Environment: Science and Policy for Sustainable Development

ISSN: 0013-9157 (Print) 1939-9154 (Online) Journal homepage: https://www.tandfonline.com/loi/venv20

Climate Change, Sea-Level Rise, & Health Impacts in Bangladesh

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To cite this article: Aneire E. Khan , Wei W. Xun , Habibul Ahsan & Paolo Vineis (2011) Climate Change, Sea-Level Rise, & Health Impacts in Bangladesh, Environment: Science and Policy for Sustainable Development, 53:5, 18-33, DOI: 10.1080/00139157.2011.604008

To link to this article: https://doi.org/10.1080/00139157.2011.604008

Published online: 02 Sep 2011.

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Climate Change, Sea-Level Rise, & Health Impacts in

Doing the laundry on the banks of a river, Bangladesh.

There is increasing evidence that global climate change will have adverse effects on human health, mainly among the poorest populations in the world. Bangladesh may experience some of the more severe impacts because of its unique meteorological and topographical conditions, coupled with its high population density and poor infrastructure. Over the past few decades, Bangladesh has already suffered from harsh climate-related events, which have adversely affected the livelihoods of the people living in environmentally fragile areas. In 2004, almost 50 percent of the total land mass of the country was inundated by flood waters for two months, while in 1998, floods affected approximately 30 million people in 52 out of 64 districts. The country experiences only 1 percent of all cyclones, but accounts for almost 50 percent of deaths from cyclones worldwide. High degrees of "vulnerability" to the impacts of climate change make this population particularly susceptible to adverse health impacts, and threaten development achievements.

In this study, Bangladesh is considered as a model country where early effects of climate change are being witnessed. These effects result not only from gradual changes in sea level and temperature but also from increased regional climate variability and extreme events, including more intense floods, droughts and storms. We review some prevalent human diseases linked to sea-level rise, particularly those from newer environmental

by Aneire E. Khan, Wei W. Xun,
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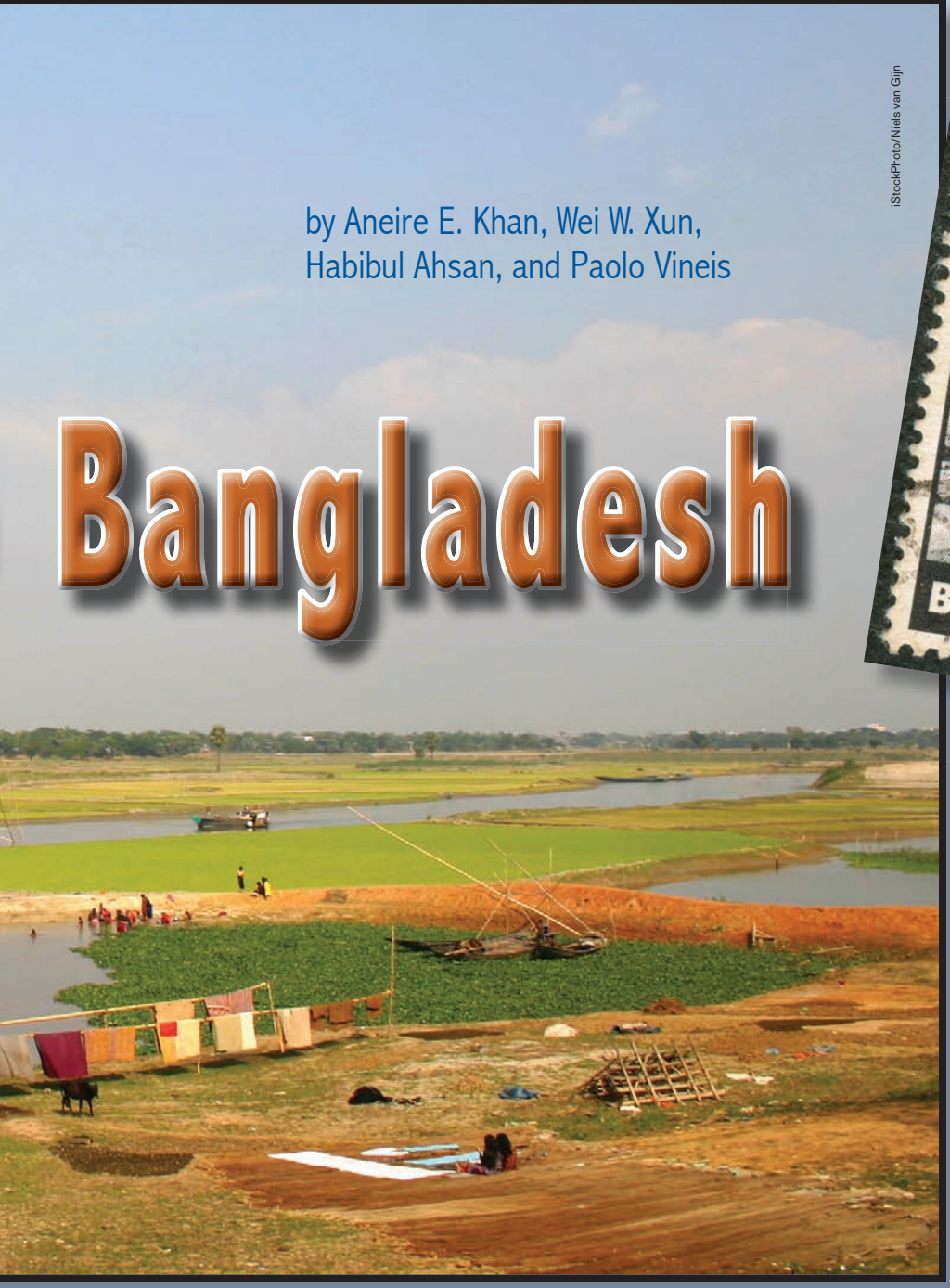
Bangladesh



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threats, such as salinity intrusion in soil and water in coastal areas. These human health impacts need to be urgently monitored with appropriate, well-designed, and methodologically sound epidemiological studies investigating climatic variation associated with diseases, combined with Modeled scenarios, so that early research results can be used to guide sustainable adaptation measures and public health policies. Finally, we identify the range of adaptation measures in current practice as well as those planned, as a set of actions complementary to national goals of Bangladesh.

