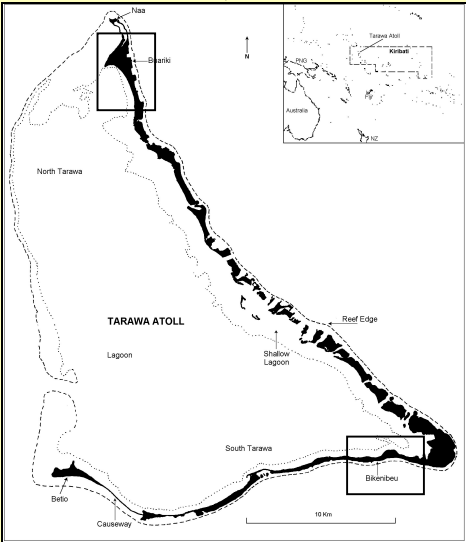# Chapter 4
Impact of Climate Change on Low Islands
The Tarawa Atoll, Kiribati

Like most atolls, Tarawa (30 km^2) is very vulnerable to sea level rise. Most of the land is less than 3 meters above sea level, with an average width of only 430–450 meters (Lands and Survey Division undated). While Tarawa lies outside the main cyclone belt, it is susceptible to storm surges and to droughts, particularly during La Niña events.

The population density of the atoll is unevenly distributed, with South Tarawa (the capital) approaching 5,500 people per square kilometer, while North Tarawa remains sparsely populated, with less than 50 people per square kilometer. As available land in South Tarawa becomes scarcer, development in North Tarawa is expected to accelerate.

Box 4. Tarawa at a Glance

Tarawa, Kiribati

Climate
- Temperature: 26–32°C (average 31°C).
- Average rainfall in central Tarawa: 2,749 milimeters.

Major influences:
- Intertropical Convergence Zone.
- South Pacific Convergence Zone.
- El Niño Southern Oscillation (ENSO).

Extreme events:
- Droughts (often associated with ENSO).
- Tropical cyclones rarely affect Kiribati (but storm surges do).

Population:
- Population of Kiribati: 77,658 in 1995 (35,000, or 45% in Tarawa)
- Average annual growth rate: 1.4% (3% in South Tarawa).
- Population Density: 250/km^2 (Gilbert Islands); 1,800/km^2 (South Tarawa).
- Growing urbanization.

Economy (Kiribati):
- GDP (1998): US$47 million.
- Average annual growth: 4.7% (1990–96).
- Dominated by public sector.
- Significant exports: copra, fish.
- Subsistence agriculture (coconut, taro, breafruit, pandanus) and fisheries vital.

Future Population Trends

Increasing population density:
- Very high population density on South Tarawa.
- Accelerated population growth in North Tarawa.

Implications:
- Denser urban structures.
- Industrial and commercial development.
- Change from traditional housing styles and materials.
- Increase in proportion of squatter housing.
- Increase in coastal infrastructure.

Future Economic Trends
- Continued dependence on natural resources.
- Agriculture will continue to be important in subsistence production, and will remain a small export earner.
- Cash economy will become increasingly important, but subsistence economy will remain significant.
- Continued dependence on foreign aid.

Future Environmental Trends
- Environmental degradation in densely populated areas.
- Continued degradation and irreversible damage to mangroves and coral reefs.
- Increased problems of waste disposal (sewage, chemical, and solid waste pollution).

Future Sociocultural Trends
- Increasing role of cash economy.
- Changes in food preferences toward imported foods.
- Increased noncommunicable diseases associated with nutritional and lifestyle changes.
- Increased poverty and social problems in urban areas.

Tarawa is already becoming increasingly vulnerable to climate change due to high population growth rates and in-migration from outer islands, accelerated development, shoreline erosion, and rising environmental degradation. In such a fragile and crowded environment, even small changes can have a large impact. Socioeconomic trends point to a continuing rise in the atoll's vulnerability in the future (box 4).

