07 Sea Level Rise

7.1 Background

The global warming may cause a Sea Level Rise, which will have a great impact on the long-term coastal morphology and an increased flooding risk. Sea level rise due to climate change experienced globally is currently a widely talked topic both nationally and internationally. Many countries with a sea front have already developed policies on sea front management to incorporate the possible damages and inundations from sea level rise. This is the first attempt in Sri Lanka to assess possible damages from anticipated sea level rise.

The Intergovernmental Panel on Climate Change (IPCC) in its 1997 report has stated for the tropical Asia that "Coastal lands are particularly vulnerable; sea level rise is the most obvious climate-related impact. Densely settled and intensively used low-lying coastal plains, islands and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front and seawater intrusion into freshwater lenses. Especially at risk are large delta regions of Bangladesh, Myanmar, Viet Nam and Thailand, and the low-lying areas of Indonesia, the Philippines and Malaysia. Socio-economic impacts could be felt in major cities and ports, tourist resorts, and commercial fishing, coastal agriculture and infrastructure development. International studies have projected the displacement of several millions of people from the region's coastal zone, assuming a 1-m rise in sea level. The costs of response measures to reduce the impact of sea-level rise in the region could be immense. "

7.1.2 Sea Level Rise Predictions

IPCC reports have predicted the possible sea level rise in its reports. The latest report published in 2007 predicts that the maximum sea level rise under the worst case would be 59cm in 100 years. However the report states that "Because understanding of some important effects driving sea level rise is too limited, the report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Table 7.1- SPM.1 shows model-based projections of global average sea level rise for 2090-2099. The projections do not include uncertainties in climate-carbon cycle feedbacks or the full effects of changes in ice sheet flow. Therefore the upper values of the ranges are not to be considered upper bounds for sea level rise. They include a contribution from increased Greenland and Antarctic ice flow at the rates observed for 1993-2003, but this could increase or decrease in the future."

The sea-level changes cannot yet be predicted with confidence using models based on physical processes, because the dynamics of ice sheets and glaciers and to a lesser extent that of oceanic heat uptake is not sufficiently understood.

Table 7.1: Projected Global averaged surface warning and sea level rise at the end of the 21st century

	Temperature change (^{0}C at 2090-2099 relative to 1980 - 1999)[a,b]		Sea level rise (m at 2090-2099relative to 1980-1999)
Case	Best estimate	Likely range	Model-based range excluding future rapid dynamic changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3-0.9	Not available
B1 scenario	1.8	1.1-2.9	0.18 -0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 scenario	2.4	1.4-3.8	0.20-0.43
A1B scenario	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1Fl scenario	4.0	2.4-6.4	0.26-0.59

Notes:

a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints

b) Year 2000 constant composition is derived from Atmosphere Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO2 –eq concentrations corresponding to the computed radioactive forcing due to anthropogenic GHGs and aerosols in 2100 (see p.823 of the WGI TAR) for the SRES B1, AIT, B2, A1B, A2 and A1Fl illustrative marker scenarios are about 600,700,800,850,1250,1550 ppm, respectively.

d) Temperature changes are expressed as the different from the period 1980-1999. To express the change relative to the period 1850-1899 add0.50C

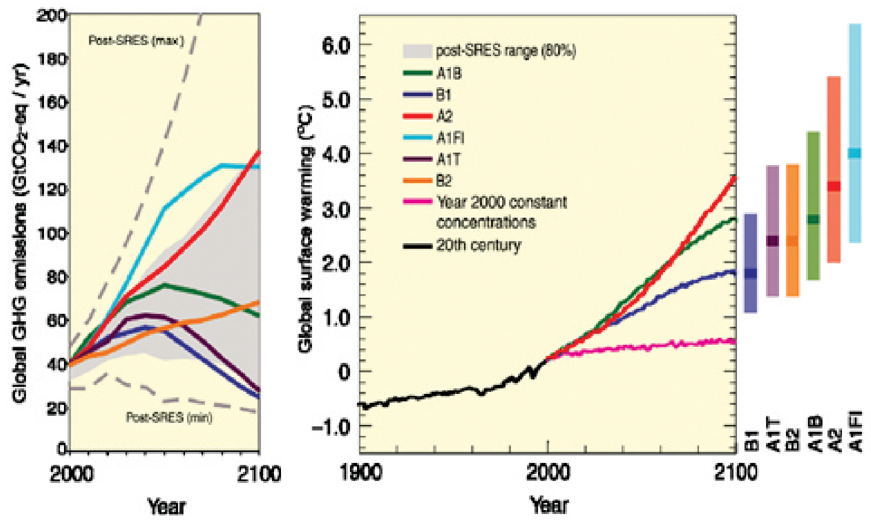

Fig 7.1: Scenarios for GHG emissions from 2000 to 2100 and projections of surface temperatures.

Different sea level rise estimates are available from various scientists. Recently, Martin and Stefan (2009), predicts a sea-level projections range from 75 to 190 cm for the period 1990–2100 using a method based on the global average temperature and claims that the model is capable of explaining 98% of variations of the past data from 1880 - 2000.