Background

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) estimates that the marine and coastal ecosystems in South and Southeast Asia will be affected by sea-level rise with "high confidence," exposing a million or so people to risk from flooding.[1] Even though the exact magnitude of the changes in global climate is still uncertain and open to worldwide scientific debate, it is broadly recognized that Bangladesh may suffer the most severe impacts from climate change. The most crucial effects will be on agriculture and water security, adversely affecting human health in a number of ways.[1] The warming trend over recent decades has already contributed to increased morbidity and mortality in many regions of Bangladesh, and climate–health relationships pose increasing health risks under future projections of climate change.[2]

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Map showing the Bay of Bengal and surrounding countries.

Bangladesh is a low-lying country, located in the delta of three large river systems, the Ganges, the Brahmaputra, and the Meghna (GBM), with a 720-kilometer coastline that meets the encroaching Bay of Bengal in the south. The coastal zone (32 percent of the total land mass) receives discharges from numerous rivers, including the GBM river system, creating one of the most productive ecosystems in the world. However, the unique geographical setting makes these regions highly vulnerable to heavy monsoons, tropical cyclones and storm surges, floods, droughts, river-bank erosion, and long-term environmental degradation.

Under scenarios of climate change, the observed climate variability is likely to increase, causing even more extreme climate conditions regionally.[3] With a population of about 160 million, the Bangladeshi economy strongly depends on agriculture and natural resources that are highly sensitive to variations in climate; this is especially true for the 35 million people living in the coastal areas (28 percent).[4] Twelve out of the 64 districts in Bangladesh fall on the "exposed coastal zone" (districts that meet the sea or lower estuary directly), where the anticipated sea-level rise could potentially affect the entire population. The main effects on health, besides direct effects such as injuries and outbreaks of diarrhea linked to extreme events like floods and cyclones, are likely to be through food security and shortage of safe drinking water. Extreme climate events are also likely to

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Workers in a paddy field—a common scene throughout Bangladesh. Two thirds of the population work in the agricultural sector.

have a considerable impact on the mental health of the population, which has been largely neglected.

These health impacts, especially for the most vulnerable communities, need to be monitored with appropriate and well-designed epidemiological studies. A particularly difficult aspect in carrying out such studies is the causal attribution of health-related events to climate change/variability, which requires the development of new epidemiological and statistical techniques. Uncertainties are even greater for indirect health effects like posttraumatic stress. There is also a scarcity of good-quality health data available in countries such as Bangladesh. Mortality statistics, which are generally only available during natural disasters, can often be subject to inaccuracy and bias.[5]

Table 1. Climate Change Scenarios, Given by the IPCC[7]
B1 (low), Year 2080 (sea-level rise 15 centimeters)
A2 (high), Year 2050 (sea-level rise 27 centimeters)
A2 (high), Year 2080 (sea-level rise 62 centimeters)
A2 (high), Year 2080 (sea-level rise 62 centimeters + 10 percent rainfall)

SOURCE: Institute of Water Modelling and Center for Environmental & Geographic Information Services, Bangladesh.

Sources of Information

This article is based on a search of the literature on health effects related to climate variability in Bangladesh, as well as gray literature available to the authors (obtained from the Bangladesh Center for Advanced Studies (BCAS) and Center for Environment and Geographic Information Services (CEGIS)). Reports by the Ministry of Environment and Forest (MOEF) of Bangladesh and the UK Department for Environment, Food and Rural Affairs, which included assessments of the impacts of climate change and sea-level rise on water resources, land suitability, livelihoods, and health of coastal populations, have been used.[6,7] The reports include a suitability model for crops called CROPSUIT,[6] which determines the physical suitability of crops and shrimp cultivation based on land characteristics and land use requirements. A hydrodynamic model was used to simulate river systems under present and future conditions.[7] The spatial and temporal distributions of inundation, salinity intrusion, and storm-surge flooding due to sea-level rise in the coastal region were determined using mathematical models.[7] Estimates for future sea-level rise and changes in intensity of cyclones and precipitation, under low and high greenhouse gas emission scenarios, were based on IPCC predictions. (Table 1).[8]

Sea-Level Rise: Time Trends and Impacts

Globally, the number of people at risk from flooding by coastal storm surges is estimated to increase from the current 75 million to 200 million in a scenario of mid-range changes in climate (sea-level rise of 40 cm by 2080).[9] In Bangladesh, large areas of coastal settlements are situated just above sea level. As a result, one-third of the country is vulnerable to flooding.[10,11] While normal floods, resulting from usual monsoon rainfall, are essential for crops, there has been an increase in the frequency of high-intensity floods that pose serious threats to livelihoods and human health.[12] Between 1954 and 1996, Bangladesh experienced 28 major floods, of which 11 were classified as "devastating" and five as "most devastating."

It is predicted that the frequency and severity of flooding, intrusion of salt water, loss of biodiversity, crop failures, and coastal erosion will increase. Higher mean sea levels are likely to contribute to the enhanced storm surges expected to result from cyclones with higher intensity. There is already evidence that saltwater from the Bay of Bengal has penetrated more than 100 kilometers inland along tributary channels, posing pressure on the availability of fresh drinking water.[13] Sea-level rise will further increase the extent and concentration of salinity in both ground and surface water in coastal areas.[6]

Global sea-level rose at an average rate of 1.8 (1.3 to 2.3) millimeters per year between 1961 and 2003, according to IPCC estimates.[14] The rate accelerated to about 3.1 (2.4 to 3.8) millimeters per year between 1993 and 2003.[1] However, this is likely to be a considerable underestimate for Bangladesh.[6] Using historical data from three coastal stations (Hiron Point, Char Changa, and Cox's Bazaar), it was shown that the rate of sea-level rise during the last 22 years in Bangladesh is many-fold higher than the global sea-level rise over 100 years.[6] The estimated rate of rise of water levels was 4, 6, and 7.8 millimeters per year for the three stations, respectively.[6] Due to tectonic movements, the ground level is sinking slightly, pushing up the average relative rise in sea levels.

There has been an increase in the frequency of high-intensity floods that pose serious threats to livelihoods and human health.