By 2050, under the climate change scenarios shown in table 2, Tarawa could experience annual damages of about US$8─$16 million (table 12). This estimate takes into account only the potential impacts of climate change on coastal areas (US$7–$13 million a year) and water resources (US$1–$3 million a year). The cost of several other important impacts—such as loss of agriculture crops and effects on public health—could not be estimated because of insufficient data. Indications suggest that these damages may be substantial.

These costs reflect annual average losses due to climate change. In years of strong storm surge, Tarawa could face capital losses of up to US$430 million in land and infrastructure assets destroyed by inundation. Relocation of communities might be needed if the loss of land and freshwater supplies become critical.

Climate change is thus likely to place a substantial burden on the people and economy of Kiribati. The projected losses could be catastrophic for a country with a 1998 GDP of

Table 12. Estimated Annual Economic Impacts of Climate Change on Tarawa, Kiribati, 2050
(millions of 1998 US$)

Impact	Annual damages[a]	Level of Certainty	Likely cost of an extreme event[b]
Impact on coastal areas			
Loss of land to erosion	0.1─0.3	Low	─
Loss of land and infrastructure to inundation	7─12	Low	210-430
Loss of coral reefs and related services	0.2─0.5	Very Low	(storm surge)
Impact on water resources			
Replacement of potable water supply due to change in precipitation, sea level rise, and inundation	1─3	Low	─
Impact on agriculture			
Agriculture Output Loss	+	Low	─
Impact on public health			
Increased incidence of diarrheal disease	++	Low	─
Increased incidence of dengue fever	+	Low	─
Increased incidence of ciguatera		Low	─
Impact of climate change on public safety and on the poor	+	Very Low	─
Potential increase in fatalities due to inundation, and water-borne or vector-borne diseases	+	Low	─
Total estimated damages	**>8─16+**		─

+ Likely to have economic costs, but impact not quantified. ─ Not available.
[a] Reflects incremental average annual costs of climate change, equivalent here to the capital recovery cost factor of land and infrastructure damaged by inundation, using a discount rate of 10 percent and a 10─ year period.
[b] Reflects financial damages to land and infrastructure caused by sea level rise and storm surge during a 1 in 14─ year storm event. For detailed assumptions, see annex A.
Source: Background reports to this study.

only US$47 million. These losses, however, assume no adaptation. Communities would likely adapt to sea level rise by elevating their houses or moving further inland, particularly if the changes were gradual. Nevertheless, sea level rise could profoundly affect the economy of Kiribati by inundating the causeways that now link the islets of Tarawa, thus disrupting socio-economic links. Much of the impact of climate change will ultimately depend on the extent to which proactive adaptation measures are adopted.

A. Impact on Coastal Areas

Climate change is likely to affect Tarawa's coast through shoreline displacement resulting from the rise in sea level (by 0.2─0.4 meters by 2050), through inundation and storm surge, and through coastal erosion due to the effect of increases in sea surface temperature and sea level on coral reefs.

To model the impact of coastal erosion and inundation, two representative sections of the Tarawa coast were selected: the islands of Buariki and Naa in North Tarawa and Bikenibeu in South Tarawa (see map in box 4). These areas represent about 20 percent of the area of North Tarawa and about 7 percent of the area of South Tarawa.

Coastal Erosion. Models of shoreline displacement indicate that while all of the atoll's islands are undergoing coastal erosion, the loss of land due to sea level rise is likely to be relatively small—a maximum of 3.2 percent of land by 2100 for Buariki and 3.9 percent for Bikenibeu, leading to economic damages averaging US$0.1-$0.3 million a year by 2050.

Higher rates of erosion could arise if sediment supply decreases, which may happen if coral reefs are weakened by climate change. Even these small changes, however, could cause significant impacts given the atoll's narrow width and population concentration.

The islands are expected to become narrower and higher, with Buariki facing a shoreline displacement of 30 percent of the island width. The frequent overwash would result in a build-up of sediments in the center of the islands. These sediments would have to be removed, or infrastructure would have to be displaced.

