Goa University was a relevant objective. This task was part of a broader one on scientific know-how transfer, not only from the EU towards India, but also, and we underline the relevance of this task, from India towards the EU. This was indeed a major objective of the groundwater component.

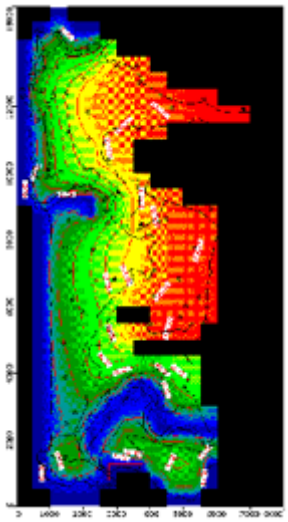
**Activities developed by LNEC and results achieved**
Resources Vulnerability Assessment and Risk Protection
The new database on Indian hydrogeology was named INVENTOR_India (Inventor comes from Inventory). This database was programmed in Microsoft Access® and was for administrative reasons subdivided in 3 databases, one for each case-study area: (1) INVENTOR_Kakinada.mdb, (2) INVENTOR_Thane.mdb, and, (3) INVENTOR_Goa.mdb.
GIS and Mathematical Modelling for the Assessment of Groundwater Vulnerability to Pollution



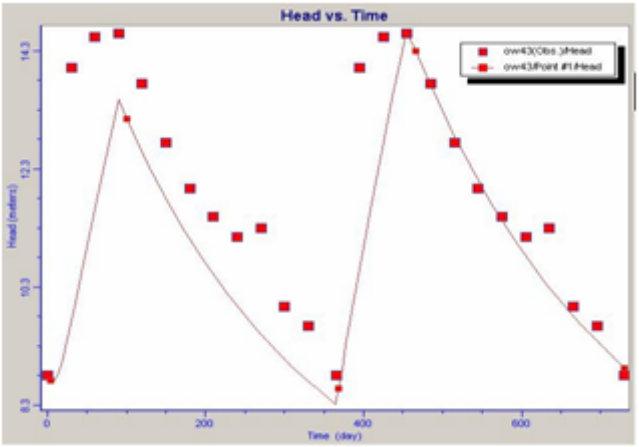



Case-Study Area in Goa Case-Study Area in Thane Case-Study Area in Kakinada



Groundwater model piezometric evaluation at the end of the rainy season LNEC prepared during the Project (and presented during the final COASTIN meeting, held in Goa, 25-27 November 2002), four different reports on GIS and Mathematical Modelling for the Assessment of Groundwater Vulnerability to Pollution:
Application to the Case-Study Area in Goa (cf. CHACHADI, RAIKAR, LOBO-FERREIRA, and OLIVEIRA (2001), and NAGEL, OLIVEIRA and LOBO-FERREIRA, 2001);
Application to the Case-Study Area in Kakinada (cf. CHACHADI, MOINANTE and OLIVEIRA 2002a).
Application to the Case-Study Area in Thane (cf. CHACHADI, MOINANTE and OLIVEIRA 2002b).




Comparison of groundwater model results versus monitored groundwater levels in Goa case-study

**Groundwater extraction and the risk of saltwater intrusion**

In coastal aquifers a body of seawater naturally exists in the form of a wedge, heavier, underlying the lighter freshwater. By intensive and prolonged pumping from a coastal aquifer and if there is no compensation of the aquifer by natural or artificial groundwater recharge, the water table in the vicinity of the coast decreases, and the phenomenon of seawater intrusion starts to develop.
The sub-topics developed were the following: LNEC applied two mathematical models for saltwater intrusion in coastal aquifers and developed two original functions relating the amount of groundwater extraction vs. the safe distance from the coastline.

**Groundwater recharge assessment**

LNEC programmed and developed a review of methodologies for the assessment of groundwater recharge, with the aim of their application to the areas to be selected in Indian coastal zones: the sequential water balance, and the piezometric levels variation.

The transferring of LNEC´s groundwater recharge assessment model BALSEQ to Goa University. A vulnerability to pollution state-of-the-art review was also transferred to Goa University partners.

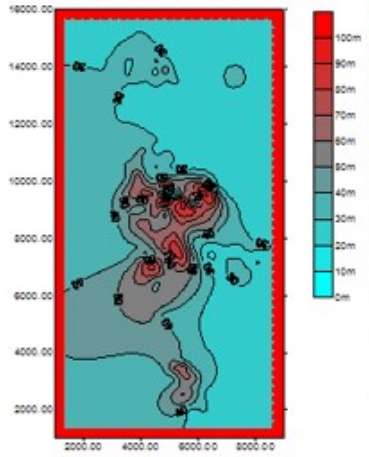
This scientific background for groundwater recharge assessment was presented to the partners and published by TERI for Indian readers as part of the achievements of COASTIN.