For future predictions, the mean water levels from high and low tide were

Cox's Bazaar, Bangladesh.

calculated at 37 stations in Bangladesh across the country's southern coast between 1977 and 2002, and ranged from 53 to 97 centimeters for the year 2100 (assuming other factors, such as population growth, remain constant), while the predicted global sea-level rise for 2100 calculated by IPCC is 9 to 88 centimeters.[7]

Analyses of the impact of inundation depth in Bangladesh show that by 2080, there will be an increase of 13 percent (469,000 hectares) inundation area in the monsoon season due to a 62-centimeter sea-level rise for a high emission scenario (based on the scenarios proposed by IPCC, described in Table 1), in addition to the base conditions of 2005 (Table 2).[7] For the same year, the inundated area is estimated to increase to about 16 percent, if the sea-level rise is accompanied by a 10 percent increase in rainfall. About 13 polders along the southwest coast are expected to be overtopped due to increased water levels. In Bangladesh alone, under the scenario of 1 meter sea-level rise, 17.5 million people (15 percent of the total population) are projected to be affected,[15] while under the worst-case scenario (for high emission (A2) at 62 centimeters sea-level rise), 51 percent of total population is expected to be exposed to high inundation (>50 cm) risk.[7] Furthermore, an additional 5.5 million people will be exposed to inundation of 50 to 100 centimeters within the next 40 years due to cyclone-induced storm surges, under the high emission scenario and a sea-level rise of 27 centimeters.[7]

The intensity of cyclones originating along the coast of Bangladesh in the Bay of Bengal has increased significantly over the past few decades.[1] Storm surges from tropical cyclones contribute to temporary but intense local flooding in Bangladesh. Since 70 percent of landmass of the country is less than 1 meter above sea level, and storm surges can range from 1.5 and 9 meters in height,[12] they cause heavy floods in these coastal regions. Meanwhile, 10 percent of the land coverage in Bangladesh is made up of lakes and rivers, which often overflow during prolonged periods of monsoon rains causing riverine floods.

Health Impacts of Floods

The direct health impacts of floods are drowning and injuries leading to increased mortality and morbidity, especially among children. Cyclones in 1970 and 1991 in Bangladesh killed

Table 2. Area (ha) Inundated due to Sea-Level Rise, During Monsoon and Dry Season in Bangladesh[7]

	MONSOON SEASON		DRY SEASON	
Scenarios	**Inundated area (hectares)**	**Additional inundation (hectares)**	**Inundated area (hectares)**	**Additional inundation (hectares)**
Base condition, Year 2005	1,720,200 (50 percent)	—	404,500 (12 percent)	—
B1 (low), Year 2080 (sea-level rise 15 centimeters)	1,863,600 (54 percent)	143,500 (4 percent)	Insignificant change	—
A2 (high), Year 2050 (sea-level rise 27 centimeters)	1,972,200 (57 percent)	252,000 (7 percent)	559,100 (16 percent)	154,600 (4 percent)
A2 (high), Year 2080 (sea-level rise 62 centimeters)	2,189,200 (63 percent)	469,000 (13 percent)	768,600 (22 percent)	364,200 (10 percent)
A2 (high), Year 2080 (sea-level rise 62 centimeters+ 10 percent rainfall)	2,271,700 (66 percent)	551,500 (17 percent)	Not applicable	

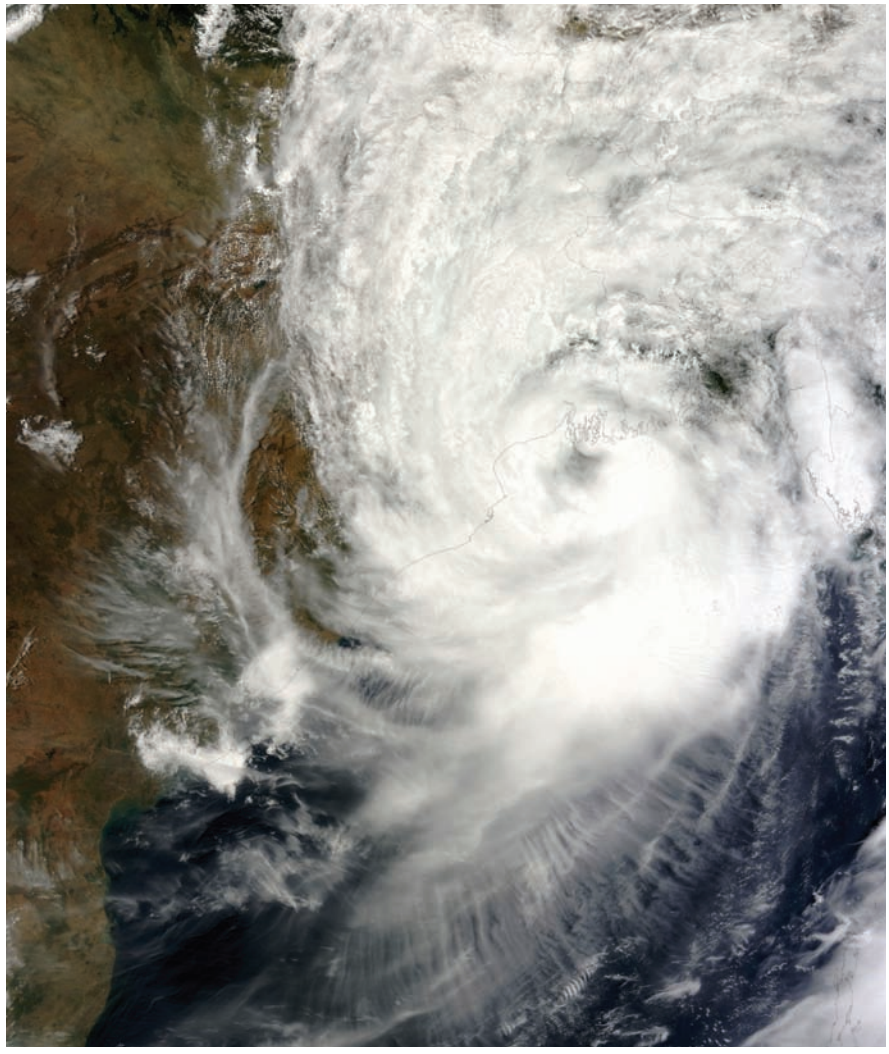
SOURCE: Institute of Water Modelling and Center for Environmental & Geographic Information Services, Bangladesh.

U.S. Navy/Christopher Lange

Damage in Bangladesh from Cyclone Sidr in 2007.

