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DREDGING, MUD, AND DUNNING-KRUGER

Dragagem, lama e *Dunning-Kruger*

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ABSTRACT

The human being has a cognitive pattern of always considering the work of others simple, and this is known as the Dunning-Kruger effect. All areas of knowledge present complexities that are only understood by those who are dedicated to going deeper into a particular topic. This manuscript talks (superficially) about mud and dredging, which is a contemporary and very relevant topic for economic development and the preservation of the environment. In short, dredging is taking sediment from one place and putting it in another. Simple! However, when this sediment is mud, there are several aspects inherent to this type of material that make the evaluation of its behavior somewhat complex, synergistically with the complexity of coastal hydrodynamics.

Keywords: cohesive sediment, hydrodynamics, flocculations, fluid mud.

RESUMO

O ser humano apresenta um padrão cognitivo de sempre considerar o trabalho dos outros simples, e isso é conhecido como efeito Dunning-Kruger. *Todas as áreas do conhecimento apresentam complexidades que somente são entendidas por aqueles que se dedicam em se aprofundar em determinado tema. Este manuscrito fala (superficialmente) sobre a lama e as dragagens, que é um tema contemporâneo e muito relevante para o desenvolvimento econômico e para a preservação do ambiente. Resumidamente, dragagens é tirar o sedimento de um lugar e colocar em outro. Simples! Porém, quando esse sedimento é lama, existem vários aspectos inerentes a esse tipo de material que tornam a avaliação do seu comportamento um tanto quanto complexa, sinergicamente com a complexidade da hidrodinâmica costeira.*

Palavras-chave*: sedimentos coesivos, hidrodinâmica, floculação, lama fluida.*

We have the natural perception that things are simpler than they are, or someone else job is simpler than our own. With experience, we learn to be more cautious about this misconception and think twice before saying 'I could do that better!'. I have learned, not much time ago, that this self-confident feeling has a name: the Dunning-Kruger effect. In technical words, it is the "hypothetical cognitive bias stating that people with low ability at a task overestimate their ability" (Wikipedia). I've been working with coastal hydrodynamics and fine sediment dynamics (or mud!) for a while. And in a Socratic point of view, I have learned how ignorant I am, or, better saying, never to anticipate too much! The world is full of hidden surprises in all areas of knowledge.

In this article, I will write about mud. Mud is everywhere. People usually don't like mud but have mud covering the floor and walls of bathrooms and kitchens. Walls, in most cases, are made with mud blocks = bricks. Of course, loose mud is a dirty thing and we want it off our houses, cars, and shoes. Mud is essentially sediment, and in the environment, it follows the sedimentary cycle of being produced, transported, and sedimented, turning into rocks again in a long period. In this cycle, the mud transits through coastal areas and sometimes it can be a major concern to human activities, especially when it stays for a while in harbors and waterways.

Economic growth is based on trade. International trade is based on maritime transport: ships & ports. Ports need space. Modern planed ports were constructed in sparsely populated areas with enough area to grow for a long time (e.g., Pecém, Ceará; Suape, Pernambuco; Porto Açu, Rio de Janeiro). However, most ports grow together with the city they originated (or vice-versa), and space became a matter of conflict (e.g., Mucuripe, Ceará; Recife, Pernambuco; Santos, São Paulo). Not only the hinterland area for operations and storage but the wet area too. Ships used to be much smaller and needed less water depth. As the ships became larger, the same occurred to its draft. So, these ports had to adapt, increasing the waterways and berths' depth by dredging. Dredging is the relocation of sediments. Relocation of sediments is very common on land, where the material is 'borrowed' from somewhere to be put elsewhere to plain the relief or build a dam. However, dredging is an underwater job and is quite more complicated to be done when compared with a land similar work.

The first complication factor is that we cannot see exactly what we are doing. We depend upon sonographic techniques to assess and monitor the operation. This requires advanced instruments and qualified staff to perform costly time-consuming surveys, process a large amount of data, and produce summary charts. In some cases this work is straightforward, meanwhile, there are situations when the conditions are not favorable or the bottom itself does not behave well, being elusive and leading to misreading. Nonetheless, this can be satisfactorily accomplished.

