

Morphology and Land-Use of the Coastal Zone of the North Jiangsu Plain Jiangsu Province, Eastern China

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ABSTRACT

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The North Jiangsu Plain is a vast flat coastal area in eastern China which formed over the last 5,000 to 6,000 years by reworking of sediments from the Yellow and Yangtze rivers along the coast of the Yellow Sea. The plain has sandy and rocky shores on the north, an eroding coastline along the old abandoned delta of the Yellow River in the centre, and vast tidal flats on the south. Salt is produced along the northern coasts. Aquaculture, primarily of shrimps and eels, is practised everywhere. A wheat- and fruit-based agriculture predominates in the drier north and a rice- and silk-based agriculture in the wetter south. The political and sociological goals are to increase the industrial output of this area. The main hindrance to this is energy supply and communications. Plans exist to enlarge one of the existing harbours in Lianyungang in the north, and built large offshore anchorages for oil tankers and coal cargo ships along tidal channels in the flatter central part of the coast.

ADDITIONAL INDEX WORDS: *Coastal plain, delta, coastal geomorphology, hazards.*

INTRODUCTION

The large North Jiangsu Plain is in Jiangsu Province in central-eastern China (Figure 1). It is bounded by the Shandong Peninsula in the north, by the Zhejiang Peninsula south of Shanghai, by large shallow freshwater lakes to the west (up to 4 metres deep and partly maintained and regulated by artificial dykes), and by the shallow waters of the Yellow Sea to the east.

The uniformly flat plain is crossed by small rivers and numerous man-made canals. Numerous southeast-northwest oriented canals redistribute water from the Yangtze River northward all the way to Lianyungang and beyond. Transverse canals, mostly built in the 1950s, carry water from the main canal outward across the plain. The northern plain is formed by sediments formerly carried by the old Yellow River into the Yellow Sea; the central and southern part primarily by sediments carried by the Yangtze River (ZHANG RENSHUN, 1984; SUK, 1989; XUE CHUNTING *et al.*, 1991). Of the 680 kilometres of coast along the Yellow Sea, ninety percent is very flat (0.15%, 0.19%), and has wide (up to 13 km) silty tidal flats. The remainder consists of an approximately 30 km long sandy coast in the northernmost reaches (Haizhou Bay), and about thirty kilometres of rocky coast just to the south, near the city of Lianyungang (Figure 1).

The Yellow Sea is rising at about 1-2 mm/yr, and has a broad shallow (10-30 m deep) shelf and a deeper (up to 80-90 m) N-S trending corridor in the central-east portion. The coast is affected by semidiurnal tides which vary greatly from

place to place, with tidal excursion of 3.10 m in Haizhou Bay to the north, less than 2 m at the head of the old Yellow River delta, and again up to 3 and 4 m just south of Wanggang, and reduced to 2 m along the north shore of the Yangtze River (VALENCIA, 1987). Anticlockwise geostrophic, tidal currents reach speed of 1.40 cm/sec along the coast (REN MEI'E and SHI, 1986; VALENCIA, 1987). The nearshore currents are locally modified, and in the Yangtze River delta area they reverse northward and northeastward during the winter (REN MEI'E, 1986). Strong (up to 2 m/sec) tidal currents develop in channels between bars and shoals offshore from Qianggang. Strong seasonal storms and occasional catastrophic typhoons, such as the No. 8114 typhoon of 1981 (REN MEI'E *et al.*, 1985a), generate large waves capable of reworking great quantities of sediment along the coast and inundating large parts of the coastal plain.

The climate changes from warm temperate in the north to subtropical on the south, roughly along the axis of the old Yellow River delta. In the north there is a drier (precipitation 850-1,000 mm/yr), warm temperate, semi-humid climate with larger evaporation (1,861 mm/yr), and in the south there is greater precipitation (1,000-1,080 mm/yr) and slightly lower evaporation (1,105 mm/yr) under subtropical humid climatic conditions (LU JUZHONG, 1990). Monsoons affect the coastal plain.

The Plain has large growth potential, at present only partially exploited due to inadequate energy supply and communications. Indeed, there are only two major harbours; an overcrowded one at Shanghai at the southern end, and a developing one at Lianyungang at the northern end. In between