The sea level rise predicted by IPCC report is revised time to time as more information and improved modelling techniques become available. The IPCC prediction is the world average figure. The local sea level rise and the rising rate may differ from place to place. Another significant limitation is that the resolution of the modelling is no greater or more accurate than the topographic data used. The resolution of the model also constrains its ability to resolve some small-scale features of the onshore terrain including narrow waterways, and no warranties are

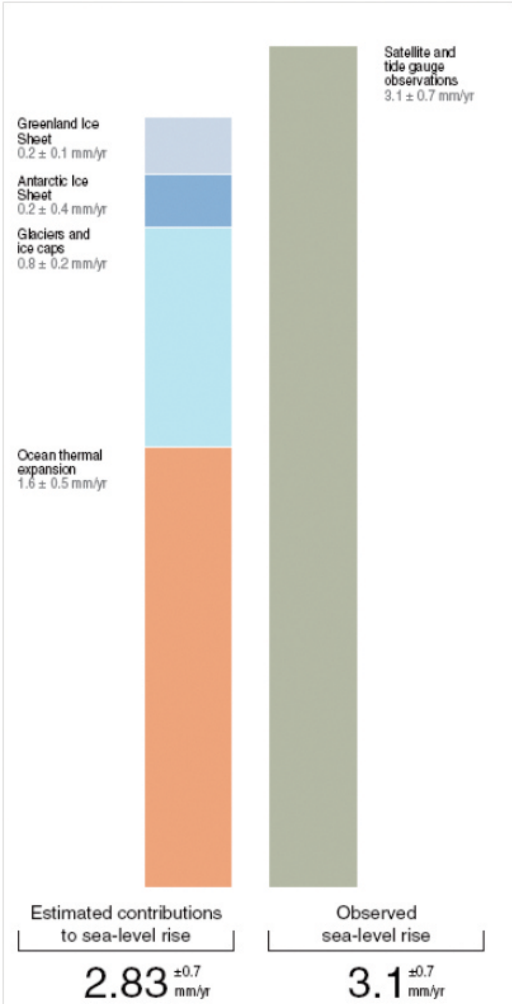

Fig 7.2: Estimated contributions to sea-level rise from 1993 to 2003 (uncertainty intervals are 5 to 95%). Source: Based on IPCC 2007

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made regarding the accuracy of the map, nor the data from which the map was derived.

The main base data for the above predictions of the sea level change is the predicted temperature rise. The temperature rise is directly due to emission and atmospheric collection of the Green House Gases (GHGs). The Fig 7.1 shows the emission patterns considered in the model used in predicting the sea level rise.

Projected sea level rise resulting from anticipated climate change for various future scenarios is from Intergovernmental Panel on Climate Change (IPCC).

7.1.3 Causative Factors

As indicated in Fig. 7.2, there are two main reasons for sea-level rise namely;

(1) Thermal expansion of ocean waters as they warm, and

(2) Increase in the ocean mass, principally from land-based sources of ice (glaciers and ice caps, and the ice sheets of Greenland and Antarctica). Global warming from increasing greenhouse gas concentrations is a significant driver of both contributions to sea-level rise (John et al 2007). Due to combined effects of several factors the sea level rise occurs as illustrated in Fig 7.3.

7.2 Scope of the Study

The scope of this work is to predict impacts of sea level rise in Sri Lankan coastal areas for the next 25 to 100 years using suitable models. In order to do that the first step is to evaluate the shoreline change from the considered scenarios and then carryout the assessments on sea level rise predictions for 2025, 2050 and 2100. Geographical Information System (GIS)

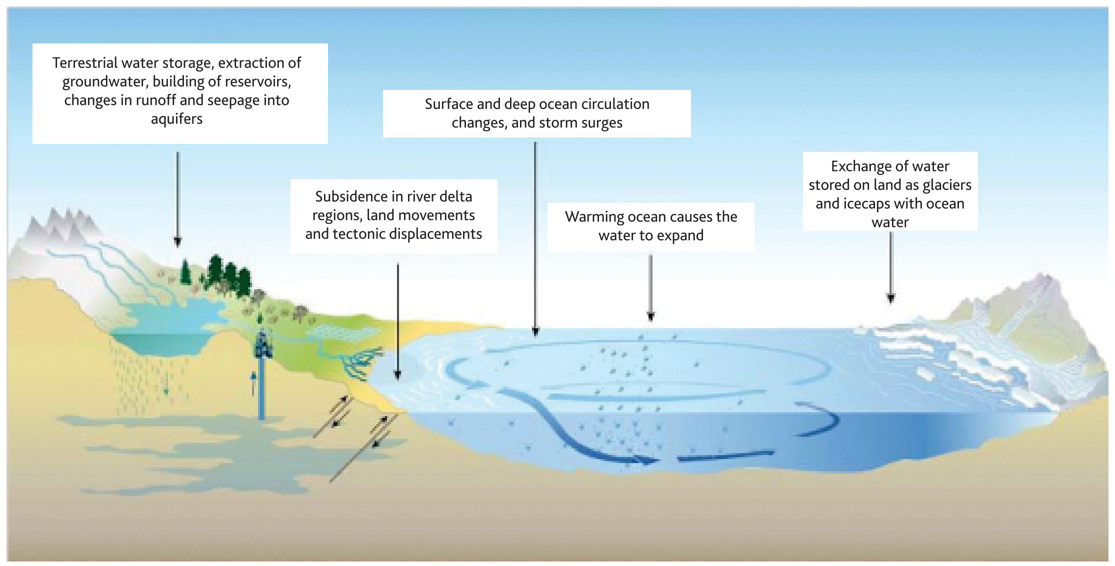

Fig 7.3: Sea level-rise and assessment of the state of the marine environment (source: http://www.grida.no/graphicslib/detail/sea-level-rise)