300,000 and 138,000 people, respectively.[16] A nonrandom survey of 45 housing clusters carried out after the 1991 cyclone showed that mortality was greatest among under-10-year-olds (26 percent) and women older than 40 years (31 percent).[16] Nearly 22 percent of people who could not reach a concrete or a brick structure died, whereas those who reached shelters survived.[16] An epidemiological study found that deaths due to drowning among 1- to 4-year-old children ranged from 10 percent to 25 percent during 1983–1995.[17] Adnan et al. in 2003 reported that drowning accounted for 43 percent of deaths in a cohort of 8,000 children and 20 percent of deaths among 1- to 4-year-olds in a nationwide survey, with children between 12 and 23 months particularly susceptible.[18] Even though, in terms of frequency, Bangladesh is not a high-risk cyclone-prone area (0.93 percent of the world's total tropical storms), about 53 percent of the total world deaths due to tropical cyclones occur in Bangladesh.[19,20] "Vulnerability" is therefore a critical element, especially for the coastal population of the country, where cyclones cause vast physical damages, deaths, injuries, outbreaks of infectious diseases, and mass migration.[21-26] However, it must be noted that considerable improvements in preparedness over the past few years, through early warnings, better access to designated cyclone shelters, and post-cyclone water and sanitation facilities, have lowered the death toll in contrast to previous disasters.

Cyclone Sidr in 2007 in the southern coasts killed 3,500 people, destroyed 500,000 homes, and affected 845,000 households.[27,28] Outbreaks of diarrhea, pneumonia, typhoid, hepatitis, respiratory disease, and skin disease were reported among the affected.[28] More recently, during Cyclone Aila in 2009, a postdisaster epidemiological study identified 1,076 cases of cholera and 14 deaths (attack rate of 44/10,000) and showed that contaminated drinking water was the probable source of the outbreak, while exposure to toxic pollutants



NASA

Cyclone Aila, which struck Bangladesh in 2009, at peak intensity before landfall.

Table 3. Key Studies Examining the Impact of Floods on Health in Bangladesh			
Authors, year, reference	**Year of flood**	**Design**	**Main results**
Fun et al. 1991[36]	Outbreak investigation	Data for patients seeking treatment for acute diarrhea, 1987–1989	Major peak for rotavirus recorded in September 1988 coincided with major flood. Occurrence of rotavirus diarrhea declined immediately after flood, but non-rotavirus diarrhea remained high.
Siddique 1991[37]	1988 flood	Flood-related deaths from hospital records; comparison of health center and district level records (n = 154)	Children younger than five years accounted for 38 percent of all deaths. Children five to nine years old accounted for 12 percent of deaths. Watery diarrhea was the most frequent cause of death among all ages (47 percent), except those older than 45 years. Respiratory disease accounted for 13 percent of deaths; acute respiratory tract infections (ARI) accounted for 7 percent. Accidents were 9.7 percent of deaths, among whom 5.8 percent died from drowning.
Choudhury et al. 1993[31]	1987 flood	Nutrition status measured pre and post flood; multivariate logistic regression analysis (n = 1197)	Post-flood the proportion of severely malnourished children was significantly higher; increase was greater among boys.
Durkin et al. 1993[38]	1988 flood	Cross-sectional study of children aged two to nine years (n = 162)	Postflood 16 children were reported to have "very aggressive behavior" (preflood = 0), representing a significant increase ($p < 0.0001$); 16 percent wet bed preflood; postflood, 40.4 percent wet bed ($p < 0.0001$).
Del Ninno 2001[32]	1998 flood	Data from three-round household surveys in 117 affected villages, 1998–1999 (n = 4433).	Higher rates of stunting and wasting among flood-exposed preschool children and higher rates of chronic energy deficiency among flood-exposed women. Children did not recover during survey period.
Kunii et al. 2002[39]	1998 flood	Nonrandomly selected individuals interviewed in two affected districts, two months after start of flood (n = 517).	98.3 percent developed health problems. Fever accounted for 42.8 percent health problems among 3109 family members; diarrhea 26.6 percent; respiratory problems 13.9 percent.
Schwartz et al. 2006[40]	1988, 1998, 2004 floods	Demographic, microbiologic and clinical data from patients in a diarrhea hospital	Cholera was the predominant cause of flood-associated diarrheal epidemics; rotavirus was the second most frequent pathogen; individuals with diseases during floods were older, more severely dehydrated, of lower socioeconomic status; more patients per day presented with Escherichia coli, Shigella, and Salmonella species–associated diarrhea

can also be a concern.[29] Other common health problems include respiratory illnesses, fungal infection of the lower part of the legs, and contact dermatitis.[30] A number of studies have analyzed the impacts of floods on health, particularly on nutrition and infectious and vector-borne diseases, as outlined in Table 3.[9,10,12,19,30-40] Among communicable diseases, cholera is found to be most common in the coastal areas of Bangladesh. Vibrio cholerae, the bacterium causing cholera, can survive longer in saline waters, making Bangladesh's coastal belt an ideal breeding ground.[41]

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A worker in Bangladesh harvesting rice.

Cox's bazaar, Bangladesh.

Shanty town near the docks, Dhaka, Bangladesh.

The 1998 floods, deemed the worst flood of the century, which inundated more than two-thirds of the country, caused 2.04 million metric tons of rice crop losses (equal to 10 percent of target production in 1998/1999) and caused diverse health effects.[32] In addition to outbreaks of infectious diseases, nutritional deficiencies were also observed among the population, which appeared to affect women and children especially acutely. This has considerable public health implications, as there are already 9.5 million children in Bangladesh suffering from stunting.[42] A survey found that the nutritional status of flood-exposed women and children severely deteriorated further from the baseline rates of malnutrition of 90 percent and 53 percent in children and women, respectively.[30] Women belonging to households affected by floods were more likely to suffer from chronic energy deficiency than those not affected; the burden was twice as high in rural mothers compared to their urban counterparts.[33] Children were observed to have protein-energy and micronutrient-related malnutrition in flood affected areas in Bangladesh.[34] "Vulnerability" to health conditions was higher among those with low socioeconomic status and poor hygiene and sanitation facilities.[43]

