# SEA LEVEL RISE IMPACT ON UNDERGROUND FRESHWATER LENS – AN ENVIRONMENTAL STUDY

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# BRIEF INTRO ….

- The republic of Kiribati (Kiribas) ---- also know as Gilbert Islands
- Low lying country made up of 33 chain of islands
- Less than 3 meter above sea level
- Approx. half of the population (i.e. 110,000) live on small atoll of south Tarawa
- Apart from rainwater, people mainly rely on underground freshwater lenses for daily water consumption

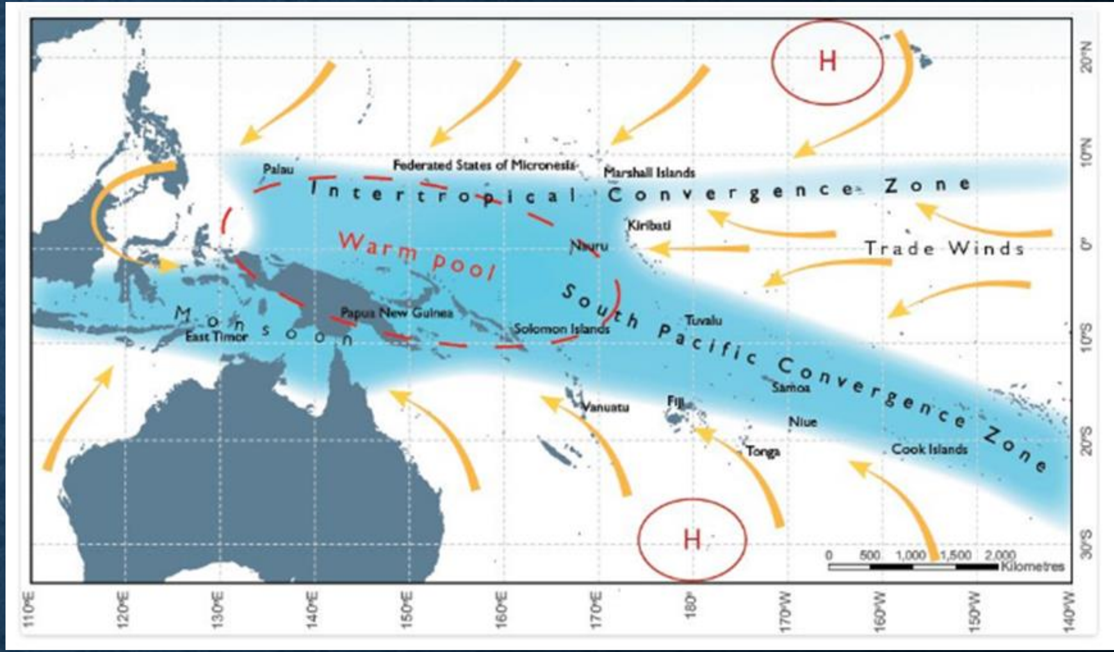


Figure 1: The average positions of the major climate features of the region in November to April.

- *The yellow arrows show near surface winds,*
- *The blue shading represents the bands of rainfall (convergence zones with relatively low pressure), and*
- *The red dashed oval indicates the West Pacific Warm Pool.*
- *H represents the typical positions of moving high pressure systems (CSIRO, 2011)*

# PROBLEM STATEMENT

# KIRIBATI (KIRIBAS) – THIS COUNTRY IS DISAPPEARING

**A YouTube link**

- https://www.youtube.com/watch?v=7Ni4gcl4tpE

**Sourced from World Post – October 24, 2018**

- https://vimeo.com/244728466

# PROBLEM STATEMENT----CONTINUED

- People use underground freshwater lenses for drinking, washing, and cooking, etc.
- Freshwater groundwater (GW) resources are becoming more unreliable.
- The thickness of freshwater lenses is being effected due to global climate change and sea level rise (SLR) (as a result of GHG (Greenhouse Gases) emissions.
- There is a risk that land of Kiribati may disappear in the near future.