will be used to predict the shoreline changes based on the elevation data. The maps will be prepared in the scale of 1:50,000 covering entire coastal zone of Sri Lanka indicating the inundation areas in 2025, 2050 and in 2100. The detail 1:50,000 maps will be published in the DMC web site.

7.3 Methodology

This section consists of the data availability & data gaps, a brief description of modelling used in the study, assessment of coastal erosion due to sea level rise, marking headlands and finally the evaluation of modelling.

7.3.1 Data Availability

Establishment of the Digital Elevation Model (DEM) is the prime requirement for GIS application for shoreline prediction with different sea level rise and for other modelling. Available contour details of 1:50,000 maps are not sufficient for generating an accurate DEM because the contours are located at large distances among them especially in the northern and eastern plains and no data to represent the details in between.

The 1:10,000 maps and high resolution LIDAR topographic data are not available to cover the entire costal area of the country. Therefore, the ASTER data with its accuracy improved by correcting the data set corresponding to the available contour data are used in areas where higher resolution topographic data are not available. Further improvement of the DEM will be performed by hydrologically correcting it to provide the same drainage network as in published maps.

7.3.1.1 Topographic Data

Four different data sets of topographic data were used to prepare the digital elevation model of the coastal zone of Sri Lanka. The data sets relating to 1:50,000 maps and 1:10,000 maps were obtained from the Survey Department of Sri Lanka. The contours and spot levels if those maps were used to derive one digital elevation model. The LIDAR data of the coastal zone was the most accurate data set used in the study. However the availability of the dataset was limited to the beach from Kalpitiya to Hambantota.

Table :7.2 Parameters for Correction of ASTER Data set

Elevation range (m msl)	Correction (m)
0 - 1	No correction
1 - 2	No correction
2 - 3	0.62578325
3 - 4	1.5745235
4 - 5	2.2984612
5 - 6	2.8880266
6 & above	3.1849299

The northern area where the 1:10,000 maps were not available was covered by ASTER data. As the data set is not very accurate in representing the elevations, the data set was corrected using correction parameters established by comparing the ASTER data with the LIDAR data and also with the elevations along the Contour lines of 1:50,000 maps. The parameters established are given in Table 7.2.

7.3.2 Modelling

7.3.2.1 Spatial Resolution of Modelling

The modelling was carried out in Geographic Projection with WGS 1984 Datum. The gridded data format was used to model the inundation due to sea level rise. The cell size used in the grid is 0.000451 x 0.000451 decimal degrees. One such cell has a surface area of 2,483m^2.

7.3.2.2 Parameters Used in Modelling

Following are the parameters used in modelling of inundation due to sea level rise in this study.

1. **Change of sea level since the establishment of the datum = 0.068m**
2. **Change of sea level due to high tide = 0.300m**
3. **Sea level rise due to climate change (100yr) = 0.59m**

Predicted sea level in 25, 50, 75 and 100 year due to sea level rise with respect to sea level of year 2000 are given below and they were determined by superimposing the change of sea level since the establishment of the datum, change of sea level due to high tide and the sea level rise due to climate change.

25 year sea level rise
= 0.14 + 0.068 + 0.30 = .508 m

50 year sea level rise
= 0.29 + 0.068 + 0.30 = .658 m

75 year sea level rise
= 0.44 + 0.068 + 0.30 = .808 m

100 year sea level rise
= 0.59 + 0.068 + 0.30 = .958 m

7.3.3 Assessing the Coastal Erosion due to Sea Level Rise

Sea level rise will inundate the present lands with low elevations. As the lands go underwater the sea coast will move landwards. In such case the sea coast will maintain its near shore slope. This will result in landward movement of the coast determined by both the near-shore slope and the sea level rise. This phenomenon is illustrated in Fig 7.4 and is termed as "Bruun Rule".

