Supplementary materials for

Coastal Vulnerability Modelling and Social Vulnerability Assessment under Anthropogenic Impacts

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Table A1. List of land satellite image data of the Bohai Sea

Region	Year	Image sensor	Path/Row
Bohai Sea	1985, 1997, 2010, 2020	Landsat5 TM, Landsat7 ETM, Landsat8 OLI.	120/034, 121/034, 122/033, 121/033, 121/0.32, 120/032, 120/033, 119/033.

Table A2. The specific interpretation signs of different land cover types

Land cover types	Hue (543 band)	Interpretation signs
Wetland vegetation	Red	Wetland vegetation comprises of natural plants such as *Suaeda salsa, Tamarix chinensis*, and *Apocynum venetum*, dominated by *Phragmites australis* in the study area.
Tidal flats	Gray-brown	Regular shapes and large areas, are mainly distributed along shore areas.
Bare lands	Cyan-gray	The uncovered bare lands are mainly distributed along the farmlands in the study area.
Water areas	Blue	A clear internal texture with a flake or strip shape in the sea water area separated from the open sea by the gray strip of sand spouts and dams
Farmland	Dark red	Waters areas refer to the rivers and reservoirs with uniform dark blue color and clear texture on the remote sensing images.
Aquaculture pond	Bright blue	The aquaculture ponds show flaky or striped distributions without vegetation coverage on the remote sensing images.
Saltern	Dark blue	The salt field is the area with uneven bright blue color, a clear texture, flaky distribution, and vegetation coverage. Reservoirs show clear boundaries with the gray dams on the images.

The governing equations used in the present study are the vertically integrated equations of continuity and momentum:

$$\frac{\partial\zeta}{\partial t}+\frac{1}{a}\frac{\partial[(h+\zeta)u]}{\partial\lambda}+\frac{1}{a}\frac{\partial[(h+\zeta)v\cos\phi]}{\partial\phi}=0,$$
$$\frac{\partial u}{\partial t}+\frac{u}{a}\frac{\partial u}{\partial\lambda}+\frac{v}{R}\frac{\partial u}{\partial\phi}-\frac{uv\tan\phi}{R}-fv+\frac{ku\sqrt{u^2+v^2}}{h+\zeta}-A\Delta u+\frac{g}{a}\frac{\partial(\zeta-\bar{\zeta})}{\partial\lambda}=0,$$
$$\frac{\partial v}{\partial t}+\frac{u}{a}\frac{\partial v}{\partial\lambda}+\frac{v}{R}\frac{\partial v}{\partial\phi}+\frac{u^2\tan\phi}{R}+fu+\frac{kv\sqrt{u^2+v^2}}{h+\zeta}-A\Delta v+\frac{g}{R}\frac{\partial(\zeta-\bar{\zeta})}{\partial\phi}=0.$$

where t is the time, λ and ϕ are the east longitude and north latitude respectively, ζ is the sea surface elevation above the undisturbed sea level, u and v are the east and north components of fluid velocity respectively, $\bar{\zeta}$ is the adjusted height of equilibrium tides, R is the radius of the earth, $a=R\cos\phi$, $f=2\Omega\sin\phi$, where Ω represents the angular speed of earth's rotation, g is the acceleration due to gravity, h is the undisturbed water depth and $h+\zeta$ denotes the total water depth, k is the BFC, A is the coefficient of horizontal eddy viscosity, Δ is the Laplace operator and $\Delta(u,v)=a^{-1}[a^{-1}\partial_\lambda(\partial_\lambda(u,v))+R^{-1}\partial_\phi(\cos\phi\partial_\phi(u,v))]$.

For governing equations (1), the numerical scheme as A1.

A1 Numerical scheme of forward equations (1)

$$\frac{\zeta_{m,n}^{2j+1}-\zeta_{m,n}^{2j}}{\Delta t}+\frac{(h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j})u_{m,n}^{2j}-(h_{m-\frac{1}{2},n}+\zeta_{m-\frac{1}{2},n}^{2j})u_{m-1,n}^{2j}}{a_n\Delta\lambda}$$
$$+\frac{(h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j})v_{m,n}^{2j}\cos(\phi_{n+\frac{1}{2}})-(h_{m,n-\frac{1}{2}}+\zeta_{m,n-\frac{1}{2}}^{2j})v_{m,n-1}^{2j}\cos(\phi_{n-\frac{1}{2}})}{a_n\Delta\phi}=0, \qquad (A1.1)$$