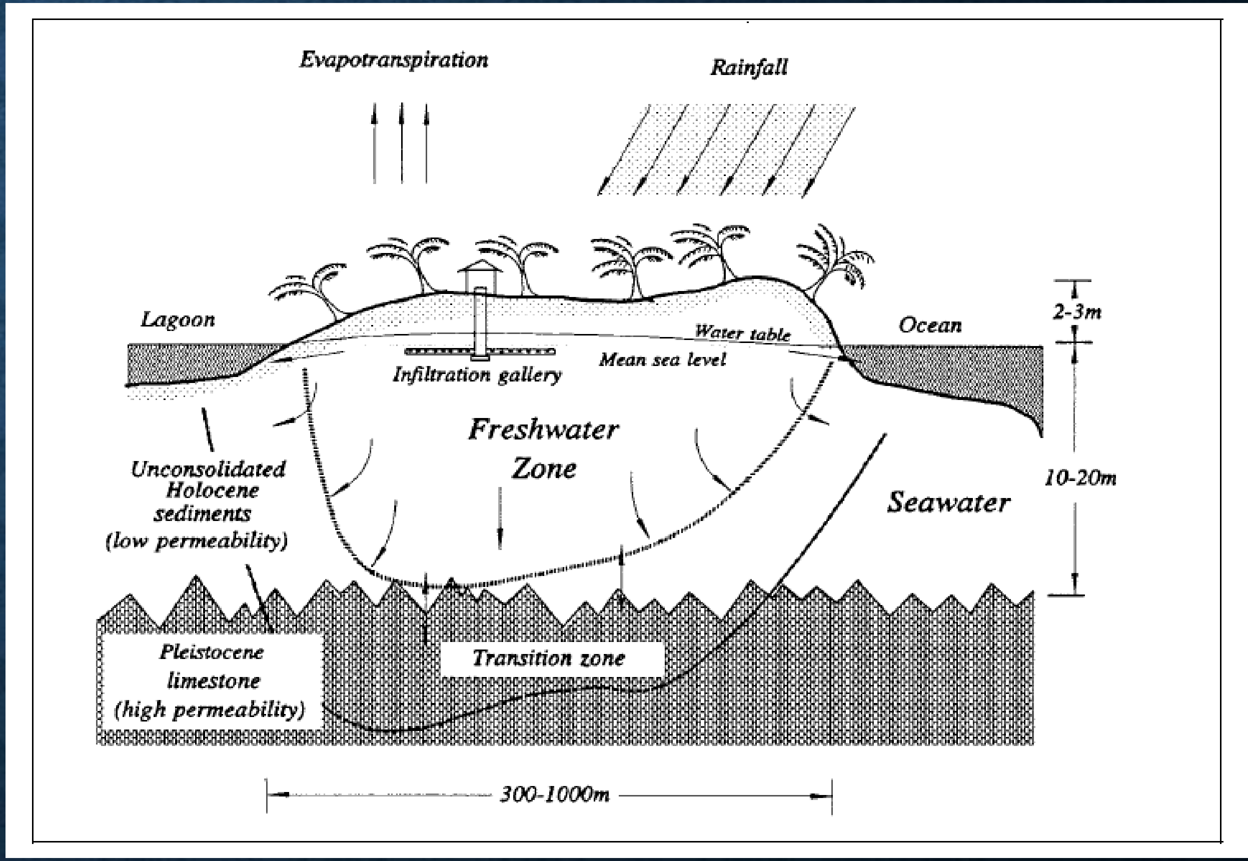


Figure 2: A cross sectional view of a small coral island showing main features of a freshwater lens and location of an infiltration gallery used for groundwater extraction in Kiribati (Sourced: Metai, 2002).

# FOCUS OF THE STUDY

- The main aim of this study was "***to assess the impacts of predicted climate change on the local underground freshwater lenses of South Tarawa, Kiribati***".

The specific objectives of this study were to:

(i) Conceptualise how the SLR may cause seawater intrusion and lift the groundwater table in coastal areas such as Kiribati.

(ii) Assess impacts of changes in climatic factors (i.e. GHG emissions, temperature, rainfall, sea level) on thickness of underground freshwater lens of South Tarawa.

(iii) Assess how local climatic factors i.e. rainfall, temperature, and sea level may change by 2030.



