by Prinya Nutalaya

Flooding and land subsidence in Asia

Flooding and land subsidence are problems that have existed in Asia for a long time and will become worse as the population grows. Many inhabitants live on the flood plains of major rivers and in urban areas located on river deltas or coastal zones, all of which are subject to flooding during hurricanes, cyclones or typhoons, and monsoon rains. In addition, as urban areas grow larger, the need for ground water will increase while recharge areas will decrease in size. Land subsidence caused by excessive ground-water withdrawal has been recorded in many Asian cities already and will continue unless remedial actions are taken. Flooding of these subsiding areas in coastal regions is one of the major problems in Asia today.

After examining flooding in Bangladesh and Thailand, the author considers ways to limit flooding by using engineering methods and the possible results of these methods. He also reviews the responses of the people and government agencies to flood disasters.

As a result of land subsidence in Japan and several Asian cities, the author looks at possible ways to control this problem. He concludes that controlled pumping of ground water combined with artificial recharge of the aquifers will avoid not only land subsidence and related problems, but together will provide good management of ground-water resources for long-term use. (Ed.)

Introduction

More than 60 percent of the world's population lives in Asia. Of that, about 66 percent depends on agriculture and lives on the flood plains of major rivers such as the Indus, the Ganges and Brahmaputra, the Huang Ho, the Yangtze, the Mekong, and the Salween. Others cluster in densely populated urban areas such as Guangzhou, Osaka, Shanghai, Tokyo, Jakarta, Dhaka, Karachi, Calcutta, Bangkok, and Manila, which are located on river deltas or coastal zones. Presently, 90 percent of the world's population growth occurs in the developing countries, and pressure on land and water supplies, already intense, will mount even higher. The flood plains and coastal zones are subject to flooding during hurricanes, cyclones or typhoons, and monsoon rains; floods will continue to create hazardous situations,

and with increasing population, loss of life and property and damage to the human-engineered environment will escalate.

A compilation of the typhoon tracks across the Philippines from 1955 to 1985 (fig. 1) impressively illustrates how vulnerable that country is to typhoon and flooding damage. The 2,000-year historical record in the People's Republic of China (PRC) shows that almost 1,600 flood episodes have inundated as much as 200,000 km² of the Huang Ho River flood plain. Damage was caused by both water and massive sedimentation (Gong and Wu, 1987). As many as 6 million lives are estimated to have been claimed by this river within the last 100 years. Most of Bangladesh is located within the flood plains of three great rivers (the Ganges, the Brahmaputra, and the Meghna). The country is highly vulnerable to regular and often

Figure 1.—Tracks of typhoons crossing the Philippines from 1955 to 1985 (taken from Punungbayan, 1986).

devastating flooding and riverbank erosion in the flood plain areas, as well as to cyclone and storm surges in coastal areas. The Bangladesh typhoon of 1970 claimed between 300,000 and 500,000 lives (Frank and Husain, 1971). More recently, the severe flood of September 1988 took an even higher toll of lives, inundated more than two-thirds of the land area, and affected nearly one-half of the 110 million population, millions of whom were driven from their homes. Houses, schools, roads, railways, and communication systems were damaged or destroyed; livestock, standing crops, and raw materials were lost (UNDP, 1989).

The expansion of urban areas in Asia to cope with the population growth together with the migration of the population into cities have increased the demand for ground water while decreasing the recharge areas. Widespread land subsidence caused by excessive ground-water withdrawal has been reported in many cities in Asia including Tokyo, Osaka, Niigata, Saga, Nagoya, and Saitama in Japan; Shanghai, Tianjin, Ningbo, and Changzhou in PRC; Manila in the Philippines; Jakarta and Surabaya in Indonesia; and Bangkok, Samut Prakan, Samut Sakhon, Nonthaburi, and Pathum Thani in Thailand. Each subsidence covers a large areal extent, and the rate of subsidence is alarmingly fast. Flooding of these populated and industrialized subsiding areas in coastal regions is one of the major problems facing Asia today.

Whereas the coming decade will be the International Decade for Natural Disaster Reduction, as approved by the General Assembly of the United Nations in December 1987, and because the developing countries in Asia are most affected by and vulnerable to natural disasters, we must concentrate not only on disaster relief but on disaster prevention, protection, and preparedness as well. This paper draws attention to some of the problems related to flooding and land subsidence in Asia and to some possible remedial measures.