Coastal Inundation. As a result of ENSO events, Tarawa already experiences significant natural fluctuations of about 0.5 meters in sea level. These fluctuations will affect the inundation potential of the atoll, particularly when combined with storm surges and the projected increase in sea level.

The coastal inundation impacts were modeled by raising the mean high water spring level (the maximum water level reached during spring

**Table 13. Likely Impact on Buariki and Bikenibeu, Tarawa, Kiribati
of Inundation Caused by Sea Level Rise, 2025, 2050 and 2100**

| | | Buariki | | | Bikenibeu | | |
| | | | Projected losses | | | Projected losses | |
Projected rise in sea level (meters)	*Scenario equivalent to*	*Percentage of land area affected*	*Structures (number)*	*Roads (kilometers)*	*Percentage of land area affected*	*Structures (number)*	*Roads (kilometers)*
0.2	2025 worst-case 2050 best-guess	18%	196 (59%)	6.55 (77%)	0%	0	0
0.4-0.5	2000 baseline + storm surge 2025 best-guess + storm surge 2050 worst-case 2100 best-guess	30%	213 (64%)	6.55 (77%)	2%	34 (2%)	0
	2050 best-guess + storm surge	55%	229(69%)	7.5 (89%)	25%	423(27%)	1.3(29%)
1.0	2050 worst-case +storm surge 2100 best-guess + storm surge 2100 worst-case	80%	245 (74%)	8.5 (100%)	54%	986 (63%)	2.83(66%)
1.5	2100 worst-case + storm surge	85%	316 (95%)	8.5 (100%)	80%	1302 (84%)	4.36 (100%)

Notes: Storm surges are based on 1 in 14-year event (Solomon 1997).
Source: Background studies to this report.

tides) by the projected increase in sea level. The sea level rise scenarios were also combined with the effects of storm surges likely to occur once every 14 years (Solomon 1997).

The results indicate that under a best-guess scenario, 18 percent of Buariki could be inundated by 2050 (table 13). By 2100 up to 30 percent of Buariki could be inundated. The impact on Bikenibeu would be relatively minor (2 percent inundation). Storm surges, however, could increase damages significantly, with up to 80 percent of Buariki and 54 percent of Bikenibeu inundated by 2050.

Projected losses in infrastructure and roads could be substantial. Under a worst-case scenario, the village of Buariki could be inundated by 2050, as could 59 percent of the structures and 77 percent of the roads. In Bikenibeu, significant impact on infrastructure is not be expected to occur until 2100 under a worst-case scenario, but it could then become substantial, with 66–100 percent of all roads lost under the combined effects of storm surge and sea level rise (figure 7).

The projected loss of land and structures is based on existing infrastructure. Actual losses in 2025 and 2050 could be substantially higher, particularly if Tarawa were affected by larger storm surges (such as one in 50-100 year events). The damage could be moderated if population growth was contained and redistributed to less urbanized areas.

Extrapolating the losses for Buairiki and Bikenibeu to the rest of North and South Tarawa, the projected financial losses of land and structure assets in Tarawa could average US$7–$12 million a year by 2050 (table 14). During years of actual storm surges, Tarawa could experience losses of capital assets approaching US$210 to $430 million.

The analysis assumes the loss of all land and structures affected by inundation and storm surge, which may overly pessimistic. However,