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# METHODOLOGY

**Conceptual Model to Visualise the Impact of SLR on GW**

- A brief explanation of how an increase in sea level could affect the GW levels in coastal areas is given below.
- Chang et al. (2011) provided a comparison of **THREE** conceptual models to visualise the impacts of SLR on salt-water wedge profile:
  - (i) Initial salt-water wedge profile before SLR,
  - (ii) Salt-water wedge profile after SLR, which is a traditional concept that ignores the groundwater lifting process, and
  - (iii) A new concept of salt-water wedge movement with groundwater level lifting process (refer to Figure 3)

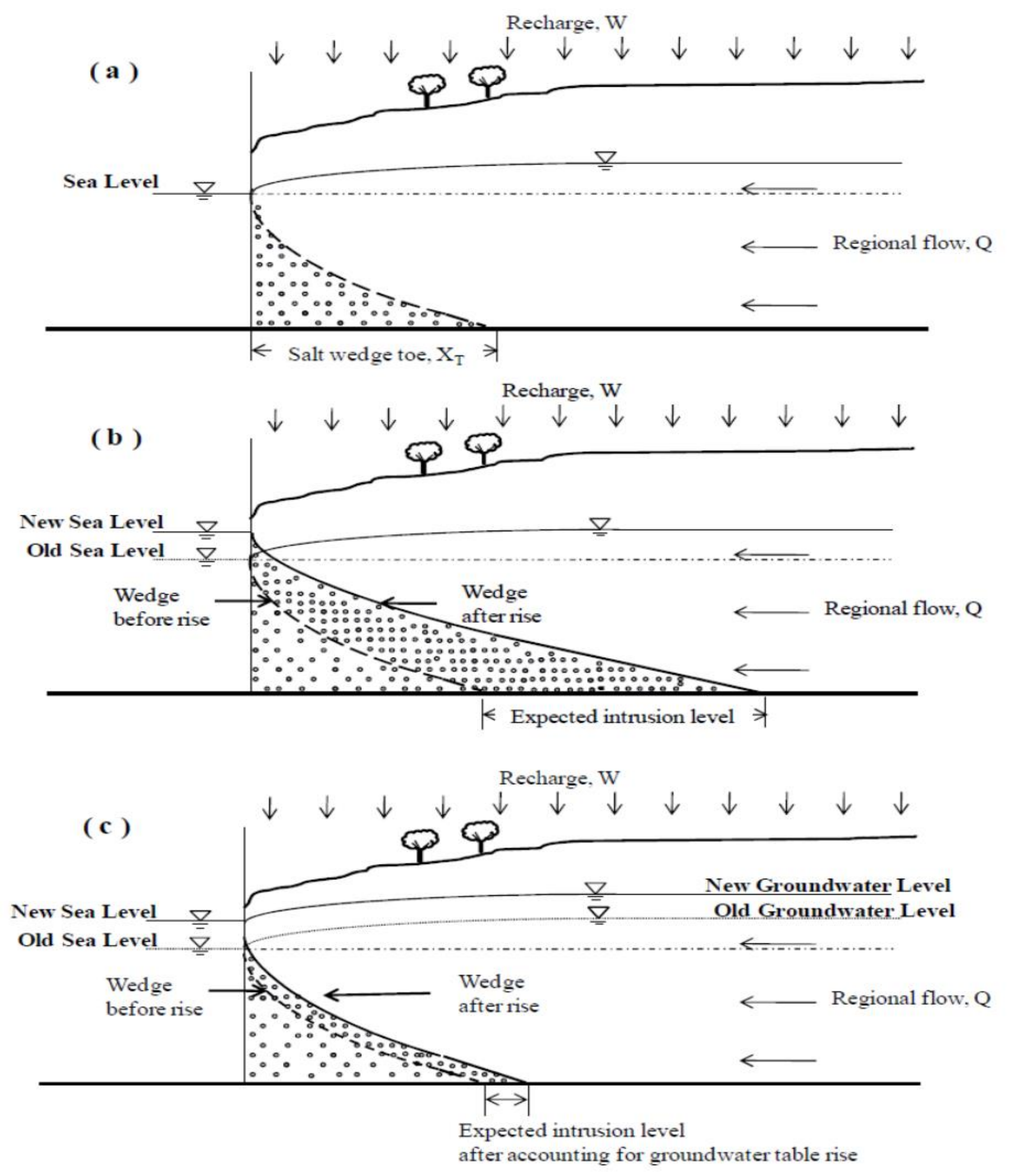


Figure 3: Comparison of three conceptual models (i) initial salt water wedge before SLR, (ii) traditional concept i.e. sea-water wedge movement and no lifting of groundwater level, (iii) new concept of groundwater lifting in response to sea-water intrusion due to SLR (Sourced: Chang et al., 2011).