Flooding in Asia

Bangladesh

The total area of Bangladesh is approximately 144,020 km², one-half the size of Italy or about the size of Illinois in the United States. The country is located on the deltas of three large rivers: the Ganges, the Brahmaputra, and the Meghna. The population is about 110 million and will rise to 165 million by the year 2005. If all the world's population were crammed into the continental United States, the population density would still be less than that of Bangladesh, where there are 11.5 persons per hectare (ha). It is also one of the poorest countries in the world, as it has an annual per capita income of only about US\$120. Because some 80 percent of the population either is wholly dependent upon the rural economy or is living simply a landless day laborers, and because the population growth rates add between 2.5 and 3 percent annually to the rural population, Bangladesh has long since run out of sufficient land resources to support its rural masses adequately. Flooding and riverbank erosion are principal contributors to landlessness and poverty. Survey data show that a citizen of Bangladesh will be subject to river erosion and displacement on an average of more than six times in a lifetime (Amin, 1987).

Floods in Bangladesh normally are associated with the yearly monsoon rains that pour into the entire Ganges-Brahmaputra-Meghna basin (fig. 2) between June and October. Although the entire land area of Bangladesh is only 144,020 km², the combined drainage basin of the three rivers is nearly 16 million km². Each year, the normal floods inundate some 2.6 million ha of land surface. During more severe floods, the extent of flooding may reach 8 million ha. Devastating floods occurred in 1954, 1955 (fig. 3), 1956, 1962,

1964, 1968, 1970, 1971, 1974 (fig. 4), 1978, 1984, 1987, and 1988 (fig. 5), each of which engulfed areas ranging from 3.5 to more than 8 million ha (fig. 6). Floods may inundate the land to depths ranging from 30 cm to 25 m. Devastating cyclonic tidal bores or storm surges also may submerge approximately 18,000 km² of the coastal area of Bangladesh (figs. 6 and 7).

Floods and riverbank erosion cause many problems, including those related to the September 1988 Bangladesh flood that were mentioned at the beginning of this paper. In addition, merchants lose their shops and goods. When everything is submerged, day laborers, who depend solely on paying jobs each day for survival, are unable to find work in the fields, in rural construction activities of various kinds, or within households. Many people are forced to flee their homes and take shelter on high ground where they must depend on charity. Floods are invariably followed by cholera, diarrhea, dysentery, and other infectious diseases. When floods persist, marginal land holders often are forced to sell the small plots of land on which they cultivate rice, wheat, and other crops in order to survive, and this accentuates the process of landlessness in the country. Riverbank erosion also has devastating effects as approximately 1 million people are dislocated each year in Bangladesh, which adds to the 50 percent of the rural population that is already landless. Riverbank erosion reduces land area and capital to such an extent that many people find themselves homeless and starving. Endless harsh struggles occur over each new spit of land as it surfaces above the receding brown waters of the Brahmaputra River (New York Times, 1987).

Flood damage reduction

The causes of floods in Bangladesh have been investigated by many researchers. Monsoon rains and high river flows across the country's boundaries are the dominant causes, but other factors such as flat and low-lying topography, tidal variations, locally rising sea level, bank erosion, siltation, earthquakes, storm surges, and manmade structures also contribute to the inundation.

Floods will continue in the future as they have occurred in the past; therefore, the dilemmas of the continuing threat to human life, the mounting flood damage, and the ever-increasing costs for flood-control structures result from the population growth and the increasing demand on land for settlement and food production. By-and-large, Bangladeshis have been living with floods since time immemorial, the people have adapted their way of life to flooding hazards, and in so doing, they have developed a remarkable degree of resilience. Immediately after the 1988 floods, the government of Bangladesh launched an appeal to the international community for assistance. The search for a lasting solution has been painfully difficult and, as well, has been studded with political issues. To date, too many flood-control programs have been of the desperate mend-and-patch variety without regard to an overall plan, and they are only washed away with the next flood. Most of the proposed plans for flood control have involved engineering measures—dams and reservoirs, levees and floodwalls, channel improvements and floodway bypasses, and channel diversions—all of which appeal to many politicians and bureaucrats. Much has been written about the cost effectiveness and the limits inherent in the many embankment projects, especially on the Brahmaputra (Rasid and Paul, 1987). Although most local inhabitants would agree with the necessity and value of engineering solutions to the flooding problems, it is nevertheless questionable whether these solutions are capable of offering the level of protection needed. At best, the heavy investment in engineering works would only partly reduce losses. Moreover, the flood protection work still has a long way to go before all flood-prone areas would be protected. The United Nations Development Programme (UNDP) put forth its report on the Bangladesh Flood Policy Study in

