NUMERICAL SIMULATION AND POPULATION-WIDE RISK ASSESSMENT OF WINDBLOWN DUST EMISSION FROM DRIED-UP BOTTOM OF ARAL SEA

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1.INTRODUCTION

The Aral Sea, once one of the world's largest inland seas, is now shrinking due to unsustainable water consumption from its inflow rivers by the Central Asian Republics (the culprit. As a consequence of the increased of irrigated area and hydropower generation in the Aral Sea basin, coupled with population increase, the Aral Sea has deteriorated into the largest inland body of salty reservoir in the world. The Aral Sea case is a very prime example of how unsustainable action can lead to an environmental disaster. The process of degradation of the Aral Sea did not only posed environmental consequences but alongside, severe social and economic crises. Each year violent sandstorms pick up at least 150,000 tons of salt and sand from the dried-up seabed and transport it across hundreds of kilometres. The sands are contaminated with industrial and agricultural chemicals residue and have been linked to high regional rates of respiratory diseases and certain types of cancer. A depressed fact is that the primary victims of these crises are the most vulnerable strata of the region’fs society, wiz children, elderly peoples with pre-existing asthmatic illness, women and less-paid inhabitants of cities and rural areas. The main objective of this research is a simulation of dust particle transport from the exposed bottom of the Aral Sea and evaluation of annual mortality rate introduced by windblown dust emission from dried bottom of Aral Sea.

Study follows an integrated approach and conceptually consists of two models: 1) numerical simulation of dust concentrations blown from the dried-up bottom of Aral Sea and 2) population-wide assessment model, which reads dust concentrations data from simulation model. Therefore, to model the movement of dusts within the region to various vulnerable points at which it may be contacted by people, a wind flow field has been developed.

2. DEVELOPMENT OF WIND FLOW MODEL

2.1 Wind field computations process

Initially, the wind filed was obtained in two steps. First, the values of Surface Friction-u_*, Air Temperature-T, Surface Pressure-P, Sensible Heat Flux-Q, Roughness Height-z_0 and Geopotential Height-Z_{GP} were approximated in the points of the domain located at the same height z_0 over the terrain using a *horizontal bi-cubic spline interpolation*. Then from this information we perform a *vertical extrapolation* to define the velocity filed in the whole domain. To find the fields at desired time, temporary interpolation was also carried out.

2.2 Vertical extrapolation

In this study, a log-linear wind profile is considered in vertical direction. This takes into account the horizontally interpolated variables and the effect of roughness on the wind intensity and direction (Montero, 1998). Above the surface layer (Z_{sl}), a linear interpolation is made using the geostrophic wind. The logarithmic profile of wind in vertical direction is given by

$$u(z) = \frac{u_*}{k}\left(\log\frac{z}{z_0} - \psi_m(\frac{z}{L})\right). \qquad (2.1)$$

where u_* is friction velocity, k-is Von-Karman constant, z_0- is the roughness height and Z_{sl} is the height of the surface layer. The value ψ_m depends on the air stability and obtained by following equations (Stull,1988).

For neutral atmosphere, ,

$$\psi(\frac{z}{L}) = 0, \qquad (2.2)$$

for stable atmosphere, ,

$$\psi(\frac{z}{L}) = -5 * \frac{z}{L}, \qquad (2.3)$$

and finally for unstable atmosphere,、

$$\psi\left(\frac{z}{L}\right) = \log\left[\left(\frac{x^2+1}{2}\right)\left(\frac{x+1}{2}\right)^2\right] - \quad (2.4)$$

$$2\arctan \quad x + \frac{\pi}{2}$$

where, $x = (1-16z/L)^{1/4}$ and L is Obukhov

2.3 Vertical wind velocity.

The vertical wind velocity is not an observed variable, and yet, its estimation appears as one of the most difficult problem for the meteorologists. However, if the wind observation is available on a grid array, the estimation of kinematic vertical velocity can obtained straightforwardly from the integration of the mass continuity equation.