One main difference between land and underwater sediment relocation, physically speaking, is that the density difference between the sediments (~ 2,650 kg/m^3) and water (~ 1,000 km/m^3) is much lower than between sediments and air (~ 1.3 kg/m^3). This has many implications. One is that requires less energy to keep sediment particles suspended in water than air. Once resuspended in water, sediment particles will take longer to return to the bed. While in suspension, the particles will be displaced horizontally driven by the currents, which are much more sluggish than winds.

A way to think about the problem above stated is to decompose it in two: the vertical and horizontal particle behavior. The processes which drive these behaviors are quite complicated indeed, but let's try to simplify it as much as possible. Under non-anthropogenic action, particles will be rose from the bed (resuspension) when enough energy is supplied, by waves and currents. As matter of fact, waves and currents supply the needed kinetic energy, but it is the turbulence generated by the friction between the moving fluid and the bottom which results in resuspension, and the uplift of denser particles in the fluid means the rise of potential energy. The turbulence produces an apparent increase of the water viscosity (turbulent viscosity) and an upwards force that we scale as a turbulent diffusivity. When in excess, this will make particles move upwards from the bed. Work is necessary to uplift the particles and sustain them. The amount of turbulence decreases with the distance from the bed, consequently, there will be less energy available, and fewer particles can be sustained. This produces a vertical profile of particles concentration with exponential shape (the Rouse profile, e.g., Boudreau & Hill, 2020). The energy source is the kinetic energy of the flow being converted in turbulence, which is converted partially in gravitational potential energy (particles uplift). The turbulence is, ultimately, dissipated in heat, and in absence of turbulence, particles will settle.

The work required to keep a particle suspended in water is due to its weight, shape, and viscous interaction with the fluid (drag), in the form of Stokes' law. This law is very important because it gives us the terminal settling velocity of a particle. For particles we call 'sand' and 'silt', this is quite straightforward. By 'sand', most people know as that white-yellowish stuff we walk on the beaches. 'Silt' is about the same stuff but smaller in size, both being made mainly by quartz and feldspar. Why is it 'straightforward'? Because these particles are unities which we can accurately measure size and density, and not so 'straightforward', because they are electrically balanced. This means that there is not a net electrical charge on their surface. They do not attract or repel each other. They are non-cohesive. Of course, if we call something of 'non-something', the other 'something' must be quite interesting! And indeed, it is!

The other 'something' is the clay (a more beautiful name for the mud). A big source of misunderstanding is when one is referring whether to the particle size or about the nature of the material itself. I mean, you can have a clay material of the size of sand, and it is even possible to have sand material (quartz) of the size of clay. Clay is the name of a vast group of minerals (clay-minerals!), as well as the name of a particle size class. Of course, the particle size class is named clay because it is composed mostly of different types of clay minerals (which are grouped in four major groups kaolinite, smectites, illites, and chlorites). Sand and silt are non-cohesive, and clay is cohesive. The cohesiveness is due to unbalanced bounds in the mineral lattice. To understand the reason for that, we need to go back to the origin of the particles: the weathering of the rocks.

Physical weathering means rock disintegration. Bigger rocks turn into smaller rocks but keep their same mineral composition. Big quartz, small quartz. Chemical weathering means rock decomposition. The rock composition is changed during the process. Big feldspar, small clay mineral. The type of clay mineral will depend on the original rock and environmental conditions, especially the climate. The climate in this case means water availability, temperature, and biological activity. If the weathered material stays where it was formed, it is soil. If it is transported elsewhere (erosion), it becomes sediment. The erosion occurs mainly by the action of the water, mainly by precipitation and surface runoff, on both climatic (rainy/dry seasons) and meteorological time scales (rain events). The anthropogenic factor accounts very much for this process. First, due to the global climate changes of course. But more directly, due to changes in the soil cover (e.g., crops) and water management (e.g., dams) in the drainage basins. Both can increase or decrease the sediment load of rivers, which will depend on many social, cultural, and economic aspects. And this will have a huge role in the sediment balance in coastal areas (e.g., Meybeck, 2003).