# METHODOLOGY------CONTINUED

**Site Specific Data:**

- Rainfall and temperature since 1970 was sourced from Kiribati Meteorological Services (KMS).
- GHG emission (in terms of $CO_2$ equivalent) data was also sourced from the KMS for the past years (i.e. 1990 to 2012) – the whole Kiribati GHG data was used due to unavailability of local South Tarawa GHG data.
- Mean Sea Level (MSL) was also sourced from KMS from 1993 to 2010.
- GW thickness data was sourced from Public Utility Board in Bikenibeu from 1993 to 2010.

**REMEMBER**: *The thickness of groundwater/freshwater lens is taken to be the distance from the groundwater table surface to the midpoint of the transition zone (refer to Figure 2 on previous slide)*

# RESULTS AND DISCUSSION - TEMPERATURE

- Kiribati has two seasons –the dry season (***te Au Maiaki***), and the wet season or (***te Au Meang***).
- From season to season, the temperature changes not more than 1 $^0$C.
- Annual average temperature is around 28.4 $^0$C.
- Annual average temperature is likely to reach 29 $^0$C by 2030.

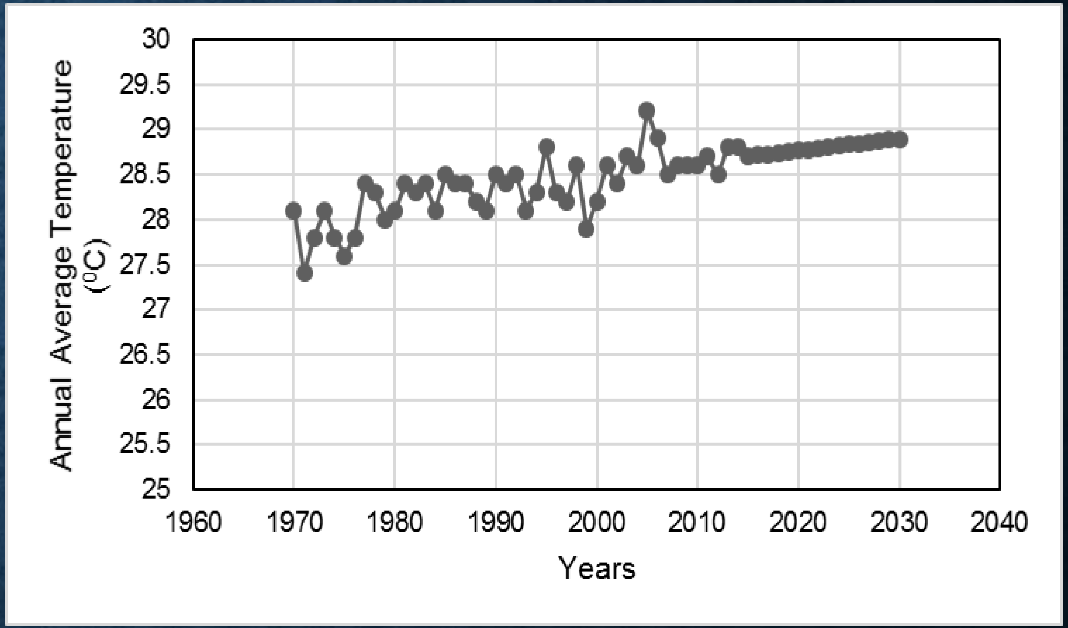


**Figure 4:** Annual average temperature for Tarawa from 1970 to 2012 with projected figures until 2030.

# ANNUAL RAINFALL

- Quite a variation in rainfall pattern.
- Annual average rainfall is 2000 mm.
- The lowest rainfall recorded was **150 mm** during 1989 – when Inter-tropical Convergence Zone (ITCZ) moved away from Tarawa.
- Highest rainfall was associated with the ITCZ moving closer to Tarawa.
- Estimated rainfall increased at a rate of 44 mm/year.
- Total annual rainfall may increase to just below **4300 mm** by 2030.
- Literature states that climate variability may continue to cause an increase in surface air and sea temperatures, increasing precipitation throughout the year, also more days of extreme rainfall and extreme heat & rising sea level (Kiribati Climate Change, 2012; 2013).

