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Short Communication

Vegetation as "Reed Diffusers" Accelerate the Hydrological Cycle of Arid Land surface

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Abstract

While arid regions are water scarce, often we find lakes in these regions even though the annual precipitation is very low, and vegetation is scanty. Although ground water supply via shallow aquifer systems is a possible explanation of the origin of these lakes, their continued existence is not discussed in detail. I opine that the reason for the existence of these lakes can be attributed to the very nature of surface energy balance characteristics and the partitioning of the net radiation consequent of the presence of water body, bare soil or vegetation. In arid regions, large lakes can still be sustained provided there are no vegetation around it because vegetation acts as a strong catalyst for water transfer between the biosphere and the atmosphere and forms a connecting conduit for mass-energy fluxes analogous to a "reed diffuser". Latent heat fluxes over vegetated landsurface could be much more than open water bodies having no vegetation nearby. Vegetation accelerates the evapotranspiration process and eventually dry the system at much faster rates than without it. This was explained using the examples of Lake Chad and Aral Sea as examples and showing the satellite retrieved signals of vegetation proliferation. This issue has to be carefully considered while developing agricultural projects in oasis environments. Excessive agriculture or date palm cultivation even with judicious water management could permanently damage oasis ecosystems and we need to find the right balance.

Keywords: Lakes in arid regions; Surface Energy Balance; Partitioning of Net Radiation; Role of Vegetation; Vertical Heat Flux; Sensible Heat Flux; latent Heat Flux

Introduction

It is understood that 72% of Earth's surface is covered with open water of which most of which is in the ocean. Sizeable amount of fresh water exists on the Earth's landsurface in the form of lakes, rivers and groundwater [1]. With the average age of Earth as long as 4 billion years, and the average solar energy flux (~250-280 W/m^2) reaching the landsurface for such long time spans, it is plausible that the magnitude of evaporation should have far exceed the rate of condensation making the Earth an arid planet over the lifetime of the Earth. However, oceans and lakes still continue to exist on the Earth's surface. Inland lakes are still sustaining even under very dry conditions such as middle of Sahara Desert and places in Central

Asia and the Arabian Peninsula where the annual precipitation is very low and where the vegetation is almost scanty. This warrants a detailed thought on why such lakes exist in these very dry ecosystems where the evaporative demand of the atmosphere is too high. One common explanation is the availability of ground water via shallow aquifers that keep these lakes evergreen [2, 3]. But I would argue that under very long-time scales (many centuries), in very dry regions (where the annual precipitation is close to negligible), the supply of ground water will eventually decline, if the evapotranspiration mechanism operates in accordance with the atmospheric demand. The continued existence of these lakes in deserts and other semi-arid regions cannot be fully explained by the role of ground water supply from shallow aquifers. Although the characteristic feature of shallow aquifers maybe the seminal reason for the creation of such lakes in these dry regions, the continued existence of these lakes in these hyper arid contexts can be explained only based on the nature of surface energy balance and the relative abundance of vegetation.

Nature of the Surface Energy Balance Differences

The surface energy balance is the physical mechanism of how the total energy (SW and LW) is partitioned on a given surface [4, 5]. While the fundamental source of SW is the solar energy, the source of LW can be from any object (land surface, clouds of heated air) whose temperature is above the 0 Kelvin. The balance between the incoming and outgoing radiation (both SW and LW combined) is called the Net Radiation (Rn). Based on the reflective nature of a given surface (quantified by albedo) that determines the absorbed SW radiation, the magnitude of Rn is primarily determined because SW is much larger than LW in terms of magnitude. Because the albedo of an arid landsurface is much higher, a significant amount of incoming SW is reflected back, and the resultant Rn is relatively low. However, in the case of open water body such as lakes, the albedo is very low and most of the incident SW radiation is absorbed resulting in much higher Rn fluxes. In the case of vegetated land surfaces where the soil is slightly moist, the Rn is somewhere in the medium range (as the albedo is also in the medium range).