Figure 2.—The size of the catchment basins of the Ganges, Brahmaputra, and Meghna compared to the size of Bangladesh (taken from UNDP, 1989).

May 1989. Provisional estimates indicate that the proposed flood-protection plan, having separate financial requirements for agriculture, will cost approximately US\$3.5–4 billion and will take more than 30 years to complete.

The storage characteristics of a basin relate to slope, soil type, vegetation, topography, channel shape and resistance, land use, and manmade structures. Floods are natural phenomena; the extent and effects of man's acts to control them are questionable. India's construction of thousands of kilometers of embankments along the Ganges and its tributaries has reduced the original flood plains, and the rejected water adds to the flooding in Bangladesh. The flood peak of the Ganges at Hardinge Bridge Station in Bangladesh has increased since India constructed Farakka Barrage on the Ganges only 18 km from the Bangladesh border (Hossain and others, 1987).

Almost 2.4 billion tons of silt are carried each year by the Ganges and Brahmaputra river systems to the Bay of Bengal, in addition to the significant amounts also deposited in the land depressions within Bangladesh. Each year, the level of land in the estuary areas goes down by about 2.5 cm as a result of soil compaction. Silt deposition on this land helps keep its level high enough to prevent encroachment of the sea and results in the formation of new land. One former minister proposed building 12 large dams, most of them in Nepal, to hold back the monsoon waters as a flood-control measure (Singh, 1989). Such dams would reduce the sediment load of the

river. The loss of this sediment supply would decrease the amount of both land formation and depression filling and might trigger coastal erosion and destruction of the deltas.

Studies of the dikes constructed along the Huang Ho River, PRC, indicate that the dikes have caused aggradation in the channel, that the river bed of the lower Huang Ho has risen about 3–5 m above the original flood plain, and that the river has become "suspended" (Gong and Wu, 1987) (fig. 8). As a parallel, we can anticipate easily what would happen to the Ganges and Brahmaputra channels if the embankment schemes were fully implemented!

Nature, to be commanded, must be obeyed

Nearly one-tenth of the land area of Bangladesh is made up of shallow depressions and abandoned river channels. During monsoon season, these areas are covered by water, and during dry months, they either dry up or remain under shallow water. Increased population encroaches upon these depressions and river beds because these areas offer refuge to the homeless. The people inhabiting these areas have adapted their living and farming habits to the seasonal change in their environment (Hossain and others, 1987). The types of adjustment by the indigenous population to cope with the flood and river-bank erosion hazards are enumerated below, as reported by Haque (1987).

Figure 3.—Flood-affected area in Bangladesh during 1955 (modified from Hossain and others, 1987).

- Use of corrugated iron sheets, wood, bamboo, and thatch as housing materials to provide easy and rapid means for salvaging housing structures and to keep their resale value; incidental and purposeful adjustment.
- Use of country boats (dingies), bullock carts, and bicycles as transportation to provide ways of moving about during abnormal flood and rapid river encroachment; incidental adjustment.
- Planting of different crops in different zones of the flood plain to use crop varieties that are best suited to particular soil characteristics; incidental adjustment.
- Maintenance of close associations among community members to mobilize necessary manpower and assistance in emergency situations; incidental and purposeful adjustment.
- Investing in livestock and other moveable assets to provide easy means for transferring or selling assets in emergency situations; incidental and purposeful adjustment.
- Building bamboo fences on the waterfront to protect land and houses from physical impact of erosion; purposeful adjustment.
- Placing brick-filled bamboo crates on the waterfront to protect land from subaqueous erosion; purposeful adjustment.
- Building earth embankments to protect settlements from river encroachment; purposeful adjustment.