Assumptions of the Bruun Rule

- Upper beach is eroded due to landward translation of the profile
- Material eroded is transported immediately off shore and deposited such that;

  Eroded qty. = Deposited Qty.
- Rise of near-shore bottom is equal to the sea level rise

Fig 7.4 shows the Bruun Rule graphically. A sea level rise of 'S' will corresponds to a near shore sea bed level rise by the same amount. The material required for this change will be transported with cross-shore currents which in turn will cause the

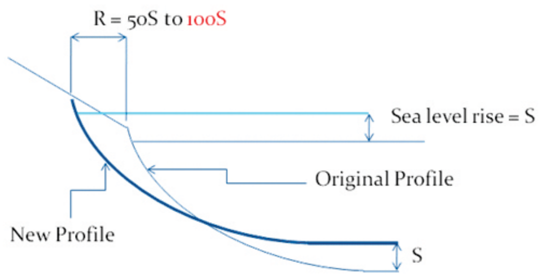

Fig 7.4 Illustration of landward movement of coast

beach erosion. The Bruun rule predicts that the shore line change will be 50 to 100 times the sea level rise.

7.3.4 Marking of Headlands

The application of the Bruun Rule to determine the coastal erosion from sea level change needed demarcation of the headlands that will resist erosion. However, some of the headlands that exist presently will go underwater and thus will not be able to resist sea level erosion.

Fig. 7.5 shows one such headland in the western coast. However some other headlands with adjoining higher elevation grounds as seen in Fig 7.6 have demarcated as headlands that may resist coastal erosion.

Coastal erosion due to sea level rise from Bruun Rule using 1:100 ratios

25 year coastal erosion extent = 50 m
50 year coastal erosion extent = 65 m
75 year coastal erosion extent = 80 m
100 year coastal erosion extent = 95 m

7.3.5 Accuracy of Modelling

Accuracy of modelling of sea level rise depends on two parameters. First is the accuracy of sea level prediction and the second is the accuracy of ground levels. The sea level prediction used in this study corresponds to the worst case scenario of IPCC 2007 report. The values given in the report are the global average of sea level rise. It is well known that this value is not globally accepted and there are different opinions as explained before. The

Fig 7.5 Headland that may go underwater due to sea level rise

Fig 7.6 Headland that may not go underwater due to sea level rise

presently available models are not capable to predict the possible changes of sea levels at different locations of world at different times. Therefore it is not possible to predict accurately what the actual sea level rise that will experience by Sri Lanka. Therefore, the best estimate of sea level rise based on IPCC prediction is calculated. The LIDAR data is the most accurate Digital Elevation Model available for this study and its accuracy ranges from -0.19 m to +0.05 m with a mean accuracy of -0.077 m. The maximum sea level rise considered in this study is 0.59 m which means that the mean accuracy of DEM is 13% and the range of error of DEM is 41% of the sea level rise. The area not covered by LIDAR survey is modelled with a corrected ASTER DEM. The accuracy of this DEM even after proposed correction may be in the range of several meters.

7.4 Hazard Profile

Table 7.3 and Figs 7.7-7.11 illustrate the inundated areas due to predicted sea level rise at the end of 25, 50, 75 and 100 years including the area covered presently as water bodies. The detailed 1:50,000 maps illustrating the inundation areas are available in the DMC web site. It should be noted here that due to the errors in the DEM of the area not covered by LIDAR some of the water bodies are not classified as inundated areas. Therefore the inundation results of the area not covered by the LIDAR survey are not reliable and the process should be repeated with more accurate data. Within the accuracy of the present modelling Puttalam district shows the highest inundation followed by Jaffna district.

	Total Inundated Area (ha)			
District	25 Year	50 Year	75 Year	100 Year
Colombo	959	1,133	1,327	1,534
Gampaha	3,638	4,154	4,631	5,073
Puttalam	11,334	12,583	13,716	14,809
Mannar	8,024	8,262	8,518	8,758
Jaffna	10,321	11,164	12,014	12,891
Mullaittivu	912	1,004	1,092	11,80
Trincomalee	2,315	2,529	2,791	3033
Batticaloa	2,325	2,443	2,568	2,702
Ampara	1,880	2,175	2,479	2,762
Hambantota	4,265	5,553	6,516	7,322
Matara	1,277	1,634	1,994	2,401
Galle	5,622	6,462	7,249	8,014
Kalutara	1,956	2,370	2,790	3,203

Table 7.3 Total inundated area in each district including water bodies

	Additional Inundated Area (ha)			
District	25 Year	50 Year	75 Year	100 Year
Colombo	201	375	569	776
Gampaha	459	976	1,452	1,894
Puttalam	1,113	2,362	3,494	4,587
Mannar	248	486	741	981
Jaffna	864	1,706	2,557	3,434
Mullaittivu	88	180	268	355
Trincomalee	252	467	729	971
Batticaloa	130	247	372	507
Ampara	293	588	892	1,175
Hambantota	885	2,173	3,136	3,942
Matara	384	741	1,101	1,508
Galle	776	1,617	2,403	3,169
Kalutara	417	830	1,251	1,664