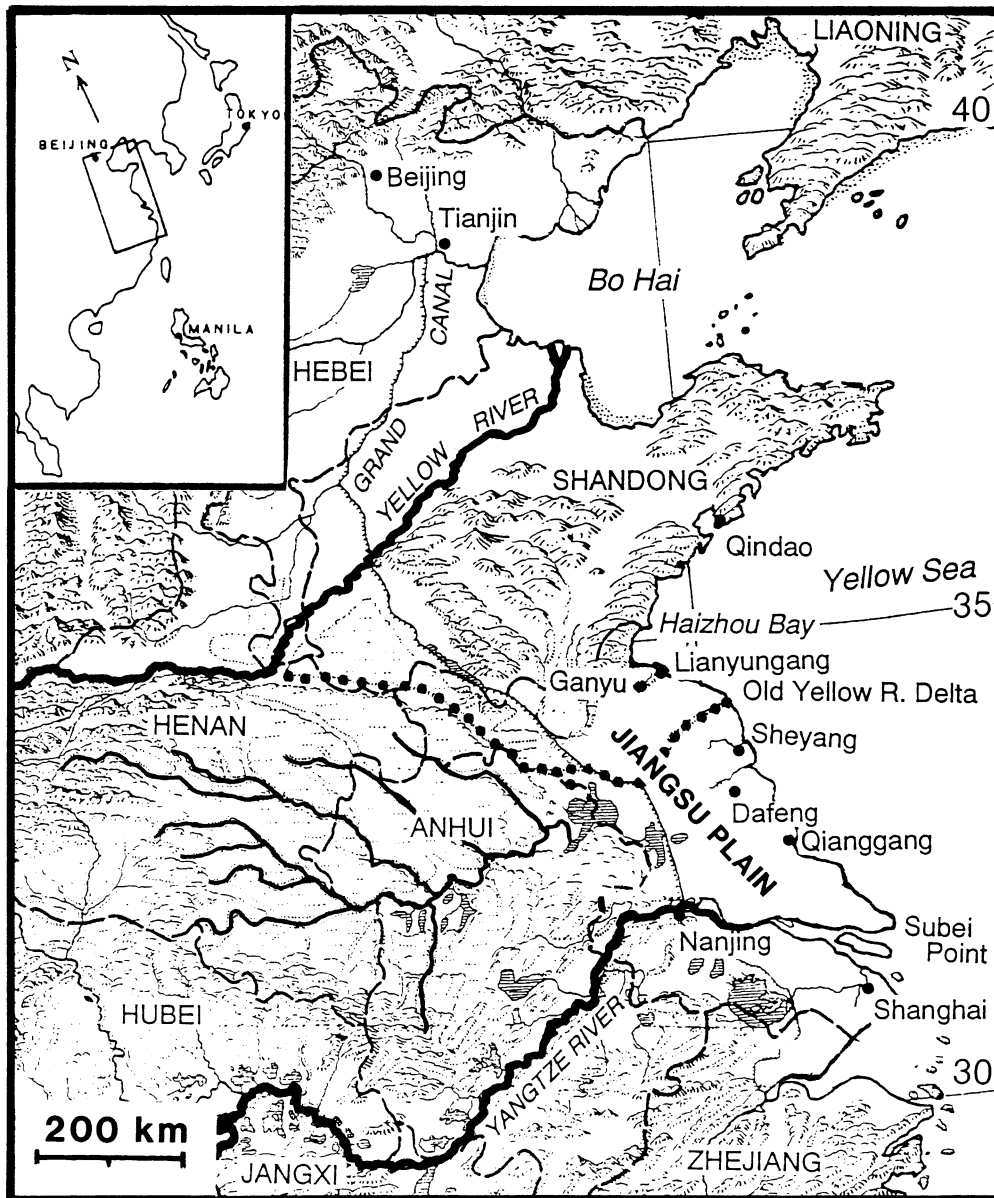


Figure 1. Location map of the North Jiangsu Plain.

the coastline is flat and shallow, with severe problems for harbour development. Inland, the major transportation route remains the ancient Great Canal which joins the Yangtze River with the Yellow River and the North China Plain, and a still inadequate network of roads.

The objectives of this paper are to: (1) provide an overview of the geomorphological evolution of the North Jiangsu Plain; (2) describe its present land and coastal use in terms of various environmental and landscape attributes; (3) note possible future developments; and (4) analyze potential hazards for the environment.

This paper is based on data obtained in the 1980s during a comprehensive geomorphological and land-use mapping of

the coastal area (REN MEI'E, 1986), on the abundant historical information available (ZHANG REN-SHUN, 1984), and on survey data on the hydrography and sediment dynamics of the tidal flats and the nearshore areas of the Yellow Sea.

GEOMORPHOLOGICAL EVOLUTION

The present North Jiangsu Plain cuts across the structure of earlier Mesozoic-Oligocene grabens and can be divided into two main structural areas which partially controlled the position of the old Yellow River and its delta (Figure 2). North of the old Yellow River delta axis relatively thin sediments rest on uplifted bedrock. South of the axis, across a complex sub-