Returning to the clay/cohesiveness subject. Clay is formed by the chemical weathering of the rocks, and this results in electrical charged particles and usually very small ones (< 10 µm or 0.01 mm). You can't see them individually. Using a microscope and magnifying it 1000x in a diluted water solution, you'll see some black dots shaking in the water. That means they are so small that they are affected by the collisions with water molecules producing the Brownian motion. Further, they are shaped like flakes with irregular edges and a smooth side (like a tiny paper sheet). Sand and silt particles are spherical. Spherical particles can settle much easier throughout a fluid than a flat-shaped one with the same mass.

The cohesiveness of the clays turns them biogeochemically reactive, and this is extremely relevant when we talk about environmental assessment of dredgings. The flat sides of the clay particle are usually negatively charged, while the edges are positively charged. When emersed, it will form a coat of positively charged ions on the sides, attracted by the particle's negative charge. There is an excess of a negative charge, and beyond the layer of cations strongly adsorbed to the particle wall will form a second cloudy layer of cations and anions. This is known as electric double-layer (e.g., James & Parks, 1982). So, any dissolved molecule with a residual electrical charge (basically anything!) can be attracted by clays. That's why there is a high correlation between organic matter with mud, and that's why there are high correlations between metal and organic pollutants with mud. In a potentially contaminated environment, you must look for the mud to find them! You'll not find it in the sand!

If two clay particles come close together, there is a much higher probability that they have a face-to-face approximation and will repel each other. Being alone, very small, and flat, the settling velocity is very, very low. Even the most sluggish river can produce enough turbulence to keep these particles in suspension, and that is why most river waters are turbid. Rivers with clear water occur when there are no clay particles available to be carried, otherwise they would become turbid as well. Well, that is not exactly true. We can find rivers with very low suspended sediments (Negro River tributary to the Amazon River), but let's pretend they don't.

The clay particles' behavior changes drastically depending on the chemistry of the water. Low pH, high dissolved organic matter content, and presence of dissolved ions (salts) can overwhelm the inter-particle repulsion and make them stick together forming aggregates or flocs. Usually is taught (for oceanography students, at least) that flocculation occurs in estuaries. It is true, but flocculation occurs everywhere the conditions allow, even in fresh-water environments (Negro River?). Flocculation is extensively used in the industry to separate materials. This is one step used in the water treatment plants to remove suspended solids. The flocculation rate also depends on the suspended sediment concentration because of the probability of particle encounters. Higher concentrations favor flocculation. Turbulence also can enhance flocculation, as it increases the probability of particle encounters. However, turbulence can also break down the flocs as they grow too large.

Flocculation is a straightforward process, qualitatively speaking. If the right conditions are provided, flocs are formed. The big (physical) issue is about what will be the resulting size and density of the flocs? We need to know these properties to infer the settling velocity, or, as we said, how long the particles will be sustained in the water column and to be advected by the currents. Numerous studies abroad assessed this problem (e.g., Fall *et al.*, 2021), and one thing that seems the rule is that there is no single rule that can be applied everywhere. By rule, we understand as a model which allows us to predict that behavior. If a model works fine in a place, it will not necessarily in another. This is due to the differences in the clay-mineral assembly, water chemistry, biological activity, etc. It is not just a matter of physics and chemistry. The environment setting has a big role in that.

However, as we are aiming at the coastal waters, we are dealing with high salinity waters (> 2 g/kg is enough!) where flocculation occurs plenty and it is very unlikely to find non-flocculated clay particles. If you take a water sample in an estuary or coastal waters, you will probably see some dirt in the water. Flocs can reach up to 1-2 mm in size (extremely big ones!), but anything bigger than 100 µm can be seen with naked eyes. And if you let this sample rest, all the dirt will likely settle in a matter of minutes. Flocs are formed by 10's of thousands of clay particles, dissolved and particulate organic matter, and water. As the floc grows in size, its density decreases non-linearly. If a floc grows too big, it is likely it will be broken up by turbulence. Further, flocs grow up in a fractal fashion, meaning smaller flocs can glue together forming larger flocs. But the most important about the flocs is that they settle much faster than the individual clay particles. However, in the environment, under the action of waves and currents, the flocs are continually growing and breaking down, and it is very hard to know (or predict!) what its settling velocity will be. For example, if you take a water sample to measure the floc size, you are changing the environment setting (turbulence!) and maybe changing the floc properties.

