Assessing aquifer vulnerability to sea-water intrusion using GALDIT method:

GALDIT Indicators Description

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IMPACT ASSESSMENT OF SEA LEVEL RISE ON THE SURFACE INUNDATION AND THE EXTENT OF SEAWATER INTRUSION IN THE COASTAL AQUIFERS USING GALDIT METHOD - A CASE STUDY OF NORTH GOA COAST

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1. The IPCC (Intergovernmental Panel on Climate Change) has predicted that the mean global temperature would increase by 1.4 to 5.8°C between 1990 to 2100 leading to accelerated Sea Level Rise (SLR) by about 9 to 88 cms due to thermal expansion of oceans and melting of glaciers, small ice caps and ice sheets.

2. Given the nature of economic activities in the developing countries and their lower capacity to adapt, the developing countries including India are more vulnerable to climate change than the industrialised countries.
3. Besides affecting socio-economic fabric of the coastal populace the eustatic SLR can inflict irreversible damages on the coastal freshwater aquifers in the form of seawater intrusion.

4. This could jeopardize the water availability and supply in the heavily urbanized coastal belts, besides irrigated agriculture, coastal infrastructure, tourism and other economic and strategic activities are at risk.
5. UNEP (1998) has identified India as one among the 27 countries to be the most vulnerable countries to SLR.

6. IPCC’s (1998) climatic models predict that India’s climate could become warmer (Lonergan, 1998) and heavy rainfall events are likely to be more frequent in South and South-East Asia.
7. There is a need to develop know-how to address the individual issues arising out of SEA LEVEL RISE.

8. GALDIT-a six parameter open ended additive model developed by Chachadi and Lobo Ferreira (2001) as part of EU Project is one such know-how to address mapping of seawater intrusion extent due to raised Sea Levels.
GALDIT APPLICATION FOR SEAWATER INTRUSION STUDIES
9. The six GALDIT parameters on which the sea water intrusion episode depend include:

1. **Groundwater Occurrence (Aquifer Type)**
2. **Aquifer hydraulic Conductivity**
3. **Depth to Groundwater Level** above sea
4. **Distance from the Shore**
5. **Impact of existing Seawater Intrusion Levels**
6. **Thickness of Aquifer being mapped**
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The following table shows the summary of the GALDIT weights and ratings:

<table>
<thead>
<tr>
<th>Parameters →</th>
<th>G (Groundwater Occurrence) [Aquifer Type]</th>
<th>A (Aquifer Conductivity) [m/day]</th>
<th>L (Groundwater Levels bmsl) [m]</th>
<th>D (Distance from Coast) [m]</th>
<th>I (Impact of Existing intrusion) [epm]</th>
<th>T (Aquifer thickness) [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights → Rates↓</td>
<td>1</td>
<td>0.0-04.0</td>
<td>&gt;2.00</td>
<td>&gt;1000</td>
<td>Cl/HCO3+CO2 &lt; 1.5</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>2</td>
<td>&gt;04.0-12.0</td>
<td>&gt;1.75-2.0</td>
<td>&gt;800-1000</td>
<td>1.0-2.0</td>
<td>&gt;2.0-3.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&gt;12.0-28.0</td>
<td>&gt;1.50-1.75</td>
<td>&gt;700-800</td>
<td>&gt;3.0-4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&gt;28.0-41.0</td>
<td>&gt;1.00-1.25</td>
<td>&gt;500-600</td>
<td>&gt;4.0-5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&gt;41.0-81.0</td>
<td>&gt;0.75-1.00</td>
<td>&gt;400-500</td>
<td>&gt;5.0-6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&gt;81.0</td>
<td>&gt;0.50-0.75</td>
<td>&gt;300-400</td>
<td>&gt;6.0-7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Leaky confined</td>
<td>&gt;41.0-81.0</td>
<td>&gt;0.25-0.50</td>
<td>&gt;200-300</td>
<td>&gt;7.0-8.0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Unconfined</td>
<td>&gt;0.00-0.25</td>
<td>&gt;100-200</td>
<td>&gt;8.0-10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Confined</td>
<td>&gt;81.0</td>
<td>≤0.00</td>
<td>&lt;100</td>
<td>Cl/HCO3+CO2 &gt; 2.0</td>
<td>&gt;10.0</td>
</tr>
</tbody>
</table>

**TOTAL GALDIT SCORE = \sum Weight(i) \times Rate(i) ; where i is a variable**

**TOTAL GALDIT SCORE = \sum 1\cdot G + 3\cdot A + 4\cdot L + 2\cdot D + 1\cdot I + 2\cdot T**

It is an open ended additive semi-empirical model.
### Computation of GALDIT Index

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Indicator</th>
<th>Weight</th>
<th>Range of importance ratings</th>
<th>Range of scores (weight*importance rating)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum</td>
<td>In between</td>
</tr>
<tr>
<td>1</td>
<td>Groundwater Occurrence (Aquifer Type)</td>
<td>1</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Aquifer Hydraulic Conductivity</td>
<td>3</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Depth to Groundwater Level above Sea</td>
<td>4</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Distance from the Shore</td>
<td>4</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Impact of existing status of Seawater Intrusion</td>
<td>1</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Thickness of Aquifer being Mapped</td>
<td>2</td>
<td>2.5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Total Score (T.S)**

| GALDIT-Index=T.S/15 | 2.5 | 5 | 7.5 | 10 |

Note: 15 is the total of all 6 indicator weight
Using GALDIT method seawater intrusion vulnerability maps both for normal and raised sea levels have been prepared for North Goa coast covering Mandovi Bay, Nerul Creek, Baga Estuary, Anjuna Beach and Chapora Creek. The value of sea level rise has been adopted as 0.5-meters which is the value obtained based on various model predictions for Goa coast.
Fig. 2: Location Map of the SLR Study Area in North Goa
Bardez Coast as seen from IRS, LISS II March 1990, Scale 1: 60,000
FIG. 4: SEAWATER-INTRUSION VULNERABILITY MAP AS DEPICTED BY GALDIT SCORES FOR NORMAL SEA LEVEL
FIG. 5: SEAWATER-INTRUSION VULNERABILITY MAP AS DEPICTED BY GALDIT SCORES FOR RAISED SEA LEVEL
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COMPARISON BETWEEN GALDIT SCORES FOR NORMAL AND RAISED SEA LEVELS IN NORTH GOA COAST

FIG. 4: SEAWATER-INTRUSION VULNERABILITY MAP AS DEPICTED BY GALDIT SCORES FOR NORMAL SEA LEVEL

FIG. 5: SEAWATER-INTRUSION VULNERABILITY MAP AS DEPICTED BY GALDIT SCORES FOR RAISED SEA LEVEL
CONCLUSIONS

• As seen from the above results the GALDIT model can provide an effective means of mapping the extent of seawater intrusion vulnerability of coastal aquifers both under normal and raised sea level conditions.
• The method can also be applied to Island aquifers.
• The seawater intrusion vulnerability area increases with 0.5m rise in the sea level.
• The surface inundation due to sea level rise is fund maximum along the Baga creek, Anjuna area, Chapora creek and Nerul creek, whereas along the main coast it is minimum due to typical topography.