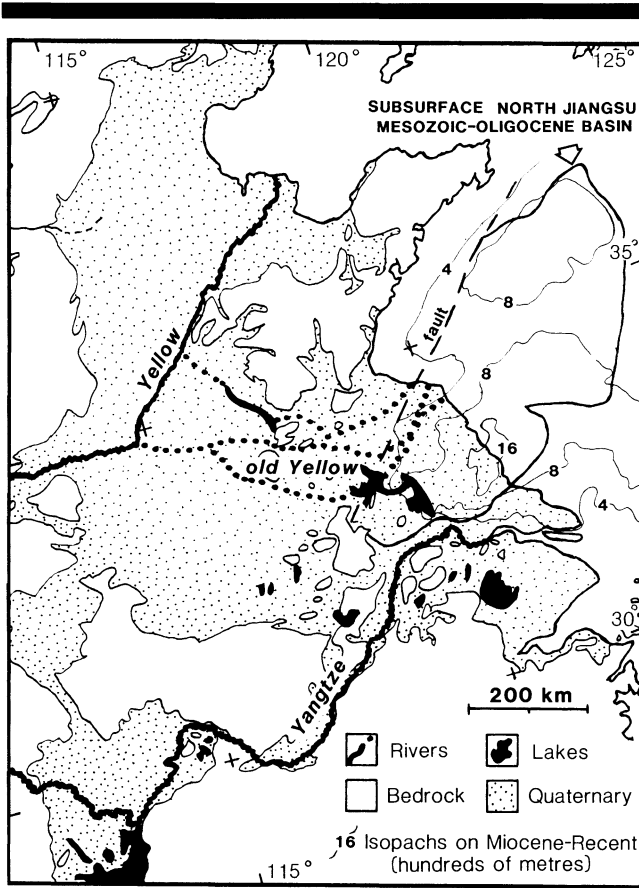


Figure 2. Major geological and geomorphological features (after ZHANG YUCHANG *et al.*, 1989).

surface fault zone, variable thicknesses of clastic sediments (up to 8,000 metres thick) fill the Mesozoic-Oligocene fault-bounded grabens of the North Jiangsu Basin (ZHANG YUCHANG *et al.*, 1989). These grabens are now inactive and blanketed by Miocene to Recent sediments. Nevertheless, the coastal plain is still differentially subsiding over the compacting sedimentary fill of the basin as shown by the variation in thickness of the Miocene to Recent sediments (Figure 2).

During the last glacial maximum (approximately 18,000 years BP) most of the western Yellow Sea area was exposed subaerially as shown by peat layers in offshore cores, and by buried, fossiliferous (*Buccella frigida* fauna) cheniers (sand ridges) dated at about 15,000 to 24,000 years BP (¹⁴C years) at the shelf break in the central east Yellow Sea at depths between 122 to 155 m (REN MEI'E and SHI, 1986). During hypsithermal times (about 6,000 years BP) much of the present coastal plain area was inundated by the sea (WANG and WANG, 1982; SUK, 1989). Since that time the North Jiangsu Plain has prograded into the shallow Yellow Sea (Figure 3).

The development of the plain was strongly influenced by varying sediment supply, particularly from the changing course of the Yellow River. The Yellow River crosses the central, high loess plateaus of China and carries finer, more calcareous and fertile load of 1.1 to 1.6×10^9 tons/yr compared

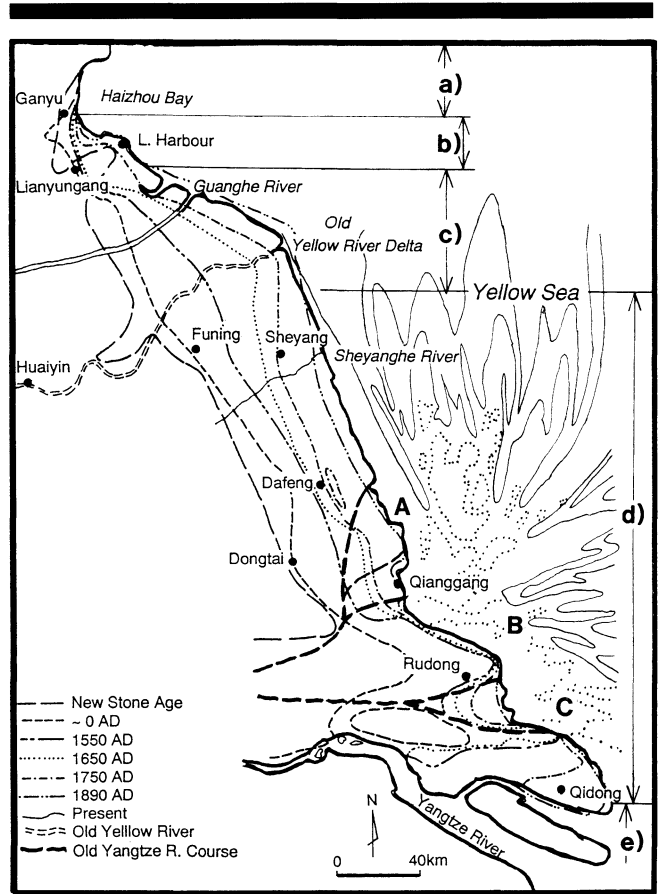


Figure 3. Paleoshores of the North Jiangsu Plain (after REN MEI'E, 1986) and tidal ridges offshore from Quianggang. A, B, & C are locations of potential offshore anchorages for large ships.

with the Yangtze river which carries a coarser but smaller sedimentary load of 0.4×10^9 tons/yr derived from inland bedrock areas (MILLIMAN and MEADE, 1983; SUK, 1989; KE and YU, 1990).