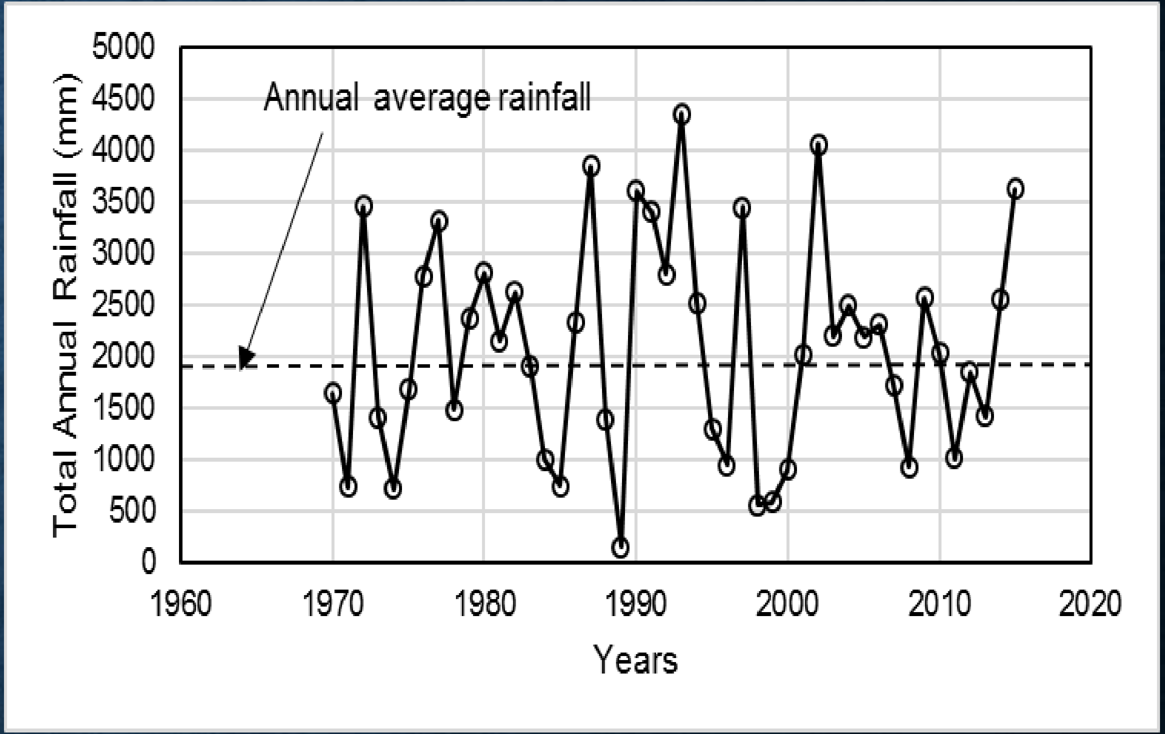


**Figure 5**: Total annual rainfall and worst drought years for Tarawa from 1970 to 2015.



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# RAINFALL & GROUNDWATER THICKNESS

The groundwater thickness was:

- between 4 and 5 m during dry periods (i.e. when the annual rainfall was below 1000 mm, on average).
- 18 m during wet seasons (i.e. when the annual total was more than the annual average of 2000 mm).
- A correlation of 72.42% was found between the groundwater thickness and annual average rainfall depth