Table 7.4 Inundated area in each district excluding water bodies

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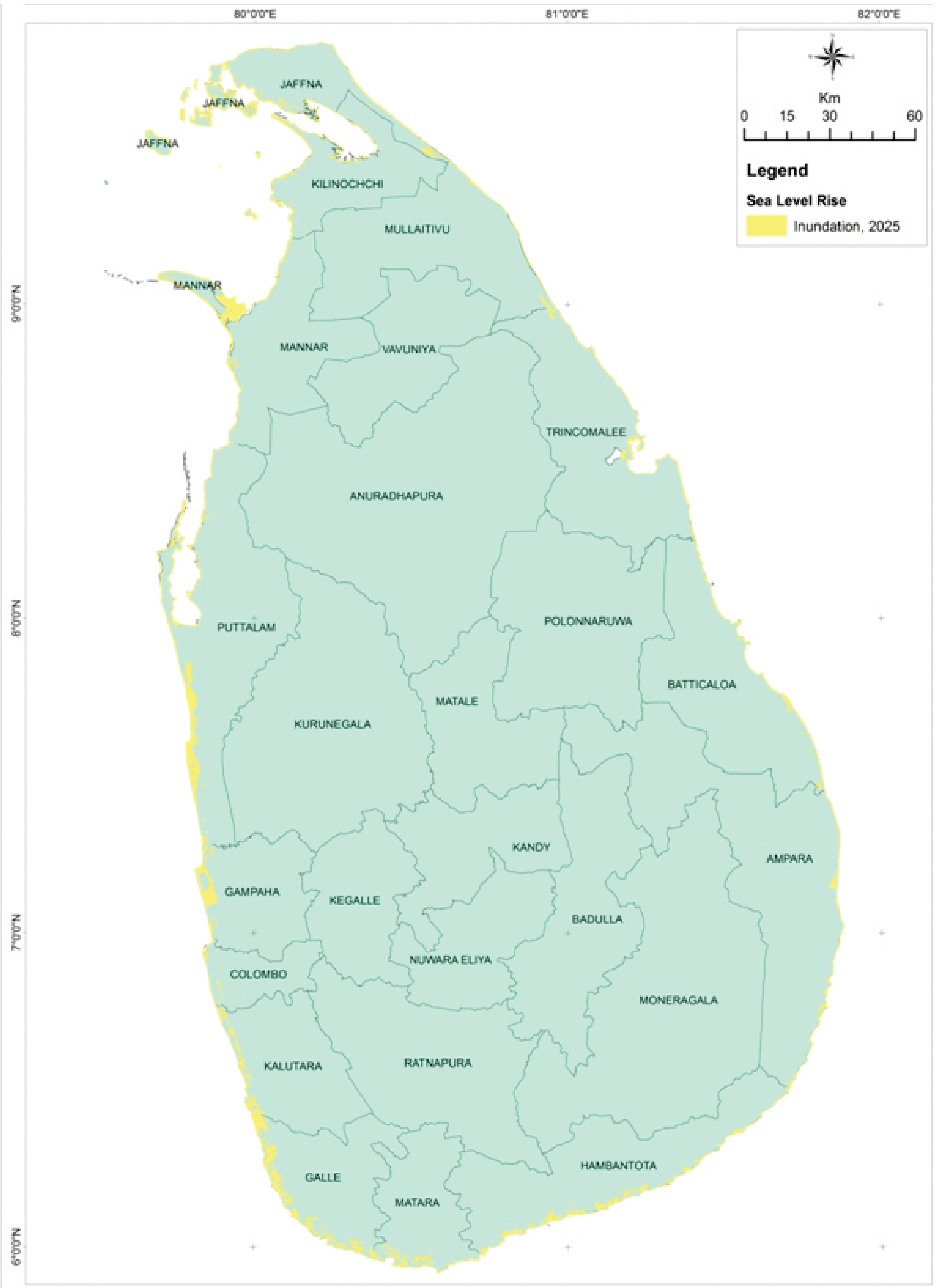