From 1129 to 1855 A.D. the Yellow River discharged into the Yellow Sea forming the old Yellow River delta, which extends laterally for 150 km from just east of Lianyungang harbour to the mouth of the small river near Sheyang (Sheyanghe River) to the south (Figure 1; REN MEI'E *et al.*, 1985b; REN MEI'E, 1992; SHU and FINLAYSON, 1993). During this time the Yellow River discharged entirely into the Yellow sea for 400 years, and partially for the other 300 years (when half of the river discharge flowed through Jiangsu Province to the Yellow Sea, and the other half discharged into the Bohai Sea to the north). During this time the old Yellow River delta added about 2,500 km² of new land to the area. After 1855, the Yellow Sea discharged entirely into the Bohai Sea, and the old deltaic coast in Jiangsu Province started eroding. Sediment removed by waves and tidal erosion from the abandoned delta was and is being dispersed along the coast, primarily to the south (KE and YU, 1990; CHEN, 1992). The amount of new land remaining is now only about 1400 km². Annual surveys near the old river mouth indicate shoreline

retreat of about 20 metres/year (CHEN, 1992). The small island of Kai Sun (Open Mountain Island) which is now 3 km offshore was located well inland in 1855. Similarly the small town of Yeu Weigang was 800 m farther inland in 1949 than it is to day.

From Sheyangh southward, most of the coast is aggrading due to deposition from longshore and offshore tidal currents (ZHU DAKUI *et al.*, 1986). The central section of this coast progrades naturally by about 40 metres/year on average, according to researchers at Nanjing University Marine Centre. Rates of progradation can reach 200 metres/year where dikes have been built to reclaim the vast, flat intertidal areas. Mudflats here are very wide, averaging 13 km. Relict features are important. Near Qianggang extensive (about 20,000 km²) shallow, locally emergent bars, ridges and channels radiate offshore (Figure 3). The inter-ridge channels up to 20–30 metres deep and have strong tidal currents (more than 2 metres/sec). The ridges formed on an old abandoned delta of the Yangtze River and the radiating pattern is in part due to palimpsestic deltaic morphology modified by strong tidal currents.

PRESENT LAND AND COASTAL USE

Though inland parts of the North Jiangsu Plain have been used since ancient times (New Stone Age), activities in the coastal zone were strongly regulated by the central government until recently. Only since the 1970s, after the open economic policy was established, did development occur (WANG YING, 1992). Present land and coastal use is based on geomorphological characteristics, climate and availability of freshwater.

For land and coastal use purposes, the present coast of the North Jiangsu Plain can be subdivided into (Figure 3): (a) sandy coasts of Haizhou Bay; (b) rocky coasts of the Lianyungang area; (c) eroding coasts of the old Yellow River delta; (d) strongly accretionary coasts centred on Dafeng; and (e) intermittently eroding coasts of the Subei peninsula.

(a) Sandy Coasts of Haizhou Bay

Haizhou Bay is concave with maximum curvature in its central south portion (Figure 3). Its sandy northern shores (near the granitic rocky coast of the Shandong Peninsula) grade south into silty and muddy shores. Well-developed high (10–15 m) foredunes occur locally in the north. The coast fronts a mesotidal sea and has a shallow (up to 10 m) offshore area. Its northern reaches are affected by southward flowing longshore currents, its southern reaches by a westward flowing longshore current. The resulting longshore drift, the discharge of fine material from local rivers, and the presence of a small island offshore which shadows the coast from direct impact of disruptive waves, all contribute to the sediment distribution and nearshore oceanographic characteristic of this bay. For instance, there is a marked change in salinity, from 27–36‰, in the north to 27–28‰, in the south, and in oxygen content in the water, from 7 mg/l in the north to 8 mg/l in the south.

The northern sandy coast of Haizhou Bay was not much used except for sand extraction which was outlawed in 1986. To remedy erosion caused by removal of sand, coastal protec-

tion works have been built near the mouths of some rivers. The shallow offshore areas are used for fishing.

The south central coast of the bay is being intensely used for varied aquaculture practices planned to best match the local substrate and oceanographic conditions. The upper part of the intertidal flats are intensely used for prawn aquaculture. Each year for five summer months, prawns 12–14 cm in length are produced for local and export markets. Chinese, Japanese, and Lion prawn are grown in different areas of the upper tidal flats. Chinese prawns reach maturity in only 2 years, and are raised in more muddy areas in waters with lower salinity and higher oxygen content of the central south part of the coast. The other types of prawn have slower rates of growth (they mature in 3 years) and are grown in coastal areas with higher salinity and lower oxygen content (note that, in any case, no prawn can be raised in water with oxygen content less than 2–4 mg/l). Small clams are captured by fencing off the lower part of the intertidal area and are then used as fresh food for the prawns (Figure 4A). Also in the uppermost part of the tidal flats and in supratidal areas, local ponds are still used to produce salt (Figure 4B), but mostly freshwater aquaculture (fish) is practised.

Deeper offshore areas are used for fishing. The shallow (about 2 m depth below mean low tide) subtidal zone is used for cultivation of kelp, “nari” (edible seaweed), and scallops. Vegetables, potatoes and rice are cultivated in recently reclaimed lands (Figure 4C).