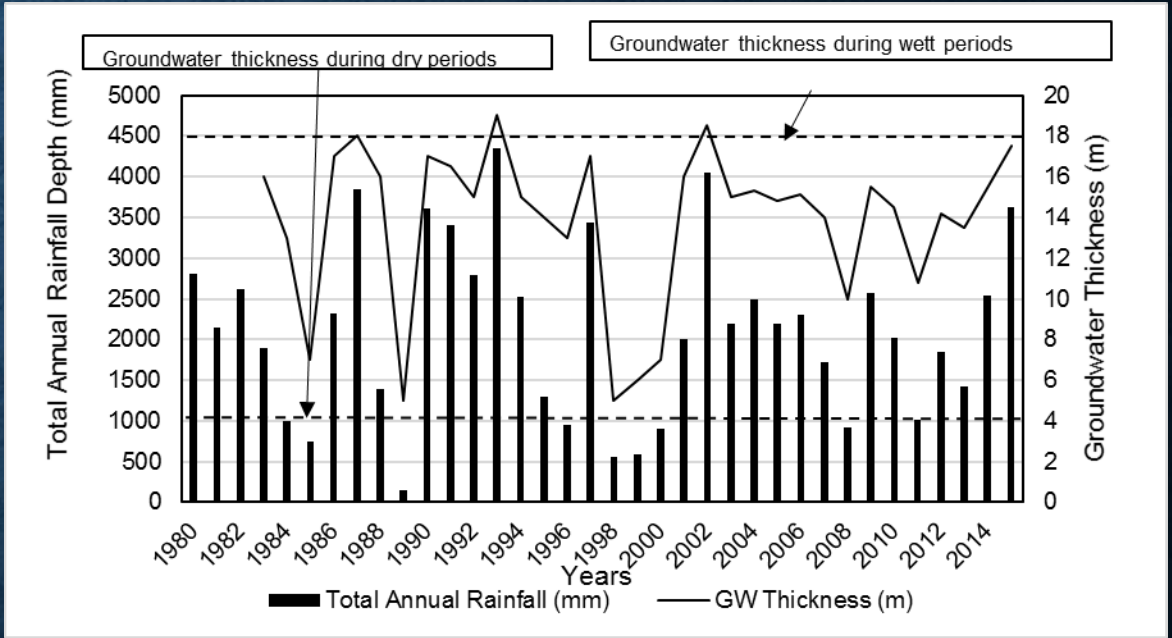


**Figure 6**: Groundwater thickness corresponding to annual rainfall amounts for South Tarawa.

# GHG EMISSIONS

- Kiribati GHGs are insignificant when compared to other countries.
- Total GHG emission in Kiribati was even less than 0.1 $MtCO_2e$ during 1990-2012.
- For example, 10975.5 $MtCO_2e$, 6235.7 $MtCO_2e$, and 3013.7 $MTCO_2e$ for China, USA & India, respectively.
- However, GHG emissions increased 100% (from 0.04 $MtCO_2$ in 1990 to 0.08 $MtCO_2$ in 2012).
- As reported by (IPCC, 2014), the global climate change is likely to impact on the groundwater resource of coastal areas including South Tarawa.
- And, this is a direct result of actions of others around the world (big industrialised countries), while people on Tarawa and other low lying nations stand in the frontlines of these impacts.
- Estimated GHG emissions in Tarawa may go up to 0.11 $MtCO_2e$ (i.e. 37.5% increase) by 2030.