Figure 4.—Flood-affected area in Bangladesh during 1974 (modified from Hossain and others, 1987).

The Bangladeshis are probably more resourceful and more resilient than any other people in coping with floods. Nonetheless, the impact of recurrent floods on this small, densely populated nation, and particularly on its economy, becomes more serious with each successive event. The question to be resolved is: what degree of protection is practicable, affordable, and justifiable in terms of structural and nonstructural measures? The UNDP (1989) has provided the guiding principles for flood-protection strategy, including:

- (1) Phased implementation of a comprehensive flood plan aimed at protection of urban, rural, commercial, industrial, and public utility centers and protection of communication networks; controlled flooding, wherever possible and appropriate, to meet the needs of agriculture, fisheries, navigation, urban flushing, soil productivity, and recharging of the surface-water and (or) ground-water resource with minimum effect on the environment.
- (2) Effective land and water management of protected and unprotected areas, involving compartmentalization, drainage irrigation, drainage decongestion, land use, cropping patterns, environment, ecology, erosion and (or) sedimentation control, and the like.

Figure 5.—Flood-affected area in Bangladesh during 1988 (modified from Hart, 1989).

Figure 6.—Sources of flooding in Bangladesh (modified from Hossain and others, 1987).

(3) Strengthening and equipping the disaster management organization, including building infrastructures for quick and effective communication and transmission during disasters.

(4) Improvement of the flood forecasting system, establishment of a reliable and comprehensive flood warning system that has adequate lead times, and at the same time, development of techniques for dissemination of information.

(5) Safe conveyance of the large water flow across country boundaries to the Bay of Bengal by channeling the water through the major rivers with the help of embankments on both sides.

(6) Effective river-training structures for the protection of embankments, infrastructures, and population centers, linked wherever possible with the reclamation of land in the active river flood plain.

(7) Reduction of the distribution of load on the main rivers through diversion of flows into major distributaries or interception of local runoff and (or) local rivers by channeling through major tributaries or special diversions.

(8) Improvement of the conveyance capacity of the river networks to ensure efficient drainage through appropriate channel improvements and ancillary structures to provide regulation and conservation.

(9) Development of flood-plain zoning as a flexible instrument to accommodate necessary engineering measures and to allocate space for habitation patterns, economic activities, and environmental assets.

(10) Coordinated planning and construction of all rural roads and highway and railway embankments with provision for unimpeded drainage.

(11) Encouraging as much popular participation as possible in the planning, implementation, operation, and maintenance of flood protection infrastructures and facilities by those who would benefit directly.

Thailand

From November 18 to 23, 1988, more than 1,000 mm of rain fell over a wide area of southern Thailand. Large-scale flooding occurred in 14 provinces, 373 people were killed, over 1.35 million people were affected, and more than 55,800 houses were destroyed. Approximately 363,350 ha of cultivable land, 5,655 km of roads, 1,545 bridges, 1,846 schools, 940 temples and mosques, and 365 public buildings were damaged. The rain also triggered hundreds of land-

slides and debris flows along steep slopes and narrow ravines. The extensive flooding, landslides, and debris flows resulted because of the following conditions. The heavy rainfall had saturated the ground, steep mountainous slopes were composed of thick residual soils and saprolites derived from granite and granite gneiss, deforestation had reduced water infiltration and retention capacity, and man-made structures such as bridges, roads, railways, and irrigation canals obstructed the flow of flood waters.

Extensive debris flows consisting of water, mud, sand, pebbles, cobbles, boulders, uprooted trees and bushes, and pre-cut logs (some of them illegally cut) caused damage to rivers, villages, agricultural land, and infrastructures (fig. 9). The losses to the flash floods of November 1988 were due mainly to debris flows that washed away numerous houses (fig. 10) and covered the flood plains with a thick layer of sand and boulders (fig. 11), over which forest debris was deposited (fig. 12).

Flood relief and rehabilitation

In most developing countries, natural disasters are considered to be isolated events that have to be dealt with on a case-by-case basis.

Figure 7.—Storm-surge data of the November 12, 1970, cyclone in Bangladesh (modified from Frank and Husain, 1971).