Groundwater piezometric level assessment of the unconfined and/or confined aquifers of Goa, Kakinada and Thane case-study areas was developed during most of the Projects life time. This data was used by LNEC and by Goa University for model development and for the calibration of the Goa case-study area optimisation modelling**.**

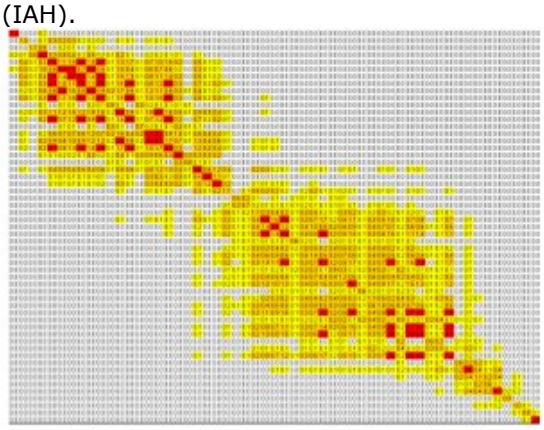
**Management policy and optimisation mathematical tools**

This task was developed during the second year of the Project, including the development of a new methodology for delineating groundwater protection zones. An application of the methodology was concluded during the second year to the unconfined aquifer of the Goa case-study area in Bardez. The aspects under consideration in LNEC were the following: (1) definition of criteria for geographical groundwater protection zoning; (2) development of a new methodology for easy determination of the wellhead protection areas, corresponding to a travel time of 50 days, without the need of detailed hydrogeological studies; (3) definition of extrapolation criteria from the case-study scales to regional scales; and, (4) demonstration of the methodology and mapping of groundwater protection zoning in a selected case-study area in India, the Bardez Taluka, Goa, using a Geographical Information System.

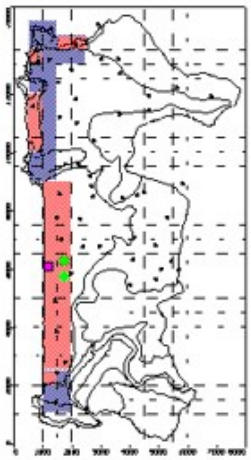
The results of this original methodology development and the corresponding mapping was published by KRIJGSMAN and LOBO-FERREIRA (2001). A paper on this topic was accepted for publication in early 2007, to be published in the Hydrogeology Journal of the International Association of Hydrogeologists (IAH).



Up gradient protection distance computed for the Summer season



The Goa aquifer response matrix (pumping rate 100 m3/d)



Example of an optimal solution for Case study 2 (QT= 1000 m3/d)

The questions during the optimization procedure were: How is it possible to find the optimal placement for the supply wells and what are the most important parameters, which have to be considered? How important is the number of wells and their distance to the hotels, taking into account the cost of coastal zone land, service-pipes, and running expenses? What is the relation between the extraction rate of the wells and the risk of saltwater intrusion? How is it possible to minimize this risk?

Based on the available hydrogeological data, a response matrix with the coefficients of influence of the aquifer was build. This figure represents the drawdowns computed in all existing or potential pumping wells of the study area due to an extraction of 100 m3/d in just one of the wells at a time, i.e. the drawdown caused by that single pumping in each one of the model cells obtained with MODFLOW groundwater flow model.

This part of the project was developed in close cooperation with Prof. Maria da Conceição Cunha, from Coimbra University, Portugal. Optimisation models were applied to two exploitation scenarios. The results obtained indicated the best solutions of the case-study problem.
A paper describing the optimisation concepts, the objective function and restrictions, as wells as the application to Bardez taluka coastal zone, Goa, was developed during the second semester of 2002. The paper on Optimal Aquifer Development of Goa Coastal Area (India) for Tourism Purposes (LOBO-FERREIRA, CUNHA, CHACHADI, NAGEL, DIAMANTINO, OLIVEIRA, 2002) was presented to the DMinUCE the 3rd International Conference on Decision Making in Urban and Civil Engineering, held in London, Nov. 2002.
The main pollution problems encountered in the three case-study areas were analysed and pollution causes were assessed from existing driving forces, e.g. agricultural and sanitation practices.
LNEC prepared and presented during the final COASTIN meeting a report on Groundwater Indicators containing an overview of the key aspects about groundwater indicators. The report (LEITÃO and LOBO-FERREIRA, 2002) starts with an introduction to the subject followed by the establishment of the main objectives of groundwater indicators. The second part is devoted to the definition of groundwater indicator types, explaining the reasons for their choice and quantifying some of the appropriate indicator values and the adequate monitoring periodicity. In the last section, the achievements for COASTIN project concerning the groundwater indicators are presented.
An example of a quantity groundwater indicator is "Consistently falling or rising groundwater piezometric levels", which indicates overexploitation of the renewable aquifer water reserves or lack of drainage in agricultural areas.

**PARTNERS**
LNEC http://www.dha.lnec.pt/nas/ ; http://www.lnec.pt
TERI (India) http://www.teriin.org/
ICC ( Spain) http://www.icc.es/portal/
Trieste Univ. ( Italy) http://www.triestesystem.it/html/univ.htm
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Goa University ( India) http://www.unigoa.ac.in/

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