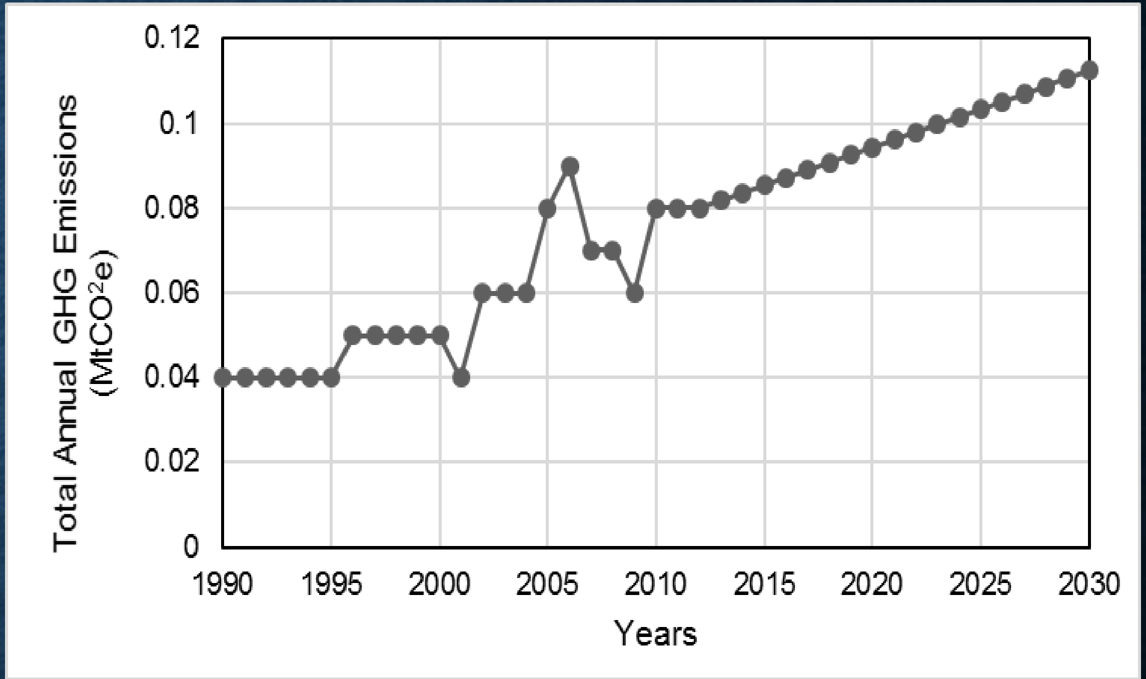


**Figure 7**: The total annual GHG emissions in terms of $CO_2$ equivalency ($MtCO_2e$) from 1990 to 2030) for Kiribati.



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# MEAN SEAL LEVEL (MSL)

- Annual mean sea level varied between 1.47 m and 1.76 m during 1993-2015.
- MSL has increased at a rate of 5 mm per year, and therefore it is expected that it may increase up to 1.83 m by 2030 – which is an alarming rate.
- It should be noted that most of lands of Tarawa are 2-3 m above sea level.
- If this trend continues then the land loss will be significant over the next 20 to 50 years.
- Melting of ice islands and ocean's thermal expansion are the main reasons of SLR globally (IPCC, 2007; 2014).

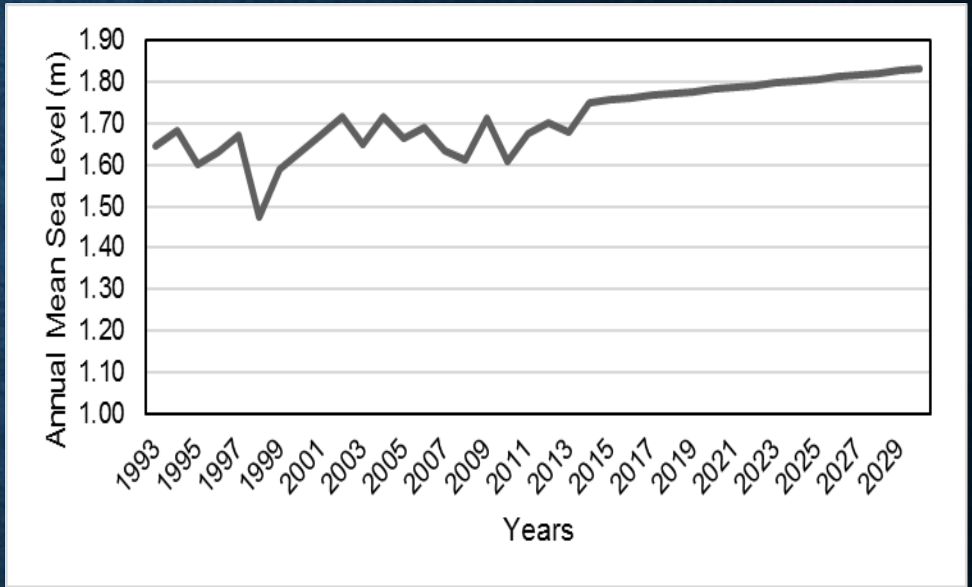


**Figure 8**: Annual mean sea level for Tarawa region since 1993.

# SEAL LEVEL RISE & THICKNESS OF UNDERGROUND FRESHWATER LENS

- Remember, in this study the thickness of the freshwater lens was the distance between the groundwater table level and the mid-point of the transitional zone.
- As the sea level rises the thickness of the transitional zone increases, which eventually lifted the freshwater lens sitting on top of it.
- This was also supported by Chang et al. (2011) with new conceptual model (Figure 2c) that the groundwater table lifting process in response to salt-water intrusion associated with SLR at the sea end boundary.
- Further, the thickness of the underground freshwater lens may decrease or increase (depending on the local recharge and pumping rates) with sea level variations (assuming that the net flux of the system does not change).
- As a result of SLR and sea-water intrusion, there is a possibility that the local groundwater may be contributing to other underground freshwater bodies due to the horizontal lateral movement of groundwater - and this requires further investigation.