The flood of November 1988 in southern Thailand is a typical example. Because of communication problems, it took at least three days for the people in Bangkok and in most government agencies to realize the extent of the flood disaster. Consequently, the response was slow, and emergency aid arrived in the affected areas rather late. Food and equipment were distributed in late November and thereafter to those who needed it. These things are still being given to villagers today, despite the fact that practically all of the distributed items are readily available in local markets.

Substantial amounts of money have been raised by private groups, and the government has earmarked US\$120 million for the rehabilitation and development of the provinces devastated by the flash floods. However, bureaucracy has hindered the distribution of these funds. Progress is particularly slow in the areas where buildings were damaged and (or) submerged in debris.

For the people who have lost their homes, a limited number of emergency shelters have been provided. Tents were donated by the United States, and single unit houses, which can be mounted on wheels for road transport, were made locally. In addition, temporary houses were constructed from corrugated steel sheets. In most cases, however, inhabitants tried to construct new houses and shelters by using the construction materials salvaged from damaged buildings and from the trees brought down during the floods. For the reconstruction of the devastated villages, the government is looking for safer land in the vicinity. However, finding such land is not always possible; therefore, plans are to relocate villages to other provinces.

Figure 8.—Flooded area of the lower Huang Ho River, "a suspended river," in PRC (modified from Gong and Wu, 1987).

Figure 9.—Debris flow wiped out a small settlement in this valley in southern Thailand, November 1988.

Figure 10.—Houses damaged by debris flow resulting from heavy rainfall of November 1988 in southern Thailand.

Figure 11.—Mud flood covered what used to be a village in southern Thailand, November 1988.

Figure 12.—Forest debris deposited by flood waters of November 1988 in southern Thailand.

Many government agencies and most ministries have been involved in one way or another in flood relief work or flood management. Because of the lack of disaster experience in Thailand and the lack of disaster preparedness, coordination of the relief and rehabilitation work of the numerous government agencies has required a major effort. One environmental research and rehabilitation project received a sizable sum of US\$8 million from the government. From those funds, only US\$3,200 were allocated to geological and hydrological mapping. Even though conferences were held to discuss and analyze aspects of the floods, flood protection, and relief management, apparently geologists and hydrologists involved in the project did not make a good impression on the project planners and the government as to their vital roles in environmental management.

Land subsidence in Asia

Overexploitation of ground-water resources and the consequent piezometric level decline have caused land subsidence in many cities in Asia. As the population grows rapidly and urbanization increases, land subsidence in urban areas will become a major problem. Estuarine cities such as Bangkok, Tokyo, Shanghai, Manila, and Jakarta have sunk below mean sea level, and some of their most valuable land needs to be protected by using dikes and seawalls. The alternative is to bring extra water to the city and use some of it to replenish aquifers in order to stop the subsidence.

Country and city examples

Japan started drilling deep wells during the decade following 1910. By the 1920s, land subsidence was observed in several cities including Aomori, Saitama, Saga, Nobi, Niigata, Tokyo, Osaka, and Nagoya. In 1939 Wadashi and Hirono (Ueshita and Daito, 1984) pointed out that land subsidence was caused by excessive withdrawal of ground water. In the Nobi plain, nearly 200 km² of the land area has subsided below mean sea level (fig. 13). The total subsidence was about 237 cm during the period from 1938 to 1975. People suffered from frequent floodings, the worst of which resulted when typhoon Isewan hit the area in 1959; 5,122 people lost their lives, 15,384 were injured, 127,625 homes were destroyed, and 3,846 homes were washed away. After the typhoon, an area of 186 km² was submerged for a long time. The control of ground-water pumping was enforced in 1956 for industrial consumption and in 1962 for household use. The land subsidence in Japan was halted finally around the middle 1970s. However, by that time, more than 40 areas

were known to be subsiding in Japan (fig. 14), and Tokyo had subsided more than 4 m (fig. 15). In fact, the altitude of the downtown area of Tokyo is reported to be below mean sea level (Ueshita and Daito, 1984). Japan's land subsidence and its corrective measures have been closely monitored annually since 1974.