Figure 7. Projected Inundation of Bikenibeu Island Tarawa, Kiribati under Worst-Case Scenario
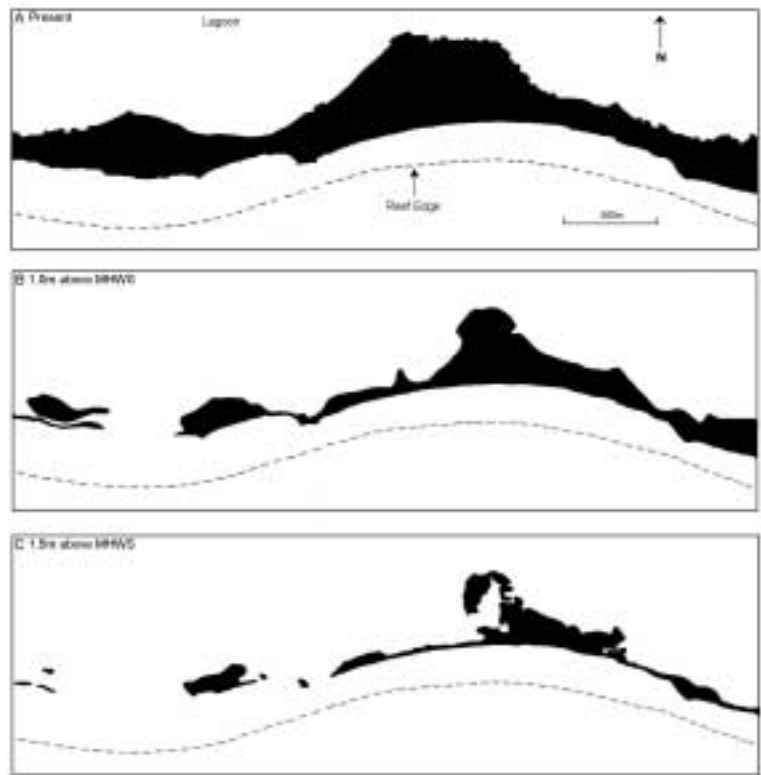
A: Present status
B: Residual island under a worst case scenario, 2100;
C: Residual island under worst case scenario and storm surge, 2100
Source: Background studies to this report.

the rise in sea level will amount to a condition of "permanent inundation" which, combined with the existing standard of housing in Tarawa, is likely to result in the loss of structures unless adaptive action is undertaken. Other factors in the analysis—such as more severe storms and increases in their frequency—are likely to have been underestimated.

Mangroves and Coral Reefs. Tarawa has lost some 70 percent of its mangroves since the 1940s, and only 57 hectares remain (Metz 1996). Hence the impact of sea level rise is expected to be relatively minor.

Healthy coral reefs may respond to increases in sea level by growing vertically. In fact, the historical accretion rate of the Tarawa reef flat (8 milimeters a year) exceeds the rate of

**Table 14. Estimated Economic Impact of Inundation Caused by Sea Level Rise
in Tarawa, Kiribati, 2050 and 2100
(millions of 1998 US$)**

	Potential Inundation Costs (in US$ million)	
Scenario equivalent to	*Annualized losses[a]*	*Capital value of lost assets during a storm surge event[b]*
2050 best-guess	6.6	158.0
2050 worst-case 2100 best-guess	12.4	374.6
2100 worst-case	69.7	497.3

[a] - Reflects the annual value of the losses, or the capital recovery factor. The costs take into consideration
      the incremental impact of a 1 in 14 year storm event.
[b] - Reflects the incremental cost of capital losses during a 1 in 14 year storm event.
Note: For assumptions, see annex A.
Source: Background studies to this report

projected sea level rise (Marshall and Jacobsen 1985). However, many corals may not be able to adapt to warmer sea surface temperatures and increased concentration of carbon dioxide in the atmosphere, both of which inhibit coral growth. As stated previously, vertical coral growth is likely to lag the increase in the sea level by at least 40 years. This could create a high-energy window, allowing waves of increasing strength to reach the shore. In addition, while the reef is growing vertically the amount of sediment for island building could decline.

For heavily damaged reefs affected by increased bleaching events a number of consequences are likely. These include further depletion of reef fisheries, failure of the reef to act as an effective buffer of wave energy, and increased island instability as sediment resources decline.