Results & Discussion ---- Continued

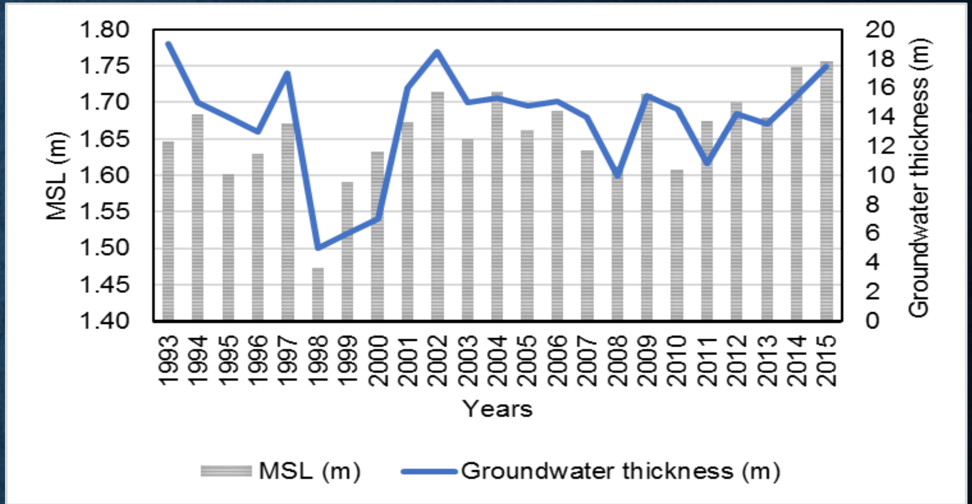


**Figure 9**: A graph showing how groundwater thickness changes with annual MSL sea level for Tarawa region since 1993.



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# SLR AND SEAWATER INTRUSION – A GENERAL DISCUSSION

- A brief general overview of few studies is provided here to understand SLR and salt water intrusion problems around the world - *refer* to section 4.0 of the paper.
- The above brief discussion proves that sea level does have an impact on sea-water intrusions, and this process can lift groundwater table.
- Therefore, a better understanding of sea-water intrusions into the formation and its self-reversal (i.e. driven back to original position) mechanism would have an enormous implication on managing the impacts of SLR in coastal groundwater aquifers (both confined and unconfined).

# SUMMARY & CONCLUSIONS

- The results showed that the air temperature hasn't changed much since 1970 and has varied between 27.4 $^{0}$C and 29.2 $^{0}$C.
- On average, annual temperature has increased by 1°C over the last 40 years. The future temperature of Tarawa may be around 29°C by 2030.
- Annual average rainfall patterns in Tarawa varies from year to year due to movement of the El Nino-Southern Oscillation (ENSO) (i.e. El Nino and La Nina) causing huge difference in rainfall amounts.
- The annual average rainfall for Tarawa was around 2000 mm, and it may increase over 4500 mm by 2030.
- Local GHG emissions have increased by 100% (i.e. from 0.04 to 0.08 $MtCO_2e$) since 1990. But, Kiribati's contribution to global GHG emission is insignificant.
- It was estimated that the total GHG emissions ($MtCO_2e$) is likely to rise to 0.11 $MtCO_2e$ by 2030, which is nominal as compared to other big players such as USA, China, and India.
- That is why the **global** climate change will have more effect (than local climatic conditions) on seal level rise and salt water intrusion in South Tarawa area - which may eventually have an effect on local groundwater quality and water table.



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# SUMMARY & CONCLUSIONS-----CONTINUED

- The sea level (in Tarawa) increased by 28 cm during 1993 and 2015.
- This increase was largely expected and was due to the global climatic effects (i.e. melting of land-based ice sheets and glaciers and seawater thermal expansion).
- The overall trend was 5 mm rise in sea level per year and it was estimated that sea level may rise up to 1.83 m by 2030.
- Lastly, the study proves that SLR can have an effect on the thickness of underground freshwater lens in coastal areas.



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