In Shanghai, the first evidence of land subsidence was observed in 1921. By 1965 the land had subsided 2.63 m. Extensive and frequent floods on the Huangpu River became major hazards that threatened safety and caused damage to properties (Liu and Sun, 1988). From 1957 to 1982 the Shanghai Municipality managed to bring land subsidence under control by using pumping-control and ground-water-recharge techniques (fig. 16).

Figure 13.—Areas below sea level in the Nobi plain, Japan (taken from Ueshita and Daito, 1984).

Figure 14.—Areas where land subsidence has occurred recently in Japan (taken from Ueshita and Daito, 1984).

Figure 15.—Typical data on subsidence in Japan (taken from Ueshita and Daito, 1984).

Figure 16.—Cumulative deformation measured at some benchmark marks in Shanghai, PRC (taken from Liu and Sun, 1988).

Land subsidence in Manila was reported first by Baura (1983). The total area of land subsidence was not known precisely, but it was thought to be quite extensive because the piezometric levels of some aquifers had dropped more than 100 m over a wide area of the Pasig River delta and in downtown Manila. The downtown area has been flooded frequently for several days and has been reported to be several centimeters below mean sea level (Baura, 1983).

Land subsidence in Jakarta was reported by Bandono (1983). Evidence of this included sinking of reference bench marks, decrease in gradient of the drainage system, damage to engineering structures, rupture of ground-water wells, and occasional flooding in the subsiding area. Substantial subsidence was observed at the Tamrin and Ancol areas of the city.

Figure 17.—Total land subsidence of Bangkok, Thailand, from 1933 to 1987 (taken from Nutalaya and others, 1989).

In Bangkok and cities in the adjoining provinces (Samut Prakan, Samut Sakhon, Nonthaburi, and Pathum Thani), land subsidence was investigated first in 1978. By that time, Bangkok already had sunk 86 cm; by 1987, the total subsidence had reached 160 cm (fig. 17). From 1978 to 1988, rapid exploitation of the ground water seriously aggravated the situation to the point that Samut Prakan, the city that is located on the north shore of the Gulf of Thailand, was flooded 22 days during one month. Bangkok itself was flooded continuously for 4 months in 1983. Since that time, flood-control measures have been partly implemented, but none has effectively halted the land subsidence. Today, the total subsiding area of Bangkok is approximately 4,000 km², and a large part of that is below mean sea level.

Possible remedial measures

In addition to flooding, which is probably the most serious consequence of land subsidence in low-lying urban areas, other effects of land subsidence are decline of piezometric pressure, saltwater intrusion into coastal aquifers, deterioration of ground-water quality, sinking of reference bench marks, damage to engineering structures due to settling at different rates, and loss of drainage gradient.

Theoretically, four possible ways to remedy land subsidence problems include filling the land, pumping control, artificial replenishment of ground water, and combinations of these three methods. Land reclamation alone is effective for a short period of time, but

the elevated ground will be lowered to the original level if ground-water pumping continues. In addition, this is the most expensive remedy. If future ground-water pumping is prohibited, the subsidence will stop within a few years. This is the most direct method of solving the problem but is not necessarily the most practical. In order to increase the amount of water in the aquifers and to restore the piezometric levels, clean water must be recharged to the aquifers. If the amount of water recharged is greater than the amount withdrawn, the subsidence will stop and the original piezometric levels will be reached eventually.

Many countries such as the UK, Japan, PRC, The Netherlands, FRG, and Israel solve land subsidence problems by combining pumping control with artificial recharge. Controlled pumping and simultaneous artificial recharge of the aquifers together will avoid land subsidence and piezometric level decline. In addition, they provide the way to manage properly the ground-water resources for long-term use.

The best long-term policy that will avoid land subsidence problems and will provide an excellent way of obtaining a good clean water supply is to treat the aquifer as both a reservoir and a distributing system. When the surface-water supply approaches exhaustion, the underground reservoir can be used to keep the city supplied; when surface water is in surplus, it can be injected into the aquifer as additional recharge. The principal advantages of underground storage are that water remains pure, does not evaporate, and does not require land area for storage, yet the reservoir also serves as the conveyance system. If the system is implemented fully, surplus flood waters in the wet years can be stored and used to balance out the dry years; the underground reservoirs can be drawn upon to the volume of recharge without inducing subsidence. Emergencies can be alleviated by drawing upon future storage capacity even though temporary subsidence may result.