The equation of continuity is:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (2.3.1)$$

Under this strong constrain of mass conservation the vertical motion is obtained by:

$$w(z) = -\int_0^z \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)dz. \qquad (2.3.2)$$

3. MODELLING OF DUST TRANSPORT

The transport scheme predicts the dust concentration by solving the following system of equation in Lagrangian framework:

$$\left(m_p + \frac{\rho_f V_p}{2}\right)\frac{d\mathbf{u}_p}{dt} = -V_p \nabla P + m_p \mathbf{g} - \qquad (3.1)$$

$$\frac{1}{2}\rho_f S C_D \mathbf{u}_r |\mathbf{u}_r|$$

$$\frac{d\mathbf{x}_p}{dt} = \mathbf{u}_p \qquad (3.2)$$

Here $\mathbf{x}_p$ is the particle position, m_p is the particle mass, ρ is the fluid (air) density, V_p is the volume of particle, $\mathbf{u}_p$ is the particle velocity, ∇P is the pressure gradient, $\mathbf{g}$ is gravity, S is the cross-section of the particle in $\mathbf{u}_r$ direction, C_D is the drag coefficient, $\mathbf{u}_r$ is particle-to-fluid relative velocity, which is defined by

$$\mathbf{u}_r = \mathbf{u}_p - \mathbf{u} \qquad (3.3)$$

The value of $\mathbf{u}$ is determined by interpolating fluid velocity from grid point to the location of particle.

The effect of the subgrid turbulent fluctuations of air motion are also need to be considered in the calculation of particle motion, therefore, x_p is expressed as

$$\mathbf{x}_p^{n+1} = \mathbf{x}_p^n + \Delta t \mathbf{u}_\mathbf{p} + \sqrt{2K_p \Delta t}\,\chi \qquad (3.4)$$

where the last term in the equation represents a simple dispersion of particles, adopted from Suzuki (2001). K_P, here, expresses particle eddy diffusivity and χ represents the Gaussian probability distribution function. The numerical solution of this function described in Press et al. (1992).

The magnitude of the aerodynamic drag depends on the flow patters around the particle. The $C_D(Re_p)$ relationship has been approximately determined by using Morci and Alexaner (1972) functions

$$C_D(Re_p) = \frac{k_1}{Re_p} + \frac{k_2}{Re_p} + k_3 \quad (3.4)$$

The particle Reynolds number defined as

$$Re_p = \frac{|\mathbf{u}_p - \mathbf{u}| D_p}{v_{air}} \qquad (3.5)$$

where v_{air} air viscosity and $D_p$is particle diameter.

3.1 Validation with satellite image

The simulated surface temperature, winds and streamlines fields are shown in Figure 3.1 and 3.3. The most outstanding feature of the flow fields was the strong northeasterly wind associated with a vigorous cool to cold airstreams for almost whole day. The location of frontal system can be easily identified from the narrow regions with sharp temperature gradients. It was found that wind erosion started in the early morning of 18 April, peaked at around 14:00 of the same day and eased at 18:00 of the same day. The simulated dust particle clouds, in general, show good agreement when compared with visibility features of the satellite picture. It should be recognized that the satellite images register only cases with very strong turbidity so in reality dust and salt could be transported to a far longer distance that can seen from satellite picture. The shape, location and extend of the dust clouds coincide well with the wind erosion area predicted by model.

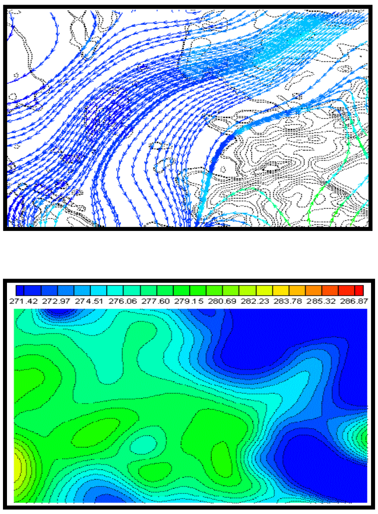


Figure 3.1 Simulated surface streamlines (a) and temperature (b) for the 18 April, 2003