(b) Rocky Coasts of the Lianyungang Area

The rocky hills of this area were islands in ancient times and have been occupied by man since before the New Stone Age (about 5,000 years ago). Silt deposited by the old Yellow River has since formed the vast subaerial coastal plain which now joins the former rocky islands. The mountains still reach the sea in places as in the Lianyungang harbour area (Figure 5). Here, the high coastal cliffs alternate with small gravelly and sandy coves. Lianyungang harbour is located in a tidal straight at the head of the promontory protected by a small offshore island (Dong Xi Linadao). The sea is mesotidal and deepens rapidly offshore from island. The deep water near the rocky shore and the protection of the small offshore island provide a safe harbour which is being expanded by building a barrage at one end of the narrow strait, changing it into a tidal inlet (Figure 5). Siltation problems are and will be experienced (Martini, 1992; Wang Ying, 1993), but the benefit of a large deep harbour in the northern part of the province, at the head of a trunk railway line will more than compensate for the future cost of dredging. The development of the harbour has also promoted rapid urbanization and industrial development, both in Lianyungang City itself and in the Lianyungang Harbour satellite town. The related increased need for energy is being addressed with proposals for building a nuclear power station in the vicinities of the harbour. Along the coast there is a conventional offshore fishery as well as development of shrimp aquaculture. Embryonic tourist facilities make use of the sandy pocket-beaches, with ancient archaeological sites and temples inland on the mountains as additional tourist attractions.



Figure 4. (A) Net-fences on tidal flats to catch small crustaceans as food for cultivated shrimps, and prawn pond; (B) Salterns in the Lianyungang area; (C) agricultural practices around Lianyungang.

(c) Eroding Coasts of the Old Yellow River Delta

The coasts here are rapidly eroding and receding at the rate of 5–10 cm/yr (ZHU DAKUI, 1990; WANG YING and AUBREY, 1987). The intertidal zone is only 0.5–1.0 kilometres wide with maximum erosion near high tide mark and the

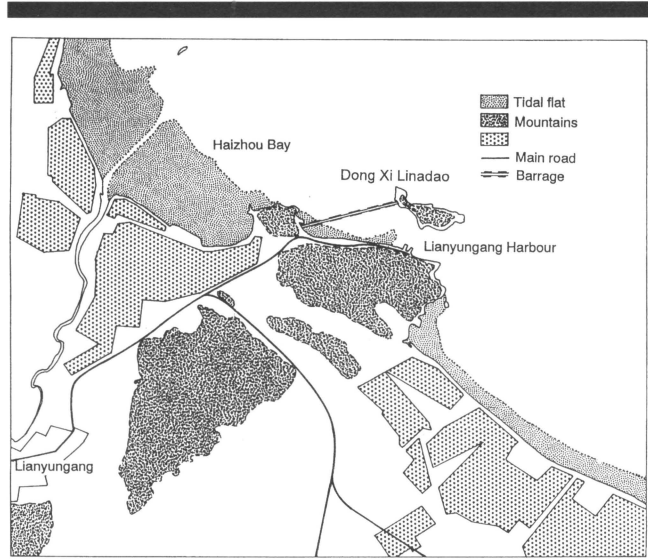


Figure 5. Map of the Lianyungang harbour area.

substrate is silty and muddy. Local people do some shore protection work, usually by building chain-like fences to break the impact of waves.

The area between Lianyungang and the old mouth of the Yellow River has been historically used for extraction of salt from salterns and has been regulated since antiquity. The salt ponds had to be frequently moved seaward to keep pace with the coastal progradation. This left the old salt pans behind, so no crops could be grown for some time because of the highly saline soils. Total salt production is now about 1.5 million tons/year. East of Lianyungang, associated with the salt production there is also development of large chemical industries producing mainly KCl, NaCO₃, Mg, Cl.

Aquaculture has been developed within the last two decades. As well as the main product of prawns, eels are also cultivated. These are kept in indoor cement tanks in order to control temperature (during winter the temperature of the area is rather low) and salinity (brackish water 30–32%), and protect this rather expensive commodity. This particular area is used for eel culture because of abundant brackish water and the low cost of land.

Inland, agriculture in this northern area is of the dry type, more oriented toward wheat production rather than rice. East of Lianyungang the substratum is muddy, with little freshwater available for irrigation. Agriculture is not well developed because the groundwater is brackish (in part because of the dewatering of marine clay and silt of the substratum).