$$\frac{v_{m,n}^{2j+1}-v_{m,n}^{2j}}{\Delta t}+\frac{\bar{u}_{m,n}^{2j}(v_{m+1,n}^{2j}-v_{m-1,n}^{2j})}{2a_n\Delta\lambda}+\frac{v_{m,n}^{2j}(v_{m,n+1}^{2j}-v_{m,n-1}^{2j})}{2R\Delta\phi}+f_n\bar{u}_{m,n}^{2j}$$
$$+\frac{k_{m,n+\frac{1}{2}}s_{m,n}^{2j}[\alpha v_{m,n}^{2j+1}+(1-\alpha)v_{m,n}^{2j}]}{h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j}}+\frac{g(\zeta_{m,n+1}^{2j+1}-\zeta_{m,n}^{2j+1})}{R\Delta\phi}-\frac{g(\bar{\zeta}_{m,n+1}^{2j+1}-\bar{\zeta}_{m,n}^{2j+1})}{R\Delta\phi} \qquad (A1.2)$$
$$-A\Delta v_{m,n}^{2j}+\frac{\bar{u}_{m,n}^{2j^2}\tan(\phi_n)}{R}=0,$$

$$\frac{u_{m,n}^{2j+1}-u_{m,n}^{2j}}{\Delta t}+\frac{u_{m,n}^{2j}(u_{m+1,n}^{2j}-u_{m-1,n}^{2j})}{2a_n\Delta\lambda}+\frac{\overline{v}_{m,n}^{2j+1}(u_{m,n+1}^{2j}-u_{m,n-1}^{2j})}{2R\Delta\phi}-f_n\overline{v}_{m,n}^{2j+1}$$
$$+\frac{k_{m+\frac{1}{2},n}r_{m,n}^{2j}[\alpha u_{m,n}^{2j+1}+(1-\alpha)u_{m,n}^{2j}]}{h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j}}+\frac{g(\zeta_{m+1,n}^{2j+1}-\zeta_{m,n}^{2j+1})}{a_n\Delta\lambda}-\frac{g(\overline{\zeta}_{m+1,n}^{2j+1}-\overline{\zeta}_{m,n}^{2j+1})}{a_n\Delta\lambda} \qquad (A1.3)$$
$$-A\Delta u_{m,n}^{2j}-\frac{u_{m,n}^{2j}\overline{v}_{m,n}^{2j+1}\tan(\phi_n)}{R}=0,$$

$$\frac{\zeta_{m,n}^{2j+2}-\zeta_{m,n}^{2j+1}}{\Delta t}+\frac{(h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j+1})u_{m,n}^{2j+1}-(h_{m-\frac{1}{2},n}+\zeta_{m-\frac{1}{2},n}^{2j+1})u_{m-1,n}^{2j+1}}{a_n\Delta\lambda}$$
$$+\frac{(h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j+1})v_{m,n}^{2j+1}\cos(\phi_{n+\frac{1}{2}})-(h_{m,n-\frac{1}{2}}+\zeta_{m,n-\frac{1}{2}}^{2j+1})v_{m,n-1}^{2j+1}\cos(\phi_{n-\frac{1}{2}})}{R\Delta\phi}=0, \qquad (A1.4)$$

$$\frac{u_{m,n}^{2j+2}-u_{m,n}^{2j+1}}{\Delta t}+\frac{u_{m,n}^{2j+1}(u_{m+1,n}^{2j+1}-u_{m-1,n}^{2j+1})}{2a_n\Delta\lambda}+\frac{\overline{v}_{m,n}^{2j+1}(u_{m,n+1}^{2j+1}-u_{m,n-1}^{2j+1})}{2R\Delta\phi}-f_n\overline{v}_{m,n}^{2j+1}$$
$$+\frac{k_{m+\frac{1}{2},n}r_{m,n}^{2j+1}[\alpha u_{m,n}^{2j+2}+(1-\alpha)u_{m,n}^{2j+1}]}{h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j+1}}+\frac{g(\zeta_{m+1,n}^{2j+2}-\zeta_{m,n}^{2j+2})}{a_n\Delta\lambda}-\frac{g(\overline{\zeta}_{m+1,n}^{2j+2}-\overline{\zeta}_{m,n}^{2j+2})}{a_n\Delta\lambda} \qquad (A1.5)$$
$$-A\Delta u_{m,n}^{2j+1}-\frac{u_{m,n}^{2j+1}\overline{v}_{m,n}^{2j+1}\tan(\phi_n)}{R}=0.$$