When the flocs settle at the bottom and accumulate, their name change to mud. If mud is resuspended, you have flocs again. As mud, we understand it as a mixture that can contain clay (in major amounts), silt, sand, water, gas, dissolved and particulate organic matter, and living & dead organisms (bacteria, fungi, algae, and animals, big (crabs) and small (worms) ones). Living organisms can either strengthen the cohesiveness of the mud (mucus has a great gluing property) or facilitate erosion (digging the mud retards the compaction). Biology has a great effect on mud dynamics, and it is quite hard to reduce it to a simple mathematical model.

In some places, we may have neither mud nor flocs, but something intermediary which we call fluid mud. Fluid mud can be understood as sediment with a lot of water between the particles, or water with a lot of sediments, however, not exactly in suspension. The number of particles is so large that they touch each other forming a 3D structure filled with water, hindering the settling. As a rule of thumb, when the concentration of sediments is higher than 10 g/L, the particles do not settle freely anymore and we have fluid mud. The threshold between fluid mud and not-so-fluid mud is of the order of 100 g/L or higher, but keep in mind that 'consolidated' still is a very soft material like yogurt texture. Far from being a solid bed that one could walk on. Fluid mud, as the name suggests, is fluid and flows accordingly. If there is a slope, it will flow downwards. However, because of the particles on it, the vertical momentum transfer is hindered. The flow does not behave like water (a Newtonian fluid), but is somewhat more complicated if one considers the way water flows as 'simple'!

Fluid mud occurs when the environmental conditions allow: a lot of mud, enough energy, and not much advection. It occurs in many ports waterways and makes sometimes difficult to have a precise measure about where the bottom is, which is paramount for navigation security. It may be measured using traditional double-frequency echo-sounders (200/33 kHz), although the accurate measurements require more sophisticated instruments (e.g., tuning fork) which can measure the mud density and viscosity. In some ports (e.g., Rotterdam Port), fluid mud properties are monitored routinely, and ships are allowed to navigate on it. However, ships are designed to navigate on water, so it is necessary to assess how the ships steer differently when their hulls are partially in fluid mud.

Another very important and curious property of mud is thixotropy. Likely, you never heard this word before. To be straight, ketchup (the tomato sauce) is a thixotropic material. What do you do before using the ketchup? You shake it. Why? Because when you let the catchup at rest for a while, the bonds between the protein molecules become stronger with time, making it difficult to flow. When you shake it, you disrupt the bonds, making it easier to flow. The mud works the same way. The period between 'shakes' matters on how the mud will behave. In a strong tidal regime, 'shakes' will be at every 6 hours. In weakly tidal regimes, 'shakes' will be caused by probabilistic events, like storms, river floods, or tsunamis, much harder to predict.

We will not enter in the matter of the horizontal movement of the water, and so, the particles it carries. This is a very complex and extensive subject too, as hydrodynamics is driven by tides, winds, waves, baroclinicity, and topography. But one issue is particularly interesting to mention as it relates to the hydrodynamics and sediment accumulation in harbors. A misconception about coastal sediment dynamics is that flocculation is the only cause of mud accumulation in estuaries. The reasoning is that the suspended sediments carried by rivers meet saline water and flocculates, settling, resulting in harbor siltation and that requires a dredging operation. Flocculation increases the vertical flux of sediments downwards, indeed, and can be the main cause of siltation in some harbors. However, in most cases, the main cause of sediment accumulation is the landwards residual currents near the bottom (Schettini *et al.*, 2013). Residual currents can be produced by different factors, such as topography, horizontal density gradients, tidal straining, tidal asymmetry, and others (Dunning-Kruger!). In many cases, most of the sediment that accumulates in a harbor is one that is being transported from the adjacent shelf instead of the direct settling from the river-borne materials. In rivers, we can be sure the water and sediment are coming from upstream. In estuaries and coastal waters, it is advisable not to be so sure about that.

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