An area that is largely overlooked is the mental health and psychosocial aspects of floods. The interaction between physical and mental health is complex, and life stressors like natural disasters can increase susceptibility not only to physical but also to mental illnesses.[5] A survey carried out by Social Assistance and Rehabilitation for the Physically Vulnerable (SARPV-Bangladesh) in the coastal districts of Tangail and Jamalpur showed that in a disaster area, 66 percent of the total population was psychologically traumatized and required emergency services, and that women were more affected psychologically than men.[44] In a prospective cross-sectional survey conducted among 2- to 9-year-olds, children were reported to exhibit "very aggressive behavior" after floods, with a significant increase compared to the preflood situation.[38] Bed wetting in children increased from 16 percent before flood to 40 percent post flood ($p < 0.0001$).[38] A qualitative study that explored the experiences of female adolescents during the 1998 floods in Bangladesh found that a number of girls were vulnerable to sexual and mental harassment through exposure to unfamiliar environments of flood shelters and relief camps.[45] The girls' difficulty in trying to follow social norms had far-reaching implications on their health, identity, and family and community relations.[45] Other common postflood mental health effects include anxiety, depression, posttraumatic stress disorder, irritability, sleeplessness, and suicide.[5]

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These kids live in a shanty town in the suburbs of Dhaka, surronded by highly polluted water. Their families earn less than US$2 a day.

iStockPhoto/Michael Buckley

Fishing for shrimp with a net from a small boat in Bangladesh.

iStockPhoto/Zeynep Mufti

Fishing boats in Shibsha River, Bangladesh.

Despite the prospect that the frequency of floods will increase in the future, there has been little systematic research work on the associated health burden. The quality of the information is often suboptimal, with descriptive studies lacking a control group or with inappropriate population sampling. In particular, the causal attribution of the health events to floods is often uncertain (see later discussion).

Salinity Intrusion and Impact on Food Security

In Bangladesh, salinity has encroached more than 100 kilometers inland into domestic ponds, groundwater supplies, and large, cultivated lands through various estuaries and water inlets, which are interlinked with the major rivers.[13,46] This has resulted in adverse effects including decreased availability and productivity of agricultural land, increased food insecurity, and increased salinity in natural drinking-water sources, such as ponds and groundwater.[47]

Food production is particularly sensitive to climate change, because crop yields depend directly on climatic conditions and land suitability. Salinity in soil decreases agricultural production through lack of freshwater for irrigation and soil degradation in coastal Bangladesh. In Satkhira, a coastal district in the southwest affected by high soil and water salinity, there was already a 69 percent reduction in rice production between 1985 and 2003.[48] The change was due to farmers switching to shrimp farming from rice farming due to loss in yield.[48] Other food plant yields like pulses, oil seeds, and vegetables are likely to be affected as well, due to gradual increase in salinity. Estimates indicate that Bangladesh has about 2.8 million hectares of land affected by salinity, which comprises about one-fifth of the total area of the country.[49]

In eastern Bangladesh, 14,000 and 252,000 tons of grain production is predicted to be lost to sea-level rises calculated for 2030 and 2075, respectively (current agricultural production for the country is 30 million tons).[12] The per-capita food grain productivity is predicted to reduce from 574 grams per person per day to 375 grams per person per day and 385 grams per person per day in the years 2050 and 2080, respectively, under a low emission scenario (B1).[7] For the same years, under the high emission scenario (A2), production is likely to reduce to 265 grams per person per day and 207 grams per person per day in the years 2050 and 2080, respectively.[7]

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Rice seedlings ready for planting in Bangladesh.

According to the National Water Management Plan (NWMP), the minimum rice food requirement in Bangladesh is 500 grams per person per day.[7] One study analyzed the production of two main food grains, Aman and Boro rice, to determine "food security" in the future, using geographic information system (GIS) techniques.[7] The estimates of the cereal production were based on flood depth and salinity concentration during monsoon. Different salinity ranges and flood depths were used to define the yield reduction factors (the factor by which yield is reduced). Results indicated that rice production will reduce from 8.1 million tons production in 2005 (base year) to 7.6 million tons in 2050 (sea-level rise of 27 centimeters) and 7.3 million tons in 2080 (sea-level rise of 62 centimeters), as a consequence of salinity alone.[7]

Water Salinity and Access to Safe Drinking Water

Salinity in surface water and groundwater is determined by several factors, including river flow, tides, precipitation, estuarine circulation, and poor management of water and land.[50,51] The rapid increase in shrimp farming in the last 10 years in the coastal region has sped up the rate of increase in soil and water salinity and also has had other significant impacts on the environment, food production, development and social cohesion.[48,52] Sea-level rise and future climate change will generally lead to higher contamination of both groundwater and surface supplies with salinity, adding a new environmental threat to the quality and quantity of freshwater access to a large proportion of the population.[47] This will especially impose hardship on women and children, who are responsible for collecting drinking water for their families. In Bangladesh currently 20 million people living along the coast are affected by varying degrees of salinity in drinking water obtained from various natural sources.[6]