$$\frac{v_{m,n}^{2j+2}-v_{m,n}^{2j+1}}{\Delta t}+\frac{\overline{u}_{m,n}^{2j+2}(v_{m+1,n}^{2j+1}-v_{m-1,n}^{2j+1})}{2a_n\Delta\lambda}+\frac{v_{m,n}^{2j+1}(v_{m,n+1}^{2j+1}-v_{m,n-1}^{2j+1})}{2R\Delta\phi}+f_n\overline{u}_{m,n}^{2j+2}$$
$$+\frac{k_{m,n+\frac{1}{2}}s_{m,n}^{2j+1}[\alpha v_{m,n}^{2j+2}+(1-\alpha)v_{m,n}^{2j+1}]}{h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j+1}}+\frac{g(\zeta_{m,n+1}^{2j+2}-\zeta_{m,n}^{2j+2})}{R\Delta\phi}-\frac{g(\overline{\zeta}_{m,n+1}^{2j+2}-\overline{\zeta}_{m,n}^{2j+2})}{R\Delta\phi} \qquad (A1.6)$$
$$-A\Delta v_{m,n}^{2j+1}+\frac{\overline{u}_{m,n}^{2j+2^2}\tan(\phi_n)}{R}=0.$$

where $\Delta\lambda,\Delta\phi,\Delta t$ represent the longitude, the latitude and the time step respectively, $\phi_n=\phi_0+(n-1)\Delta\phi$, ϕ_0 is the initial latitude, $a_n=R\cos(\phi_n)$, $\overline{u}_{m,n}^{j}$, $r_{m,n}^{j}$, $\overline{v}_{m,n}^{j}$, $s_{m,n}^{j}$ are the same with Lardner (1993a).

A2 Numerical scheme of adjoint equations (2)

$$
\begin{aligned}
&\frac{\tau_{m,n}^{2j+2}-\tau_{m,n}^{2j+1}}{\Delta t}+\frac{(u_{m,n}^{2j+1}+u_{m-1,n}^{2j+1})(\tau_{m+1,n}^{2j+2}-\tau_{m-1,n}^{2j+2})}{2a_n\Delta\lambda}\\
&\quad+\frac{(v_{m,n}^{2j+1}+v_{m,n-1}^{2j+1})[\tau_{m,n+1}^{2j+2}\cos(\phi_{n+\frac{1}{2}})-\tau_{m,n-1}^{2j+2}\cos(\phi_{n-\frac{1}{2}})]}{2a_n\Delta\phi}\\
&\quad+\frac{k_{m+\frac{1}{2},n}\mu_{m,n}^{2j+2}u_{m,n}^{2j+1}\sqrt{u_{m,n}^{2j+1^2}+\overline{v}_{m,n}^{2j+1^2}}}{(h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j+1})^2}+\frac{k_{m,n+\frac{1}{2}}v_{m,n}^{2j+2}v_{m,n}^{2j+1}\sqrt{\overline{u}_{m,n}^{2j+1^2}+v_{m,n}^{2j+1^2}}}{(h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j+1})^2}\\
&\quad+\frac{g(\mu_{m,n}^{2j+2}-\mu_{m-1,n}^{2j+2})}{a_n\Delta\lambda}+\frac{g(v_{m,n}^{2j+2}-v_{m,n-1}^{2j+2})}{a_n\Delta\phi}-K_\zeta D_{m,n}(\zeta_{m,n}^{2j+1}-\hat{\zeta}_{m,n}^{2j+1})=0,
\end{aligned}
\qquad (A2.1)
$$

$$
\begin{aligned}
&\frac{v_{m,n}^{2j+2}-v_{m,n}^{2j+1}}{\Delta t}+(f_n-c_{m,n}^{2j+1})\overline{\mu}_{m,n}^{2j+2}-e_{m,n}^{2j+1}[(1-\alpha)v_{m,n}^{2j+1}+\alpha v_{m,n}^{2j+2}]\\
&\quad+\frac{(h_{m,n-\frac{1}{2}}+\zeta_{m,n-\frac{1}{2}}^{2j+1})[\tau_{m,n}^{2j+1}\cos(\phi_n)-\tau_{m,n-1}^{2j+1}\cos(\phi_{n-1})]}{a_n\Delta\phi}\\
&\quad-\frac{\mu_{m,n}^{2j+2}(u_{m,n+1}^{2j+1}-u_{m,n-1}^{2j+1})}{2R\Delta\phi}-\frac{v_{m,n}^{2j+2}(v_{m,n+1}^{2j+1}-v_{m,n-1}^{2j+1})}{2R\Delta\phi}\\
&\quad+\frac{v_{m+1,n}^{2j+2}u_{m+1,n}^{2j+1}-v_{m-1,n}^{2j+2}u_{m-1,n}^{2j+1}}{2a_n\Delta\lambda}+\frac{v_{m,n+1}^{2j+2}v_{m,n+1}^{2j+1}-v_{m,n-1}^{2j+2}v_{m,n-1}^{2j+1}}{2R\Delta\phi}\\
&\quad+A\Delta v_{m,n}^{2j+2}+\frac{u_{m,n}^{2j+1}\mu_{m,n}^{2j+2}\tan(\phi_n)}{R}=0,
\end{aligned}
\qquad (A2.2)
$$