The economic losses of coral reef degradation attributed to climate change would be in the order of US$200,000–$500,000 a year primarily as a result of lost fish production (table 12). This estimate does not include loss of coastal protection, which was reflected in the inundation analysis, or other important reef functions that could not be quantified.

B. Impact on Water Resources

Climate change is likely to affect the water resources of Tarawa through variations in rainfall, evapo-transpiration (caused by a rise in temperatures), increases in the sea level, and extreme events (figure 8). Average rainfall is expected to either decrease by 8─11 percent, or increase by 5─7 percent by 2050 (most models predict an increase). The economic losses resulting from these changes are estimated at about US$1–3 million a year (in 1998 dollars) by 2050.

Figure 8. Likely Impact of Climate Change on Water Resources in Tarawa, Kiribati
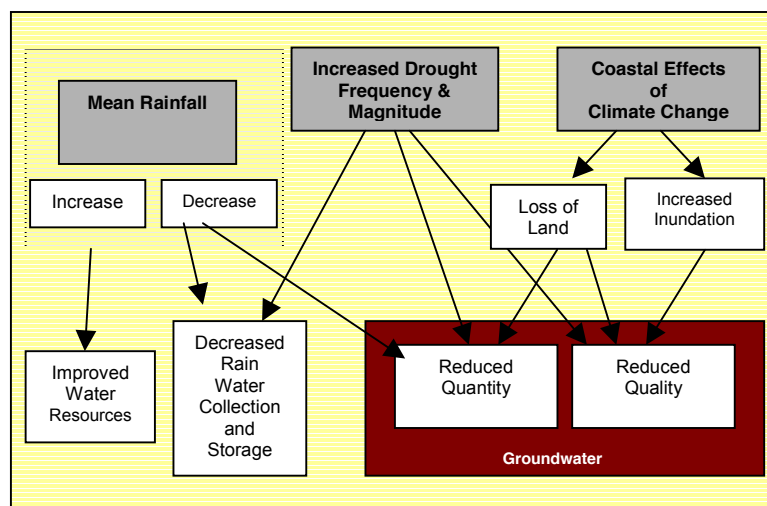
Tarawa receives less rainfall than surrounding atolls. The population relies primarily on groundwater resources, complemented by rainfall collected from roofs and desalinated water (a desalination plant has been operational since 1999). Population growth and economic development are likely to place considerable pressure on these resources over the next century.

Water Supply. Models of climate change impact on Tarawa's main groundwater supply (Bonriki) indicate the following:

- *Changes in rainfall.* By 2050 a 10 percent decline in rainfall could cause a 14 percent reduction in groundwater recharge. If, by contrast, average rainfall increased by 7 percent, the groundwater recharge would increase 5.5 percent.

- *Changes in evapo-transpiration.* Evapo-transpiration would increase if the climate warmed, but its effects on groundwater recharge would be much milder than the effect of changes in rainfall. A 10 percent increase in annual evapo-transpiration could result in a 6 percent decline in groundwater recharge.

- *Changes in sea level.* A rise in sea level of 0.4 meters (the worst-case scenario in 2050) would have little effect on the groundwater supply and could even raise its volume, as the groundwater table (the top of the freshwater lens) would tend to rise while its base remained relatively unaffected. However, if the width of the islands were reduced by inundation—which is likely—the thickness of the groundwater could decline 29 percent.

The combined effect of these impacts is shown in table 15. By 2050 if rainfall declines by 10 percent, the sea level rises by 0.4 meters, and the islands' width is reduced by inundation, the thickness of the groundwater could decline as much as 38 percent. The resulting economic impacts, extrapolating for the Tarawa atoll, would be on the order of US$1.4─$2.7 million a year. If, by contrast, average rainfall increased in the future, the annual economic costs would amount to US$0.7─$1.3 million.