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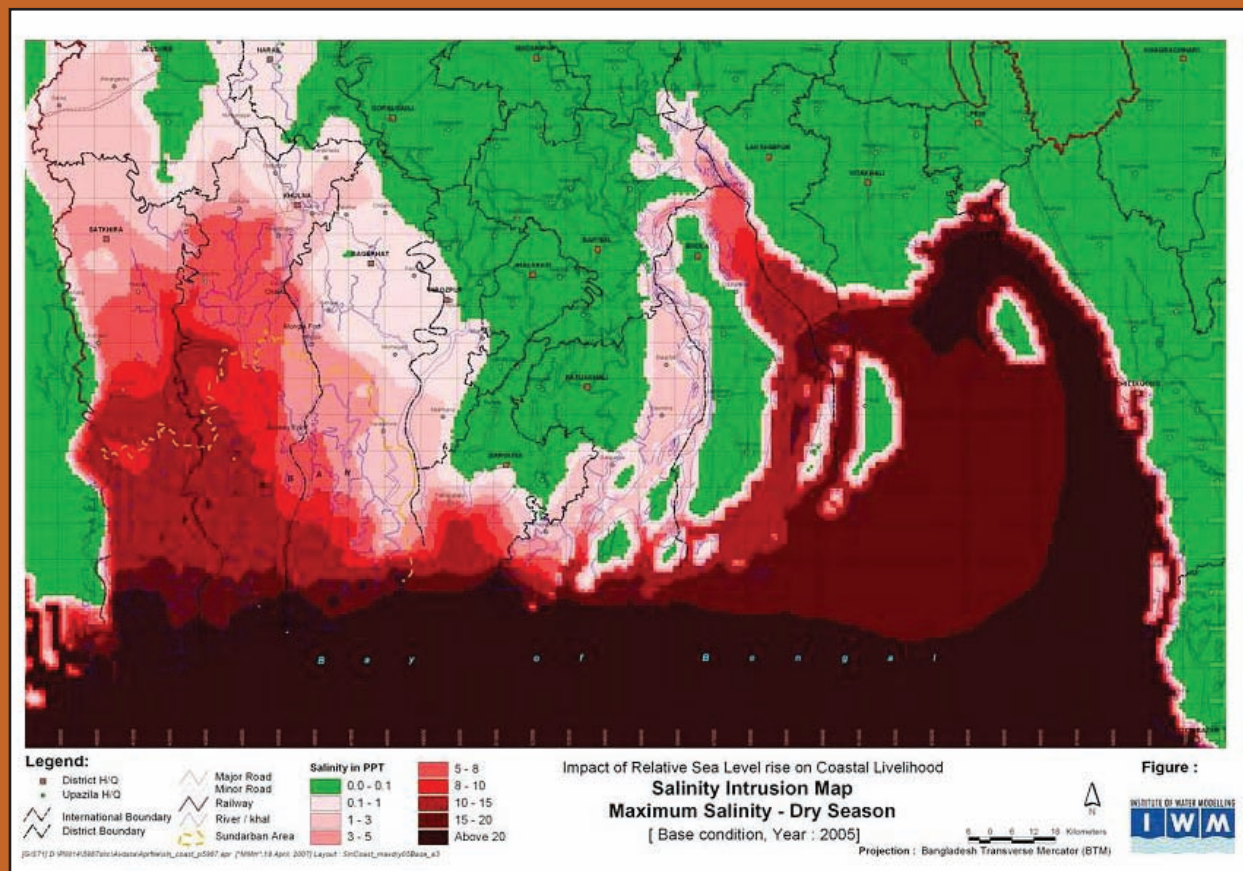
Residents of Dhaka, Bangladesh, pull clients in rickshaws.

Figure 1: Saltwater intrusion map of coastal Bangladesh.[7]



Institute of Water Modelling and Center for Environmental & Geographic Information Services, Bangladesh

In some coastal villages in the southwest region of Bangladesh, surface-water salinity is alarmingly as high as 15 parts per thousand, which is well above the Food and Agriculture Organization (FAO) allowable drinking water limit of <0.5 parts per thousand (see Figure 1).[7] The coastal population relies heavily on surface water (ponds and rivers) and groundwater (tube wells) for drinking. A baseline survey in three villages of Satkhira found that 61 percent of households used pond water for drinking and 81 percent used it for household purposes in the dry season.[52] There are concerns over the potential effects of salinity in drinking water and nutritional intake of the coastal populations affected, especially on maternal and child health.[6] To date, few surveys on the potential effects of water salinity have been conducted.

There are concerns over the potential effects of salinity in drinking water.

Salinity in groundwater was found to increase the burden of diarrheal diseases in coastal populations.[52-54] Among the population living in Satkhira, a range of health problems linked to increased exposure to salinity included increases in hypertension, premature delivery due to (pre)eclampsia, skin diseases, and acute respiratory infection.[52,55,56] Current epidemiological research has found that the diagnosis of hypertension and (pre)eclampsia in women undergoing antenatal checkups is significantly higher in coastal than in noncoastal regions.[57] A seasonal pattern to the incidence of hypertension in pregnancy was also observed, which coincides with the dry season when salinity in rivers and groundwater is higher.[57] Preliminary results of a research study being conducted in Dacope, Khulna, in Bangladesh show that pregnant women are consuming very high amounts of salt, as illustrated in their urinary sodium levels, and this consumption is known to adversely affect health.[58] Estimated salt intake of the population from drinking water is 5–16 grams per day during the dry season (depending on the water source), which could increase systolic blood pressure by approximately 9–18 mm Hg or 15–30 mm Hg, respectively, potentially leading to a large

proportion of the population becoming hypertensive.[58]

Salinity is estimated to intrude more inland during the dry season, as the freshwater flow from upstream is low.[51] This is partly due to the operation of the Farakka Barrage, which the Indian government uses to regulate flow on the Ganges during dry months.[51] Consequently, brackish water area is expected to increase. For a high emission scenario, a sea-level rise of 27 centimeters

If salinity intrusion in the coasts remains unchecked, a global crisis related to freshwater quality may be seen.