$$
\begin{aligned}
&\frac{\mu_{m,n}^{2j+2}-\mu_{m,n}^{2j+1}}{\Delta t}-(f_n+b_{m,n}^{2j+1})\overline{v}_{m,n}^{2j+1}-d_{m,n}^{2j+1}[(1-\alpha)\mu_{m,n}^{2j+1}+\alpha\mu_{m,n}^{2j+2}]\\
&\quad+\frac{(h_{m-\frac{1}{2},n}+\zeta_{m-\frac{1}{2},n}^{2j+1})(\tau_{m,n}^{2j+1}-\tau_{m-1,n}^{2j+1})}{a_n\Delta\lambda}\\
&\quad-\frac{\mu_{m,n}^{2j+2}(u_{m+1,n}^{2j+1}-u_{m-1,n}^{2j+1})}{2a_n\Delta\lambda}-\frac{v_{m,n}^{2j+1}(v_{m+1,n}^{2j+1}-v_{m-1,n}^{2j+1})}{2a_n\Delta\lambda}\\
&\quad+\frac{\mu_{m+1,n}^{2j+2}u_{m+1,n}^{2j+1}-\mu_{m-1,n}^{2j+2}u_{m-1,n}^{2j+1}}{2a_n\Delta\lambda}+\frac{\mu_{m,n+1}^{2j+2}v_{m,n+1}^{2j+1}-\mu_{m,n-1}^{2j+2}v_{m,n-1}^{2j+1}}{2R\Delta\phi}\\
&\quad+A\Delta\mu_{m,n}^{2j+2}+\frac{\mu_{m,n}^{2j+2}v_{m,n}^{2j+1}\tan(\phi_n)-2v_{m,n}^{2j+1}u_{m,n}^{2j+1}\tan(\phi_n)}{R}=0,
\end{aligned}
\qquad (A2.3)
$$

$$\frac{\tau_{m,n}^{2j+1}-\tau_{m,n}^{2j}}{\Delta t}+\frac{(u_{m,n}^{2j}+u_{m-1,n}^{2j})(\tau_{m,n}^{2j+1}-\tau_{m-1,n}^{2j+1})}{2a_n\Delta\lambda}$$
$$+\frac{(v_{m,n}^{2j}+v_{m,n-1}^{2j})[\tau_{m,n+1}^{2j+1}\cos(\phi_{n+\frac{1}{2}})-\tau_{m,n-1}^{2j+1}\cos(\phi_{n-\frac{1}{2}})]}{2a_n\Delta\phi}$$
$$+\frac{k_{m+\frac{1}{2},n}\mu_{m,n}^{2j+1}u_{m,n}^{2j}\sqrt{u_{m,n}^{2j\ 2}+\overline{v}_{m,n}^{2j\ 2}}}{(h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{2j})^2}+\frac{k_{m,n+\frac{1}{2}}\nu_{m,n}^{2j+1}v_{m,n}^{2j}\sqrt{\overline{u}_{m,n}^{2j\ 2}+v_{m,n}^{2j\ 2}}}{(h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{2j})^2} \qquad (A2.4)$$
$$+\frac{g(\mu_{m,n}^{2j+1}-\mu_{m-1,n}^{2j+1})}{a_n\Delta\lambda}+\frac{g(\nu_{m,n}^{2j+1}-\nu_{m,n-1}^{2j+1})}{a_n\Delta\phi}-K_\zeta D_{m,n}(\zeta_{m,n}^{2j}-\hat{\zeta}_{m,n}^{2j})=0,$$