(d) Strongly Accreting Coasts Centred on Dafeng

These coasts have broad tidal flats which are generally 4–6 kilometres wide, up to 13 kilometres wide, and with gentle gradients of 0.1–0.5 m/km (ZHU DAKUI, 1986) (Figure 6A, B). The tidal flats grade offshore into the shallow, wide shelf of the Yellow Sea. The radiating bars and ridges off Qianggang have very shallow water at their crest and some emerge at

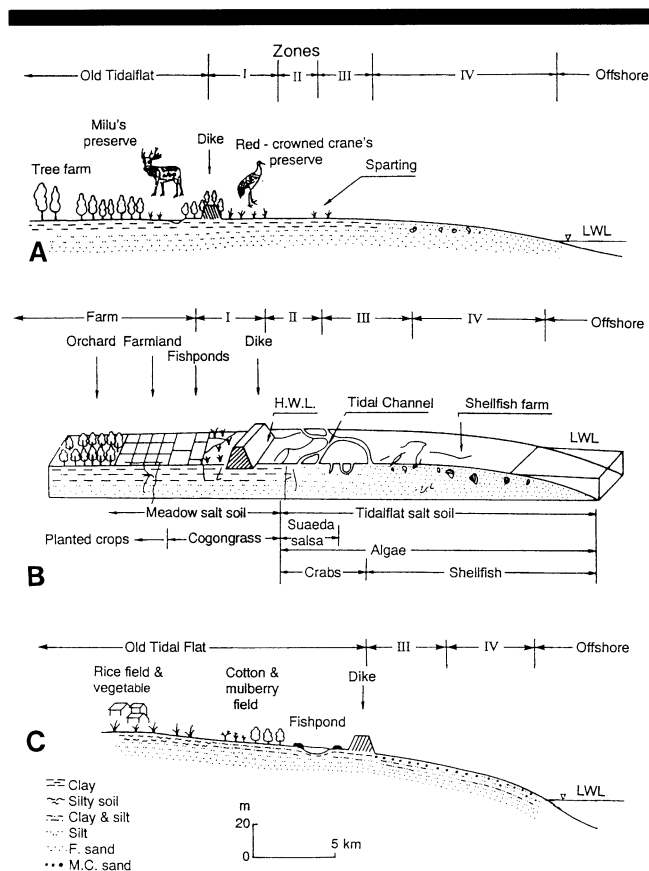


Figure 6. Tidal flat sections of the central and southern coast. (A) tidal flats off Dafeng; (B) tidal flats off Rudong; (C) tidal flats off Quidong.

low tide. During storms, erosion occurs on the offshore side of ridges, and the material is deposited in part on the onshore flank of the ridges and in part is transported shoreward onto the prograding tidal flats.

All along this shore, land has been reclaimed from the sea since antiquity by building dikes. Coastal land-use is similar to that of the coasts to the south and is dealt with later (see next section). Two major wildlife reserves have been established on reclaimed tidal flats of the northern part of Dafeng County (Figure 6A). In the first, a large natural area has been set aside for Red Crested Cranes and other birds. About 300 pairs of these cranes winter here, and migrate for the summer to marshlands of northern China (Han Long Jiang Province) and adjacent Russia. In the second, approximately in the same area, a natural reserve has been established for Milu (David) deer. This deer was found by an English naturalist (David) in the Ching Emperor's gardens in the mid 1800's but was not known in the wild, although 9,000–10,000 old fossil bones have been found in the general area of the Jiangsu Plain. The deer were taken from the Emperor's garden to London, England in the late 1800's and then in 1980's returned to China. They have been re-introduced in the coastal preserve of Dafeng County where there are now more than 100 pairs.

(e) Intermittently Eroding Coasts of the Subei (Quidong) Peninsula

Just north of the Yangtze River, the tidal flat is narrow and affected by large waves and fast tidal currents which enter close to shore along a southeast-northwest trending, relatively deep channel (REN MEI'E, 1986; WANG YING and AUBREY, 1987) (Figure 6C). During the winter, some of the Yangtze River sediments are transported northward to accumulate in this area; while during other times of the year erosion occurs.

The land-use of the two southern coastal segments (d and e) are similar, since they have similar substrates and climatic conditions (Figure 6). Though the area is not very good for salt production because of high rainfall and limited evaporation, a few small salterns are still producing salt for local use. Fishing is practised offshore, naturally grown shells (mollusks) are harvested on the 5–6 km wide, silty tidal flats just north of the Yangtze River. Aquaculture, as everywhere else, is gaining in importance.

North of the Yangtze River agriculture is good, not only because of the suitable climate but also because of availability of water from the groundwater aquifer and from the numerous irrigation canals and a lot of rice is grown. There is also limited growth of fruit such as apples, and in the southern part of the plain there is a rich culture of mulberry bushes for silk worms. Cotton is grown in quantity as well since cotton can grow in muddy soils even if somewhat saline.

POSSIBLE FUTURE DEVELOPMENTS

On the whole the economy of the Jiangsu Province is growing. But the Northern Jiangsu Plain (and its coastal area in particular) lags behind the area south of the Yangtze River. While the Northern Jiangsu Plain has two thirds of the land area and half the population of the province, it has less than one third of the its productivity. Lack of harbours and energy for industry are the major limiting factors for developing the North Jiangsu Plain. Remedying these two things and constructing facilities for tourism would strengthen the existing industries in the area and would foster new development for the next century.