The value of the groundwater was estimated based on what it would cost to replace it by alternative sources, either through expansion into alternative groundwater sources or through desalination. A third alternative source—

Table 15. Estimated Annual Economic Costs of Climate Change on Water Resources in Tarawa, Kiribati, 2050
(millions of 1998 US$)

Climate change scenario	Percentage change in groundwater thickness[a]	Economic costs of substitution by alternative sources	
		Expansion into new groundwater sources	*Desalination*
Current sea level, 7% increase in rainfall	+5.5	+0.2	+0.4
Current sea level, 10% reduction in rainfall	-14.0	-0.5	-1.0
0.2 meter sea level rise, current rainfall	-0.9	-0.0	-0.1
0.4 meter sea level rise, current rainfall	+2.0	+0.1	+0.1
0.4 meter sea level rise, 10% reduction in rainfall	-12.0	-0.4	-0.8
0.4 meter sea level rise, current rainfall, reduced island width	-29.0	-1.0	-2.0
0.4 meter sea level rise, 7% increase in rainfall, reduced island width	-19.0	-0.7	-1.3
0.4 meter sea level rise, 10% reduction in rainfall, reduced island width	-38.0	-1.4	-2.7
Total costs (under a reduced rainfall scenario)		-1.4 to -2.7	
Total costs (under an increased rainfall scenario)		-0.7 to -1.3	
Total costs		**-0.7 to -2.7**	

a. Reduction in thickness was modeled for the Bonriki freshwater lens in Tarawa and may not apply to other groundwater sources.
Note: Shaded areas indicate the most relevant scenarios of those shown in the table. See annex A for detailed assumptions.
Source: ADB 1996 and background studies to this report.

rainfall collectors—could be less costly but may not be able to compensate for the shortages.

Extreme Events. The effects of extreme events on the water supply of Tarawa could be significant. Currently, high sea levels during El Niño years can lead to seawater contamination of freshwater lenses. Recovery is generally rapid due to the accompanying high rainfall.[6] The higher overtopping and inundation that may occur in the future, however, could considerably increase the risks of saline contamination.

The impacts of droughts could also be substantial, though difficult to quantify. The 1998–99 drought, for example, dried rainwater tanks in South Tarawa and caused shallow groundwater reserves to become brackish (White and others 1999). When rain arrived in March and April 1999, it contaminated groundwater wells, causing a high incidence of diarrhea.

C. Impact on Agriculture

Many of the crops grown in Kiribati are affected by changes in climate. Production of copra—the main cash crop for about 55 percent of Kiribati's population—is sensitive to rainfall, as coconuts require annual rainfall of at least 1,000–1,500 millimeters. *Te babai* (giant taro) is extremely sensitive to reductions in groundwater. *Te babai* pits are also prone to saltwater intrusion as a result of storm surges and overwash.

Climate change is most likely to affect agricultural crops through changes in rainfall. If wetter conditions prevail, production of water-sensitive crops—coconut, breadfruit, and *te babai*—is likely to increase.   If rainfall decreases, coconut and *te babai* production will likely decline.

Climate variability may also affect agricultural production, especially during La Niña years, when droughts are most likely to occur.

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[6] El Niño increases rainfall in Kiribati. La Niña events are generally accompanied by droughts.

Sea level rise could affect agriculture crops in two major ways: first, through saltwater intrusion, which would affect *te babai* production in particular. Second, through loss of coastal land due to inundation, which could reduce production of copra, breadfruit, and pandanus. Estimates of the cost of damage could not be made due to data and time constraints.

D. Impact on Public Health

Climate change could exacerbate public health problems in Tarawa. The incidence of ciguatera poisoning, diarrheal disease, malnutrition, and vectorborne diseases, such as dengue fever, is likely to rise as a result of increased temperatures and changes in rainfall.

Dengue Fever. There have been four known outbreaks of dengue fever in Kiribati, two during the 1970s and two during the 1980s. South Tarawa is at a relatively high risk of dengue fever epidemics due to a combination of crowded urban areas, ideal climate conditions for the vector (average temperatures of 31°C and rainfall of 500 millimeters a month), the presence of an international airport, and the proliferation of discarded empty bottles and used tires.