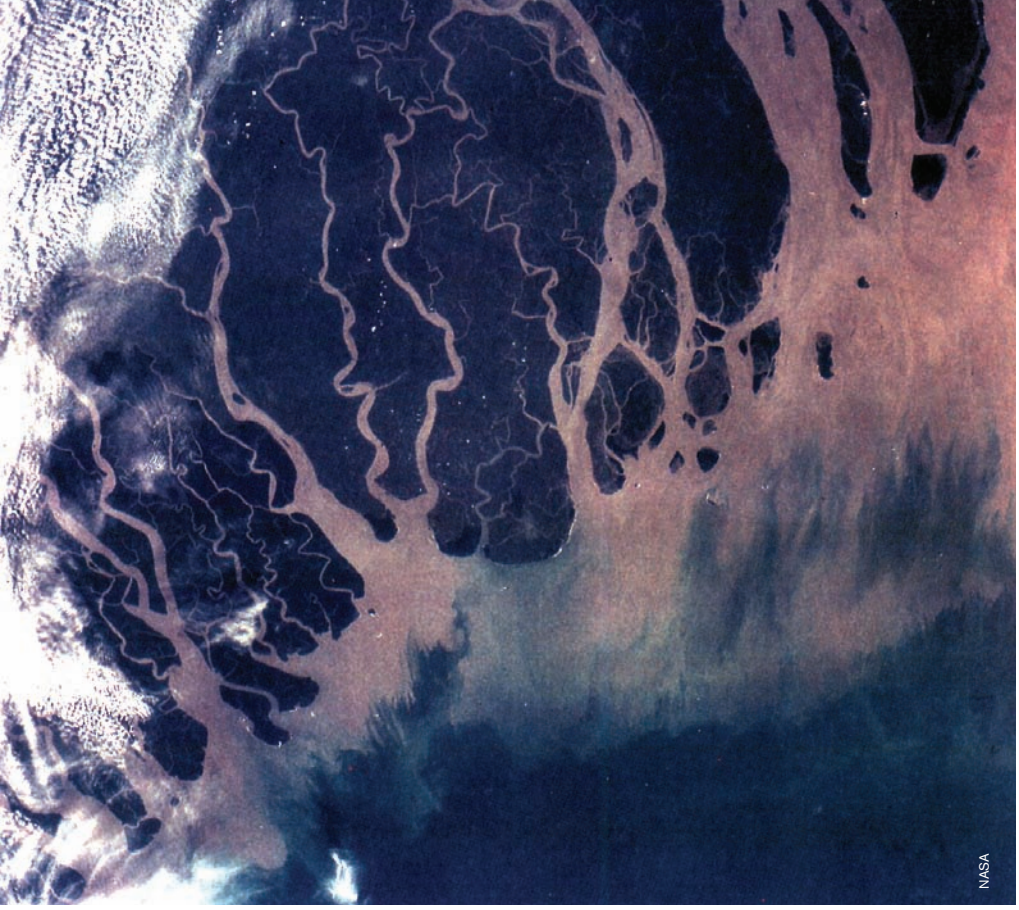
is predicted to cause 6 percent increase in brackish water area compared to base conditions in 2005,[6] whereas with a sea-level rise of 62 centimeters, it will increase to 9 percent. In 2005, about 6 million people were exposed to very high salinity (>5 parts per thousand), which is likely to increase to 13.6 million and 14.8 million in the years 2050 and 2080, respectively.[7] The problem of saline intrusion potentially affects all 11 Asian mega-deltas and other large deltas such as the Nile and Mississippi, and if salinity intrusion in the coasts remains unchecked, a global crisis related to freshwater quality and availability with clear human implications may be seen.

Implications for Future Research

Priorities for future research on climate change in low-income countries need to consider not only the short-term acute health effects, but also the impact on long-term chronic or "knock-on" effects, including nutritional and mental health. Epidemiological studies investigating climatic variation associated with diseases, combined with modeled scenarios, are crucial in influencing national and international health policies

Satellite image of Bangladesh in October 2001.

Boats are a major method of transportation in Bangladesh, a floodplain with more than 700 rivers.



As seen in this photograph, the tributaries and distributaries of the Ganges and Brahmaputra Rivers deposit huge amounts of silt and clay that create a shifting maze of waterways and islands in the Bay of Bengal.

and designing appropriate and sustainable adaptation measures.

To design effective epidemiological studies that investigate the health impacts of climate-related events, some methodological suggestions can be considered. If we examine the studies on the consequences of flooding in Table 3, there are several methodological problems that arise. First, control groups for comparison with populations affected by floods were usually lacking. However, identifying suitable comparison groups can be a major problem, because the unaffected populations may live at a long distance from the flood, thus making comparisons difficult or impossible due to confounding factors. Secondly, routine data are usually utilized, but measurement error is very often unknown. The use of objective measures of disease outcome with standardized criteria is infrequent. Also, there is often no follow-up of the situation after normalization in climate. Little is known about potential confounding factors, depending on the outcome that is investigated. The situation is likely to become more difficult if indirect effects of climate change, such as mental health, are tackled. It is possible that the most challenging goal will be the attribution to climate change of indirect problems that are endemic in low-income areas of the world. Certainly, linear causality patterns are unlikely.

One possibility is to set up large prospective studies like those already in place to investigate the effects of arsenic exposure. These studies need to be cheap and sustainable in the local communities, with the aim of monitoring the health consequences of impoverished nutrition and water availability. Such studies should find adequate comparison groups in areas less affected by climate change and address the issue of potential confounding. They also need to take into consideration the strong seasonal variability of climate and of most exposures, including food and water availability and exposure to infectious agents and pesticides. Finally, investigations should not be self-serving activities, but strictly linked to mitigation and adaptation strategies. To this end, the investigation of local vulnerabilities is essential, since the effect of climate change will certainly affect in different ways a diverse spectrum of society, as demonstrated by the striking observation that 1 percent of cyclones affect Bangladesh but 50 percent of cyclone-related deaths occur in this country.

Models of causality such as Bradford-Hill's that consider single risk factors are becoming less and less satisfactory. There might be some analogies between the development of systems biology in chronic diseases epidemiology and the investigation of climate change effects (at different levels of reality, from micro to macro). Three characteristics of systems biology have been suggested as central: (a) The experimental/observational data should reflect the processes of the intact system rather than that of an isolated component; (b) data interpretation is often conducted using methods inspired by other natural sciences (e.g., physics); and (c) an analysis of nontrivial competing explanations is conducted, and the structure of the model should reflect the underlying mechanisms in the biological system.[59] Similar postulates may apply to the newborn science of health effects of climate change, but this is still a vague analogy.

Adaptation Practices

Bangladesh has partly succeeded in implementing effective adaptation measures in the past few years. Coping strategies in response to climate change and sea-level rise have been developed by the World Bank (July 2001), CARE- Reducing Vulnerability to Climate Change (RVCC) (2002–2005), Organization for Economic Cooperation and Development (OECD 2003), and International Union for Conservation of Nature (IUCN: July 2004). The Ministry of Environment and Forests, Government of Bangladesh, prepared a National Adaptation Program of Action (NAPA) in 2005 to address immediate needs to deal with climate change and drafted the Bangladesh Climate Strategy and Action Plan in 2008. The main adaptation options outlined include: (1) strengthening early warning systems, (2) providing more safe facilities to the vulnerable population and livestock, (3) readjusting the embankment system in-