Harbours

Jiangsu Province has only one large and growing harbour, in Lianyungang. The other harbour used is Shanghai which has some limitations in terms of shallowness of channels and congestion of traffic. No other large harbour exists along the coast of the North Jiangsu Plain because the coast consists of wide, silty shallow tidal flats. However, recent studies indicate that deep sea anchorages capable of receiving ships as large as 100×10^3 tons, could be constructed utilizing the deepest (more than 20 m) tidal channels of the radiating bars and channels zone offshore from Qianggang (A, B, C on Figure 3).

A large anchorage could be constructed at the head of a large southeast-northwest trending channel (B, Figure 3). Such a facility would be capable of receiving supertankers and ironore supercargo ships from the Middle East, Australia

and Brazil. The oil could then be shipped via pipeline to Shanghai, Nanjing and Whuan eliminating the present need of transferring material via small ship to these industrial centres along the Yangtze River. The iron ore could be initially processed to improve the iron content (from about 60% iron in the ore to 99%) onshore, and then shipped by rail or barges to the steel mills of inland industrial centres.

A second anchorage could be constructed at the southern end of the western channels offshore from the Wanggang area (A, Figure 3). Such a facility could receive coal from northern China.

A third large anchorage could be constructed near the tip of the Subei Point peninsula along a deep SE-NW tidal channel that parallels the coast (C, Figure 3). This would be ideal as a service-base for the large, proven, but as yet unexploited oil-field found offshore under the Yellow Sea. Such an anchorage and associated onshore support facilities would be much closer, hence less expensive, to the offshore field and would relieve the traffic congestion in Shanghai.

Other smaller safe harbours could be built all along the coast for fishing fleets by modifying the mouth of several rivers now dammed to impede salt water intrusion inland. What would be needed is the construction of gravity lock canals for the ships to bypass the existing barriers.

Energy

If the large anchorages in the Wanggang area were built, then fossil fuels can be used to increase the output of existing small thermoelectric stations, and can be distributed reasonably rapidly and inexpensively throughout the southern part of the North Jiangsu Plain. Availability of abundant coal, for instance, would make new large thermoelectric stations feasible. Some are already planned, one on the north shore of the Yangtze River, upstream of Shanghai, one in Qianggang area inland from the proposed deep sea anchorage and one in the Lianyungang area (Figure 1). The latter one may be supplemented in the more distant future by the planned nuclear station. In future, more energy might be supplied to the province from the proposed hydro dams of the Three Gorges along the Yangtze River. Availability of all this power would double the output of existing industries and would certainly favour establishment of new and more modern industries (REN MEI'E, 1986).

Tourism

At present, tourism has not developed at all along the North Jiangsu coasts, except to a minor extent in the Lianyungang area. Yet there are great opportunities both in term of number of potential users and coastal sites. Jiangsu Province together with neighbouring inland Anhui Province (Figure 1) can provide more than 300 million potential clients, whose life style is improving rapidly and whose demand for recreation and relaxation will increase drastically in the near future.

The northern sandy and rocky coasts are natural sites for tourism development if facilities are provided and if the planning is such that the natural beauty of the area is preserved (including the large coastal foredunes). The mountainous

high coasts of the Lianyungang harbour area are good natural sites for recreational facilities, hotels, cottages. Again care should be taken to assure that development does not destroy the scenery, and development should consider safety as well because of the potential instability of rocky slopes which have downslope dipping beds on coastal cliffs. Tourist facilities must include not only improved access routes and housing, but also recreational activities on the water (boating, cruising, surfing, fishing and the like), on shore, and in the hinterland.

Tourist activities need not be limited to the northern coasts. Even the accretionary coasts of the central southern part of the North Jiangsu Plain can locally offer attractions. In particular, the lower reaches of rivers and canals can be fruitfully exploited. Warm, clean water for bathing and recreational boating exist behind the dams at river mouths, and forested banks along the streams, canals and costal embankments can provide relaxing conditions (CHEN *et al.*, 1992).

ENVIRONMENTAL HAZARDS

The Northern Jiangsu Plain is affected not only by local events, but also by what occurs hundreds of kilometres offshore and hundreds of kilometres alongshore and inland. Inhabitants and authorities of the North Jiangsu Plain are well aware of some of these effects, as they have experienced major shifts of the Yellow River in the past, some caused by man. But, as ever-increasing pressure grows for further development, the danger of contamination will increase here as it has repeatedly in other parts of the world.

Some of the disruptive pollution threats are obvious. For example, large coastal towns and harbours, such as Shanghai, are already experiencing severe problems. Pollutants can be carried out to sea, but some are returned and redistributed along the coasts by tidal and storms currents. Furthermore, future potential dangerous threats are the large tankers and cargo ships which will be utilizing treacherous seaways to reach proposed anchorages in the shallow central parts of the coastal plain. Similar problems may be caused by the development of the offshore oil field in the Yellow Sea. Major mishaps are bound to occur and are likely to pollute the coastal areas, destroying coastal industries such as fisheries, shellfish collection and aquaculture. Unless efforts are made to establish strict safety regulations to prevent disasters and contingency plans to remedy any problem, the consequences may be severe.