Fig 7.7: Predicted sea level rise in 2025 in Sri Lanka

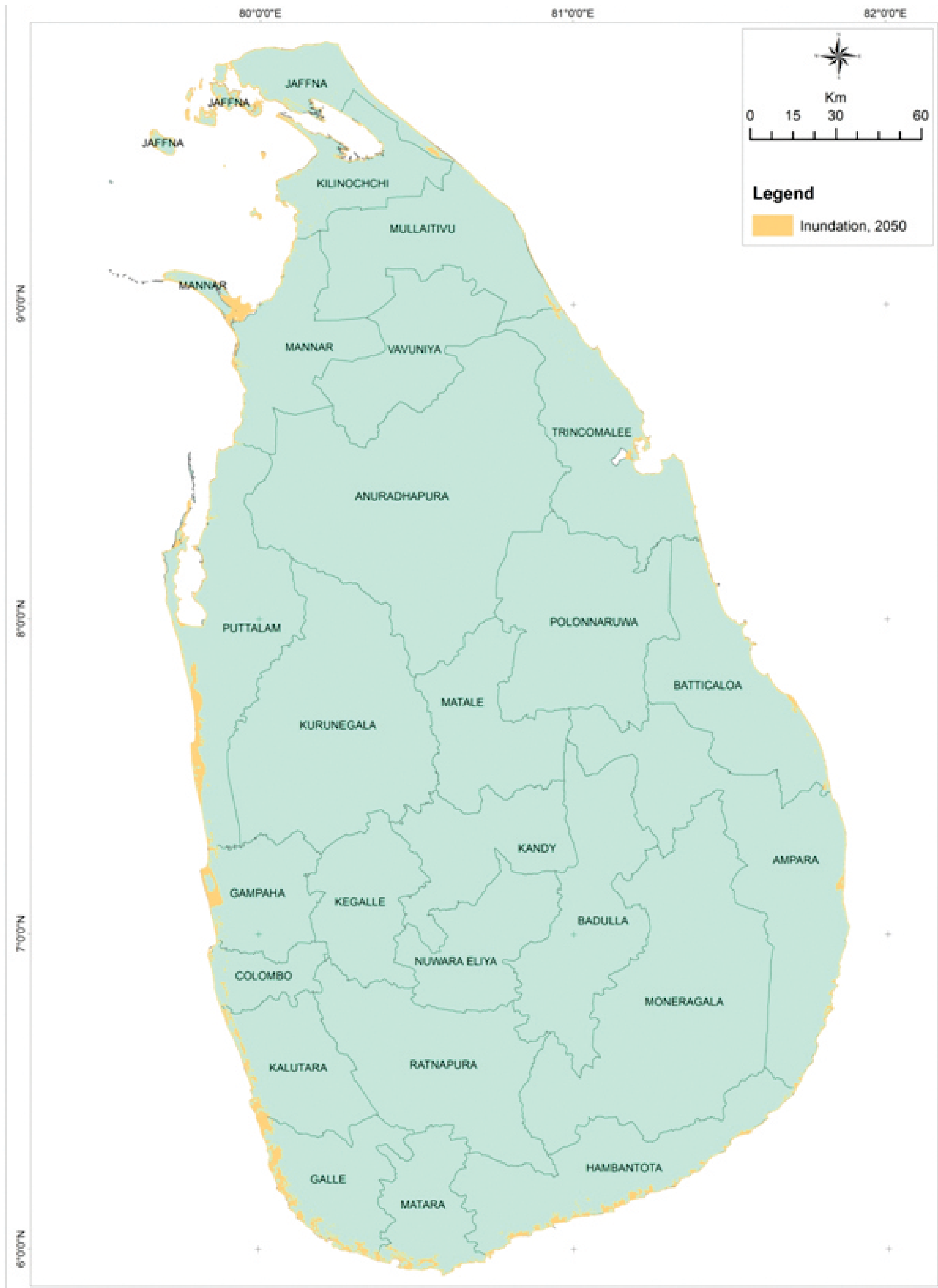

Fig 7.8: Predicted sea level rise in 2050 in Sri Lanka

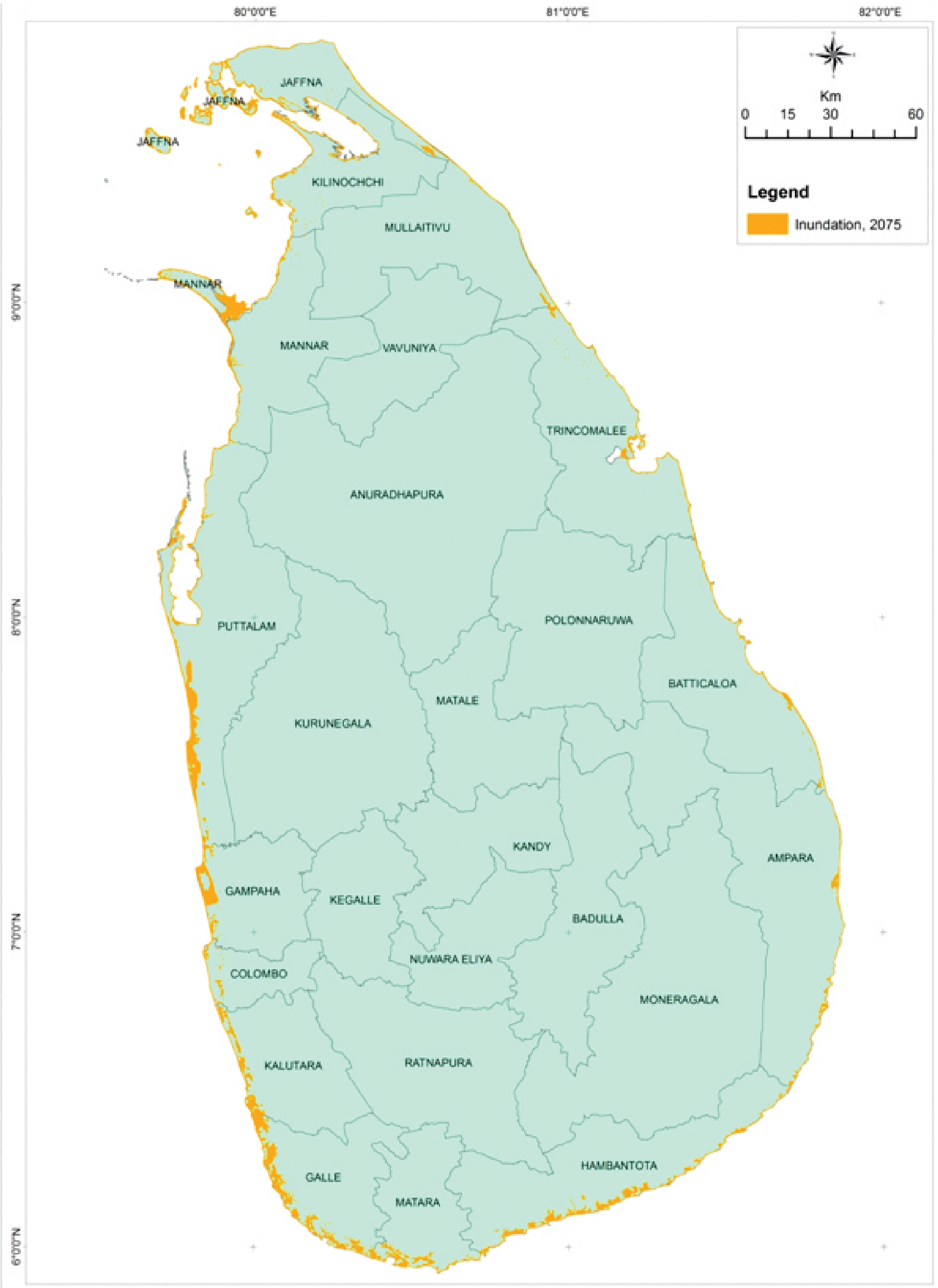

Fig 7.9: Predicted sea level rise in 2075 in Sri Lanka

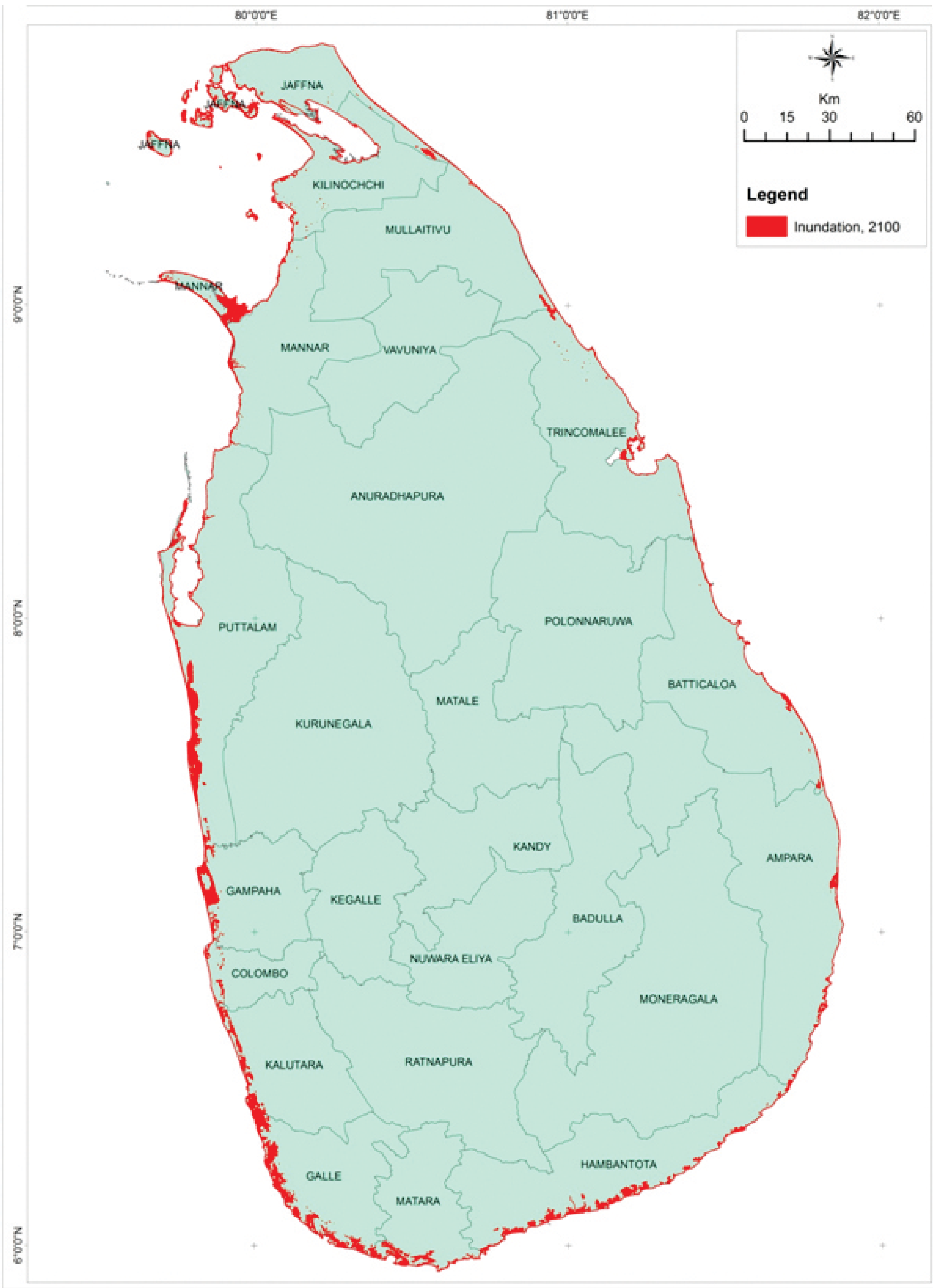

Fig 7.10: Predicted sea level rise in 2100 in Sri Lanka

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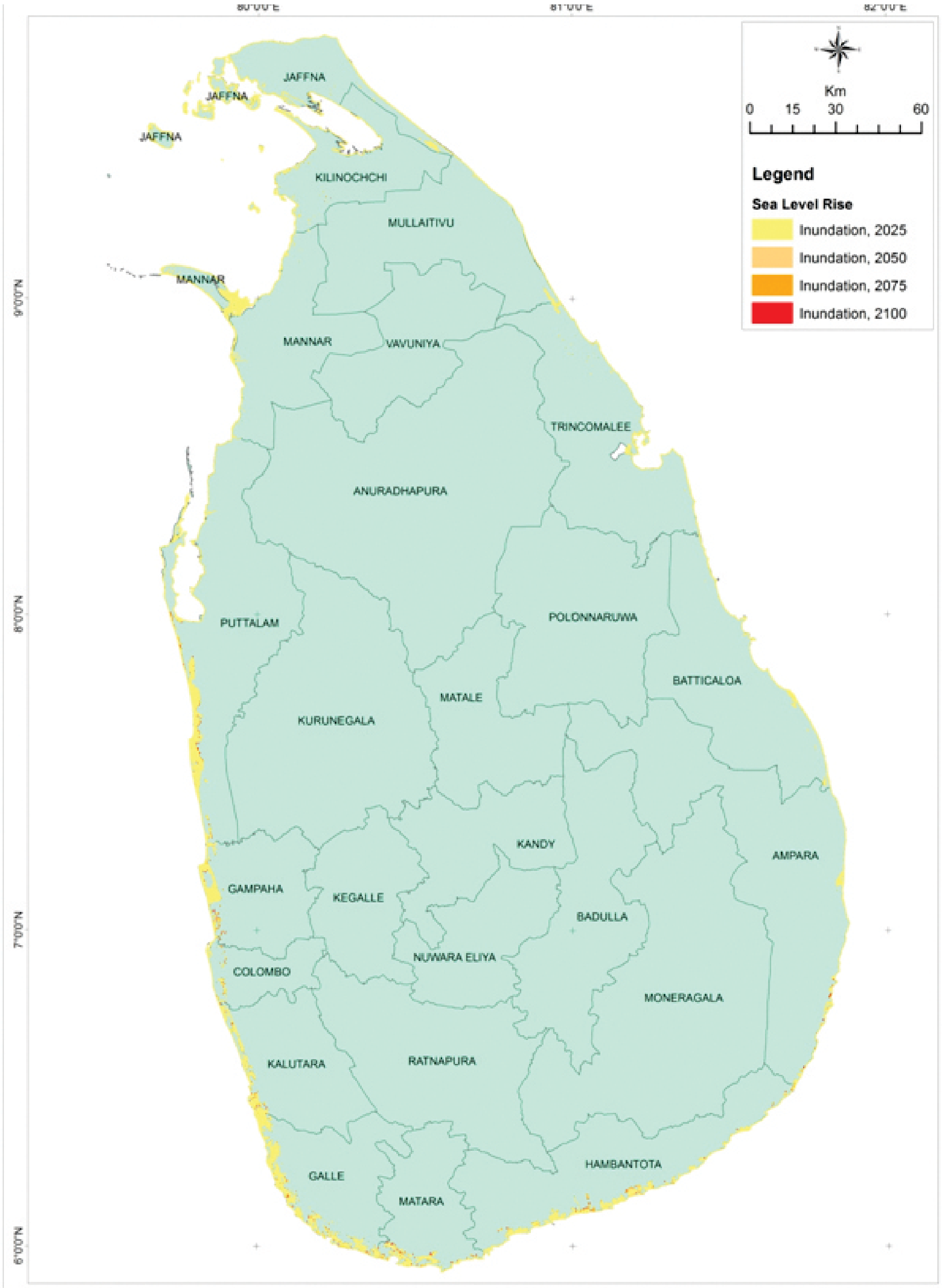

Fig 7.11: Predicted sea level rise in from 2025 to 2100 in Sri Lanka

Table 7.4 shows the land area inundated with sea level increase. Here again the Puttalam district has the highest impact followed by the Hambantota district.

7.5 Conclusion and Recommendations

Inundation due to sea level rise is a progressing phenomenon expected to occur at different rates with time. Predicting sea level rise in Sri Lanka is based on IPCC assessment of 2007 and the available digital elevation models. The accuracy of the used DEM's are not found to be accurate enough for sea level inundation prediction with the present maximum sea level rise of 0.59 m.

Therefore the inundation assessment should be carried out repeatedly with improved DEM data and with revision of sea level rise prediction. Present study identifies that the Puttalam district has the highest impact from sea level rise followed by the Hambantota district.

Future long-term studies are recommended for longterm planning on this issue.

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