$$\frac{\mu_{m,n}^{2j+1}-\mu_{m,n}^{2j}}{\Delta t}-(f_n+b_{m,n}^{2j})\overline{v}_{m,n}^{2j+1}-d_{m,n}^{2j}[(1-\alpha)\mu_{m,n}^{2j}+\alpha\mu_{m,n}^{2j+1}]$$
$$+\frac{(h_{m-\frac{1}{2},n}+\zeta_{m-\frac{1}{2},n}^{2j})(\tau_{m,n}^{2j}-\tau_{m-1,n}^{2j})}{a_n\Delta\lambda}$$
$$-\frac{\mu_{m,n}^{2j+1}(u_{m+1,n}^{2j}-u_{m-1,n}^{2j})}{2a_n\Delta\lambda}-\frac{\nu_{m,n}^{2j+1}(v_{m+1,n}^{2j}-v_{m-1,n}^{2j})}{2a_n\Delta\lambda} \qquad (A2.5)$$
$$+\frac{\mu_{m+1,n}^{2j+1}u_{m+1,n}^{2j}-\mu_{m-1,n}^{2j+1}u_{m-1,n}^{2j}}{2a_n\Delta\lambda}+\frac{\nu_{m,n+1}^{2j+1}v_{m,n+1}^{2j}-\nu_{m,n-1}^{2j+1}v_{m,n-1}^{2j}}{2R\Delta\phi}$$
$$+A\Delta\mu_{m,n}^{2j+1}+\frac{\mu_{m,n}^{2j+1}v_{m,n}^{2j}\tan(\phi_n)-2\nu_{m,n}^{2j+1}u_{m,n}^{2j}\tan(\phi_n)}{R}=0,$$

$$\frac{\nu_{m,n}^{2j+1}-\nu_{m,n}^{2j}}{\Delta t}+(f_n-c_{m,n}^{2j})\overline{\mu}_{m,n}^{2j}-e_{m,n}^{2j}[(1-\alpha)\nu_{m,n}^{2j}+\alpha\nu_{m,n}^{2j+1}]$$
$$+\frac{(h_{m,n-\frac{1}{2}}+\zeta_{m,n-\frac{1}{2}}^{2j})[\tau_{m,n}^{2j}\cos(\phi_n)-\tau_{m,n-1}^{2j}\cos(\phi_{n-1})]}{a_n\Delta\phi}$$
$$-\frac{\mu_{m,n}^{2j}(u_{m,n+1}^{2j}-u_{m,n-1}^{2j})}{2R\Delta\phi}-\frac{\nu_{m,n}^{2j+1}(v_{m,n+1}^{2j}-v_{m,n-1}^{2j})}{2R\Delta\phi} \qquad (A2.6)$$
$$+\frac{\nu_{m+1,n}^{2j+1}u_{m+1,n}^{2j}-\nu_{m-1,n}^{2j+1}u_{m-1,n}^{2j}}{2a_n\Delta\lambda}+\frac{\nu_{m,n+1}^{2j+1}v_{m,n+1}^{2j}-\nu_{m,n-1}^{2j+1}v_{m,n-1}^{2j}}{2R\Delta\phi}$$
$$+A\Delta\nu_{m,n}^{2j+1}+\frac{u_{m,n}^{2j}\mu_{m,n}^{2j}\tan(\phi_n)}{R}=0.$$

where $\overline{\mu}_{m,n}^{j},\overline{\nu}_{m,n}^{j}$ are similar to $\overline{u}_{m,n}^{j},\overline{v}_{m,n}^{j}$, and

$$b_{m,n}^{j}=\frac{k_{m+\frac{1}{2},n}}{h_{m+\frac{1}{2},n}+\zeta_{m+\frac{1}{2},n}^{j}}\frac{u_{m,n}^{j}\overline{v}_{m,n}^{j}}{\sqrt{u_{m,n}^{j\ 2}+\overline{v}_{m,n}^{j\ 2}}},\quad c_{m,n}^{j}=\frac{k_{m,n+\frac{1}{2}}}{h_{m,n+\frac{1}{2}}+\zeta_{m,n+\frac{1}{2}}^{j}}\frac{\overline{u}_{m,n}^{j}v_{m,n}^{j}}{\sqrt{\overline{u}_{m,n}^{j\ 2}+v_{m,n}^{j\ 2}}},$$

$$d_{m,n}^{j} = \frac{k_{m+\frac{1}{2},n}}{h_{m+\frac{1}{2},n} + \zeta_{m+\frac{1}{2},n}^{j}} \frac{2{u_{m,n}^{j}}^{2} + {\bar{v}_{m,n}^{j}}^{2}}{\sqrt{{u_{m,n}^{j}}^{2} + {\bar{v}_{m,n}^{j}}^{2}}}, \quad e_{m,n}^{j} = \frac{k_{m,n+\frac{1}{2}}}{h_{m,n+\frac{1}{2}} + \zeta_{m,n+\frac{1}{2}}^{j}} \frac{{\bar{u}_{m,n}^{j}}^{2} + 2{v_{m,n}^{j}}^{2}}{\sqrt{{\bar{u}_{m,n}^{j}}^{2} + {v_{m,n}^{j}}^{2}}}$$