Other pollution threats are less obvious because they act cumulatively over a long time. They can occur when development of the coast and its hinterland occurs too rapidly and is not properly regulated.

For example, exponential increase in aquaculture on the coast can lead to costly problems for the industry itself. One problem is the construction of retaining ponds in the upper part of the intertidal area and deployment of nets over vast part of the tidal flats to collect foodstuff for the shrimps themselves. This will inevitably lead to increased rate of siltation on the flats requiring perhaps economically unacceptable remediation along some coasts which are already rapidly accreting naturally. Another problem is pollution associated

with aquaculture, ancillary industries and other shore activities. Central America provides classical examples of this, albeit in different settings. There, large tracts of mangrove were deforested to make way for aquaculture. This caused both the elimination of the natural hatchery to replenish the stock and increasing coastal erosion with siltation of coastal water. Eventually extensive tracts of coast became unfit for aquaculture (CLARK, 1992).

Less obvious are the effects of inland agricultural practices, which are widespread over the whole land. Agriculture has been practised for a long time on the Northern Jiangsu Plain, but until recently, fundamental, ancient conservation practices have been followed. As agriculture is increasingly changing into a modern industry, maximum production may become the goal, and more and more fertilizers and pesticides may be used. These chemicals will seep into the groundwater and waterways to reach lakes and eventually the coast. Perhaps much of this pollution will be dispersed by the strong marine currents and storms. But many pollutants attach themselves to fine sediment particles which can selectively accumulate in higher parts of the tidal flats and in embayments, possibly affecting shellfish and bottom grazing organisms as well as aquaculture. Dangerous pollutants may re-enter the food chain in this way (GOBAS and MACKAY, 1990).

One example is what is happened in some of the Great Lakes of North America, such as Lake Erie and Lake Ontario. Over the last hundred years, large towns and industries gradually developed along the shores of these lakes, while agriculture in the hinterland recently changed into a multimillion dollar industry using large amounts of fertilizers and pesticides to grow crops, and raising large numbers of animals like pigs, cattle and chickens. In a few decades the two lakes have become polluted receiving an enormous amount of nitrogen, phosphorous and all sort of chemical materials including cancer producing PCB's and others. As a consequence commercial fisheries had to be closed in the lakes in part for health reasons, sport fishing is discouraged, and even bathing is at times not safe. Yet many large towns still get their drinking water from the lakes, but have to purify it for human consumption through complex and expensive processes. Pollution prevention was not practised, and both Canada and the United States of America are now faced with an expensive clean up (ONTARIO MINISTRY OF THE ENVIRONMENT, 1984).

Not all cases of intensive coastal development are bad examples. The Netherlands, for instance, offer a successful example of a highly managed, intensely used, but not excessively polluted coastal environment, similar to the North Jiangsu Plain. Like the North Jiangsu Plain, the Netherlands have reclaimed much of the territory from the sea by building coastal dikes. Since antiquity though, the draining of the reclaimed land and the prevention of pollution have been carefully regulated. Even so, the quality of the waterways has locally deteriorated in recent times due to increased urbanization, and maintenance of the dikes is a costly albeit necessary activity to avoid disastrous inundations.

Nevertheless, unless possible environmental hazards are evaluated and addressed on the North Jiangsu Plain (with the experience and examples of other countries in mind), un-

controlled expansion of trade, industry, agriculture, aquaculture and tourism will eventually cause them to self-destruct.

CONCLUSIONS

The modern coastal portion of the North Jiangsu Plain has developed over the 5-6,000 years since the last major post-glacial sea level rise. The plain is formed by sediments derived from the Yellow River in the north and the Yangtze River in the south. The rate of coastal progradation has been strongly enhanced by the construction of coastal dikes since 1128 AD. Originally these dikes were built to protect the land from marine storms and inundations, but they are now constructed to reclaim land from the sea.

In the past, activities along the shore have been highly regulated, and since ancient times the major exploitation was limited to fisheries and salt production. In the last two decades, aquaculture became predominant all along the shore. Different coastal tracts have their own peculiar geomorphological, climatic and oceanographic conditions which require different land and coastal use practices, and offer varying potentials for various future development. Rocky shores in the north offer the only possibility for a large onshore sea harbour, while sandy and rocky coasts of the area also have a great potential for future tourist development. Eroding silty shores associated with the old abandoned delta of the Yellow River still have great potential for production of salt and associated chemical manufacturing. Along the strongly accretionary shores in the central part of the Plain natural fisheries occur. Here, there is also a great developmental potential if proposed large anchorages for oil supertankers and coal ships are built offshore along tidal channels which are the only deep avenues into an otherwise very flat shallow shelf. Farther south the potential exists for development of a harbour and inland facilities to serve the offshore oil field activities.

Constructions of offshore anchorages for large ships, onshore facilities for receiving coal and oil, thermo-electrical plants, and improvement of highways will lead to future increase in industrial and tourism development. All this requires careful planning in order not to irrevocably damage the natural setting, thus not to endanger things like the presently successful aquaculture industry.

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