The capacity of Asian urban water-distributing systems usually lags behind the city growth, partly because most developers who sink wells and pump water for their own consumption have always taken for granted the use of aquifers as an already existing water-distribution system. These consumers should be asked to pay the realistic price for the ground water, which would take into consideration the overall costs of the water-management system and facilities.

Along with the projected population growth, most estuarine urban centers in Asia will grow. Cities will continue to sink unless the necessary management of ground-water resources is instituted. The consumers must pay a realistic price for water. This price will be determined by the amount of both surface and subsurface water available; the amount of investment needed to treat, distribute, and recharge waters; the degree of land subsidence that can be tolerated; and the capacity of the storage reservoirs both on and under the ground surface. As the price of land skyrockets in the urban areas, and as pollution increases in the environment, the 21st century will be the century of underground reservoirs.

References

- Amin, A.T.M.N., 1987, Settlement strategy for riverbank erosion displaces in Bangladesh: A human resource development approach; International Symposium on the Impact of Riverbank Erosion, Flood Hazard and the Problem of Population Displacement, Dhaka, Bangladesh, 1988, Proceedings, p. A1-A62.
- Bando, 1983, Investigation of land subsidence due to groundwater pumping in Jakarta area, Indonesia; Bangkok, Asian Institute of Technology, Master's thesis, 80 p.
- Baura, C.A., 1983, A review on engineering geology of metro Manila; Bangkok, Asian Institute of Technology, Master's thesis, 82 p.
- Frank, N.L., and Husain, S.A., 1971, The deadliest tropical cyclone in history? Bulletin of the American Meteorological Society, v. 52, no. 6, p. 438-445.
- Gong, S.Y., and Wu, Z.Y., 1987, Flood hazards and its prevention on the lower reaches of the Yellow River: U.S.-Asia Conference on Engineering for Mitigating Natural Hazards Damage, Bangkok, 1987, Proceedings, p. B2-1-B2-15.
- Haque, C.E., 1987, Human responses to riverbank erosion hazard in Bangladesh: Some lessons from indigenous adjustment strategies; International Symposium on the Impact of Riverbank Erosion, Flood Hazard and the Problem of Population Displacement, Dhaka, Bangladesh, 1988, Proceedings, p. F1-F31.
- Hart, C., 1989, Bangladesh bounces back: World Development, v. 2, no. 3, p. 6-10.
- Hossain, M., Islam, A.T.M.A., and Saha, S.K., 1987, Floods in Bangladesh—Recurrent disasters and people's survival; Dhaka, Bangladesh, Universities Research Center, 104 p.
- Liu, T.Z., and Sun, S.S., 1988, Case study on the laws of land subsidence in Shanghai, in Atlas of urban geology in Asia and the Pacific; China, v. 3; Bangkok, UN/ESCAP, p. 3-11.
- New York Times, 1987, Life in Bangladesh delta: A race bred by disaster: 21 June 1987.
- Hossain, M., Yong, R.N., Chumnankit, T., and Buapeng, S., 1989, Land subsidence in Bangkok during 1978-1988: Workshop on Bangkok Land Subsidence—What's Next? Bangkok, 1989, Proceedings, p. 1-48.
- Punungbayan, R., 1986, Disaster preparedness systems for natural hazards in the Philippines: An assessment: Seminar-Workshop on Preparedness for Geologic Disaster in the Philippines, Quezon City, Philippines, 1986, Proceedings.
- Rasid, H., and Paul, B.K., 1987, Flood problems in Bangladesh: Is there an indigenous solution? Environmental Management, v. 11, no. 2, p. 155-173.
- Singh, M.M., 1989, Who flooded Bangladesh? The view from Nepal: World Development, v. 2, no. 3, p. 8-9.
- Ueshita, K., and Daito, K., 1984, Land subsidence in Japan and a case study on the Nobi Plain: International Symposium on Geotechnical Aspects of Mass and Material Transportation, Bangkok, 1984, Proceedings, p. 439-460.
- UNDP, 1989, Bangladesh flood policy study final report: Dhaka, Bangladesh, United Nations Development Programme, 133 p. □

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