Table 4. Criteria for Selecting Priority Activities for Mitigation
Intervention-Type Measures
1. Promoting adaptation to coastal crop agriculture to combat increased salinity.
2. Adaptation to agriculture systems in areas prone to enhanced flash flooding in northeast and central regions.
3. Promoting adaptation to coastal fisheries through culture of salt-tolerant fish, especially in coastal areas of Bangladesh.
4. Adaptation to fisheries in areas prone to enhanced flooding in northeast and central regions through adaptive and diversified fish culture practices.
5. Construction of flood shelter, and information and assistance center to cope with enhanced recurrent floods in major floodplains.
6. Reduction of climate change hazards through coastal afforestation with community participation.
7. Providing drinking water to coastal communities to combat enhanced salinity due to sea-level rise.
8. Enhancing resilience of urban infrastructure and industries to impacts of climate change including floods and cyclone.
Facilitating-Type Measures
1. Capacity building for integrating climate change in planning, designing of infrastructure, conflict management, and land/water zoning for water management institutions.
2. Exploring options for insurance to cope with enhanced climatic disasters.
3. Mainstreaming adaptation to climate change into policies and programs in different sectors (focusing on disaster management, water, agriculture, health, and industry).
4. Inclusion of climate change issues in curriculum at secondary and tertiary educational institutions.
5. Climate change and adaptation information dissemination to vulnerable community for emergency preparedness measures and raising awareness on enhanced climatic disasters.
6. Promotion of research on drought-, flood-, and saline-tolerant varieties of crops to facilitate adaptation in the future.
7. Development of eco-specific adaptive knowledge (including indigenous knowledge) on adaptation to climate variability to enhance adaptive capacity for future climate change.
SOURCES: From NAPA Report, November 2005, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh.

cluding embankment height and drainage openings, and (4) coastal forestation as a green belt to reduce risk from sea-level rise and cyclone surge (see Table 4).

The government policies need to focus on strengthening rural health systems to improve access to care for the poor. A feasible and timely strategy is needed to manage the health effects from climate variability and environmental degradation. One possibility is to investigate area or district-based health risks, and identify the most vulnerable regions that are naturally prone to climate change and sea-level rise. In Bangladesh, women are responsible for managing household resources and should be fully integrated into climate change mitigation and adaptation strategies at all levels.[60] Finally, the adaptation options that are already in place and those that are planned by NAPA must ensure sustainability. The challenges now are to achieve the proposed targets with the help of nongovernment organizations, which play a key role in the development process in Bangladesh, and also to integrate climate change adaptation into mainstream development. To help achieve these goals, there needs to be a much greater global effort to improve the institutional and skilled capacity, policy analysis, and technology transfer in developing countries.

Conclusions

Climate change is now acknowledged as a reality, but its impacts will be felt with considerable inequity in

different parts of the world. In spite of the increasing data availability on the meteorological and physical aspects of climate change, very little is known on its current and potential health impacts, especially in developing countries.

The evidence of current and future health effects related to sea-level rise in Bangladesh is still relatively scanty and of variable quality. However, we have adequate information to believe that the coastal communities, as much as two-thirds of Bangladesh total population, are likely to be adversely affected by climate change in the near future, including short–term physical trauma as well as long-term consequences of physical and mental health problems and threats to food- and water-security. Unfortunately, the vulnerabilities of Bangladesh are not intrinsically unique, many cities and settlements along the 11 mega-deltas in Asia are potentially susceptible in a region that comprises overwhelmingly of low-to-mid-income countries whose populations make up a large proportion of the global total.

Urgent actions are needed to develop evidence-based adaptation and harm-reduction strategies that are cost-effective. Here the sharing of first-hand experiences from countries such as Bangladesh will be invaluable, while participation of the international health community could be a real benefit in engaging governing bodies, facilitating information exchange and fostering partnerships. At the same time, conducting appropriate, empirical longitudinal epidemiological studies are crucial in order to quantitatively assess the early impact of climate change on health and identify sub-populations who are disproportionally susceptible to such effects.

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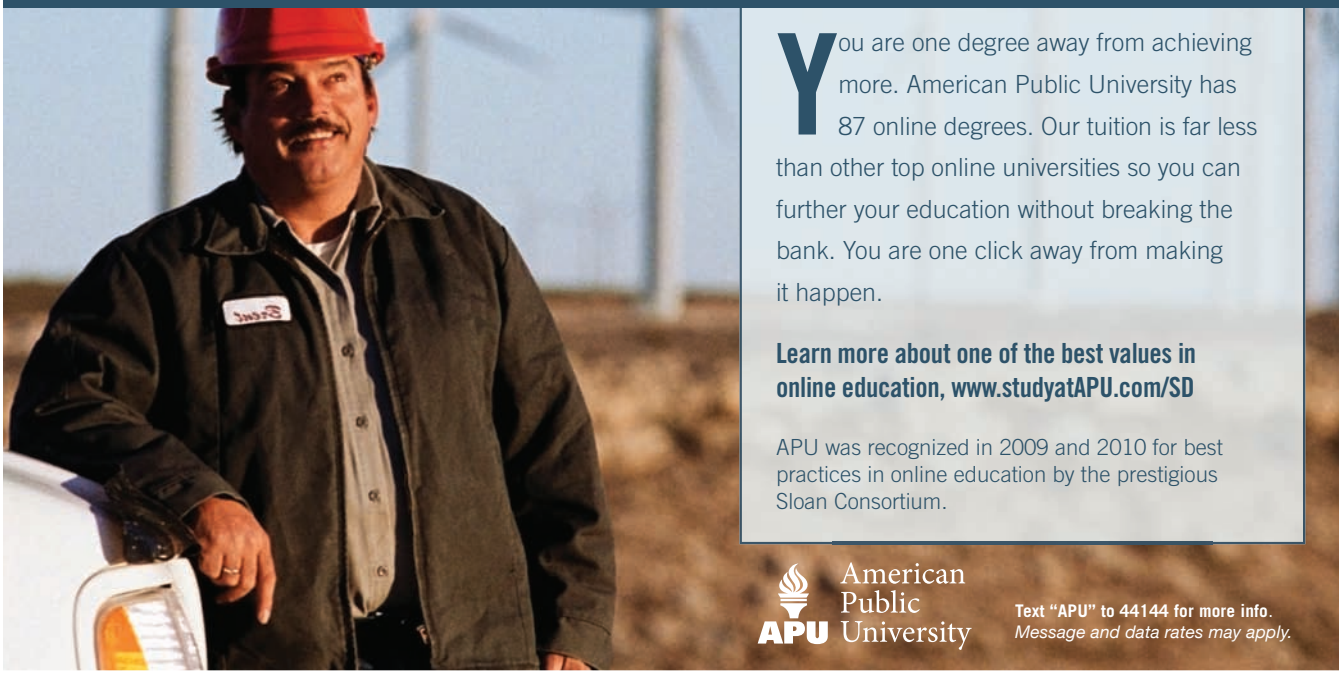

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