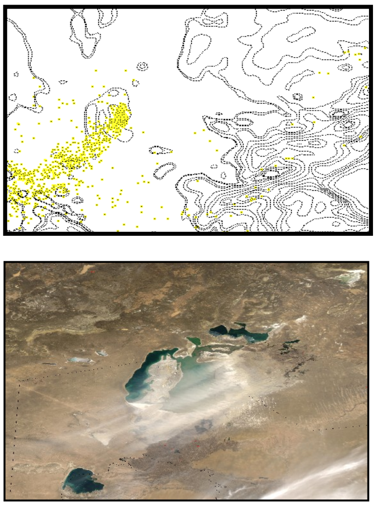


Figure 3.3 Observed (a) and simulated (b) of 18 April 2003 dust storm in the dried up seabed

4. EFFECT OF DUST PARTICLES ON ANNUAL MORTALITY RATE

4.1 Methods

The distribution of dust concentrations are generated by Dust Transport model by combining area-specific population densities with atmospheric concentrations for each of the areas where contact to air pollutants occurs. The exposure-response function adopted from the reviewed literature. The change in mortality evaluated from the daily averaged particle matter concentrations in micrograms per cubic meter and gives quantitative measure of adverse effect of air pollution introduced by windblown dust emission from the dried bottom sea of the Aral Sea.

4.2 Formulation of the response function in response to particle concentration

Deck et al. (1996) carried out a particle matter risk assessment for Philadelphia and Los Angeles. The concentration response functions used in their analysis were empirically estimated relationship between average ambient ambient concentrations of the pollutant of interest (PM) and the health endpoint of interest reported by epidemiological studies. Mathematically the relation given by

$$R(c) = r(o)\exp(\gamma c) \qquad (4.2.1)$$

where $R(c)$ is the response function, c is the concentration of interest, thus here dust particle matter, $r(o)$ is a standard mortality rate used as endpoint, γ is given by

$$\gamma = \frac{\log_e(RR)}{\Delta c} \qquad (4.2.2)$$

where RR represents relative risk for concentration change.

In this study, the same way as Deck et al. (1996) has been followed and used the relative risk *(RR*) of 1.025 (a 2.5% increase) for mortality as a result of

$\Delta c = 50 \mu g / m^3$ increase in PM concentration, using one-day averaging time, so that $\gamma = 4.9 \mathbf{x} 10^{-4}$ was used. Then the concentration response function be writing as follow

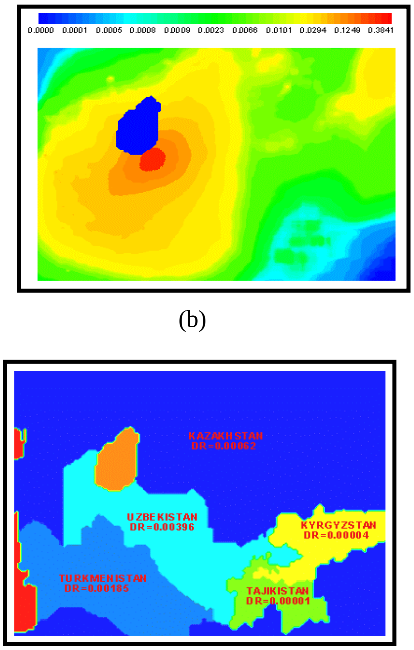
$$R(c) = r(o)\exp(4.9\mathbf{x}10^{-4}c) \quad (4.2.3)$$

However, to avoid the computational problem, which may be often caused by large value of c, after small side calculation we rewrite (4.4.2) in more suitable form

$$R(c) = 1.025^{\frac{c}{\Delta c}} r(o)$$

4.3 Results from applying the method

The final result of this model is a function that expresses the actual number of people likely to be affected.


(a)

(b)

Figure 4.7 Contour map of concentration response function: (a) on each cell, (b) averaged for each republics

The Figure 4.7 demonstrates the numerical illustration of concentration response function. As expected, we observed that the Aral Sea dust storm has major impact on mortality rate of the population of Uzbekistan, Kazakhstan and Turkmenistan.

Results from this study identify high exposure areas for policy makers in a simple and realistic way, and can help generate hypothesis or show associations between population, health, and air quality indicators. In addition, the exposure assessments help provide some probabilistic estimates of the population likely to be affected. The mapping technique used can convey complex information very quickly and many people find the visual interpretation very easier than statistics information. Especially, for the case of Aral Sea problem, it helps the people to realize that most of the problem resulted from the wasteful water-consumption lifestyle. And since much of the blame is ours, we should have much obligation for finding solutions.

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