A simple model suggests that the risk of dengue fever will increase in the future as a result of climate change, with the epidemic potential—an index measuring the efficiency of disease transmission—expected to increase 22─33 percent by 2050 (table 16). Most of South Tarawa's population would be exposed in the event of an epidemic. However, while future epidemics could expand faster, the number of cases would probably not increase from current levels. The increased prevalence of all dengue-virus serotypes worldwide could also lead to a higher incidence of severe forms of dengue fever—in particular dengue hemorrhagic fever and dengue shock syndrome, which can be fatal.

Ciguatera Poisoning. Kiribati has one of the highest rates of ciguatera poisoning in the Pacific (Lewis and Ruff 1993). The disease is contracted by consuming reef fish that have been contaminated by ciguatoxins.

A recent study found a statistically significant relation between sea surface temperatures and the reported incidence of ciguatera fish poisoning in Kiribati (Hales and others 1999). This relation was used to model the projected increases in ciguatera poisoning (table 16). The model shows that a rise in temperatures is expected to increase the incidence of ciguatera poisoning from 35–70 per thousand people in 1990 to about 160–430 per thousand by 2050.

These results should be interpreted cautiously, as the model is based on many uncertainties and limited data. The overall impact of climate change on ciguatera should perhaps be measured not in terms of incidence rates but in terms of how people respond to the increased risk (Ruff and Lewis 1997). This may include changes in diets, decreased protein intake, increased household expenditures to obtain substitute proteins, and loss of revenue from reef fisheries. In addition, reef disturbance has been linked to ciguatera outbreaks (Ruff, 1989; Lewis 1992), suggesting that improved management of coastal areas would be an important adaptation strategy.

Diarrheal Disease. Increased rainfall would likely result in a reduction in the overall rate of diarrhea due to improved water quality and availability (though flooding may also lead to groundwater contamination). Decreased rainfall—particularly if it resulted in an increase

in droughts—would increase the incidence of diarrhea, as water shortages exacerbate sanitation problems. The projected rise in temperature may increase the incidence of diarrhea, primarily by increasing the likelihood of spoiled or contaminated food. Sea level rise could also increase the incidence of diarrhea by decreasing the size of the freshwater lens, exacerbating overcrowding conditions, and disrupting sanitation and water supply.

Tarawa has experienced cholera outbreaks in the past. It is possible that increased temperatures may enhance the pathway of cholera transmission through the high level sewage contamination in Tarawa's coastal waters.

Indirect Public Health Effects. The indirect public health effects of climate change could be far-reaching. They could include increases in malnutrition due to losses of subsistence agriculture and fisheries; deterioration in standards of living due to impacts on primary sectors; loss of land and infrastructure, leading to increased crowding and land shortages; and the immense economic, social, and cultural impacts associated with population relocation if it was required as a result of inundation or water shortages. These diffuse effects could well prove to be the most important impacts of climate change on the public health of the atoll.

Table 16. Estimated Increases in Dengue Fever Epidemic Potential and Incidence of Ciguatera Poisoning in Kiribati as a Result of Climate Change, 2025, 2050, 2100

Impact	Baseline 1990	2025	2050	2100
Dengue fever				
Projected epidemic potential[a]	0.18	0.20	0.22—0.24	0.25—0.36
Percentage change from 1990	n.a.	11	22—33	39—100
Ciguatera poisoning incidence				
(per thousand population)	35—70	105—240	160—430	245—1,010

[a] - The epidemic potential index measures the efficiency of disease transmission. A value of 0.2 or above indicates a high epidemic potential.
n.a. – Not applicable.
Note: Ranges indicate best-guess and worst-case scenarios. Changes in atmospheric temperatures were used as a surrogate for sea surface temperature in forecasting the incidence of ciguatera. The model assumed a reporting case rate of 10–20 percent.
Source: Background studies to this report; Hales and others (1999).