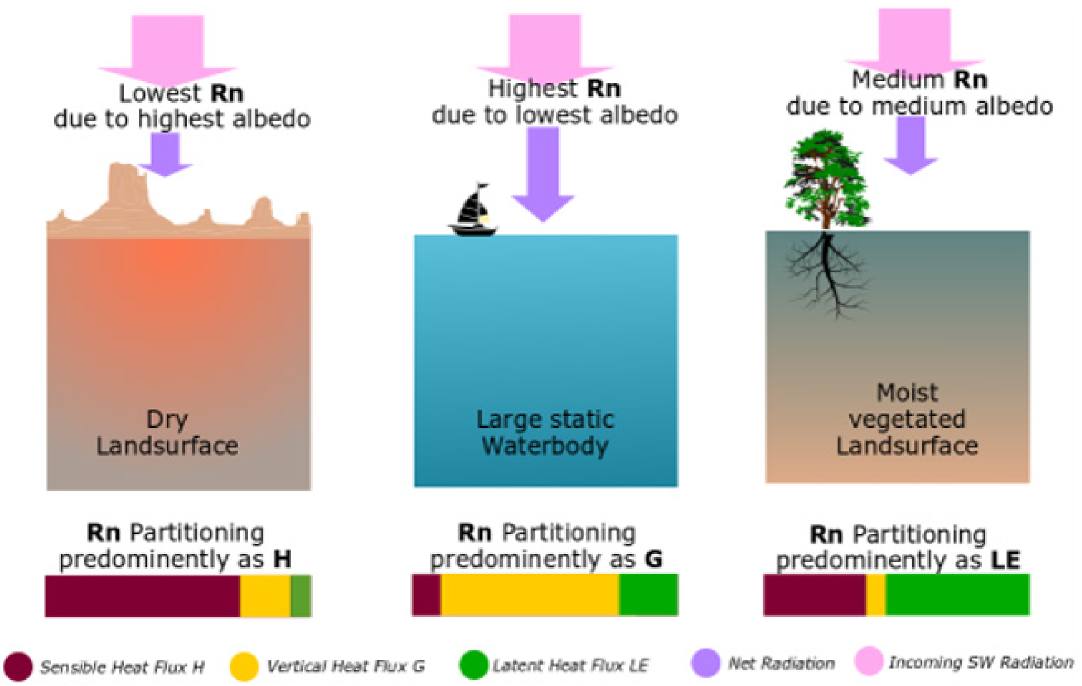

Figure 1: Mechanism of Surface Energy Balance and Partitioning of Net radiation in contrasting surfaces of the Earth's surface. This is the fundamental reason for the existence of lakes in arid regions. This is valid under conditions of zero advection effects.

The consequence of this landsurface-characteristic surface energy balance (and the resultant Rn) is used to perform three physical processes in the boundary layer of the atmosphere [6]. These three processes are: [1] Sensible Heat Flux (H), i.e. energy used to heat the air, [2] Latent Heat Flux (L), the energy used to change the phase of water from liquid water to gaseous water and [3] Vertical Heat Flux into the interacting medium (G). It is the G term that is hugely different on bare soil and water bodies. If the interacting medium is a bare soil, this G component is ground heat flux and if the surface is an open water body, it is the heat transmitted towards the deeper layers to heat the water column. On open water bodies, the net radiation is preferably partitioned into G rather than H and LE unlike a partially wet-land surface having vegetation where most of the energy is partitioned as LE or dry land surface (with no vegetation) where energy is primarily partitioned as H [7] . This difference in energy partitioning in different scenarios is primarily because of the following three reasons in acting together or alone. Firstly, the unique physical property of water with its high specific heat capacity and high latent heat of vaporization has a greater role. When energy interacts any given medium, the net energy is immediately used to raise the temperature of the interacting medium. If the medium is a dry landsurface having lower specific heat capacity, it quickly rises its temperature whereas if the medium is a water body having high heat capacity, it takes much more energy to make a temperature difference. In the case of dry land surface, as the surface get quickly heated related to the air immediately above, the air in the boundary layer becomes turbulent and thickness of boundary layer in arid landsurface is much larger than a water body. This warrants that a sizeable energy be fluxed as sensible heat thereby heating the air on a dry landsurface [8]. However, in the case of waterbody, such turbulent features are minimal, and the energy continues to be fluxed predominantly for heating the water column (though very slowly due to its very high specific heat capacity). These three mechanisms (H, LE and G) are valid under conditions of no advection (i.e. no influence of horizontal wind for energy alterations).

Vegetation as a Catalyst for Accelerating the Land surface Hydrological Cycle

The nature of the above-mentioned physical mechanism perturbs when vegetation comes to the picture [9, 10, 11]. When vegetation occurs on a given land surface, it implies that the soil is somewhat moist. Water existing in the soil matrix (consisting of liquid-gas interface) in the vadose zone are held by strong physical forces. This water is absorbed by the plants by their root system and carries it upwards to the plant canopy because of high suction developed in the canopy during the daytime. In this process, water is absorbed from a significant depth (depending on the root system) and eventually liberated via stomatal pores to the atmosphere. Most of the time deeper soil water that is transpired via vegetation is not directly in contact with the surface energy balance processes, instead they are made to move upward due to high suction developed in the vegetation canopy which derives its energy from the Rn. The pressure state of water in the soil is often below the atmospheric pressure and we often call it as “suction”. At such low pressures, the water is naturally having the tendency for a phase transformation and higher mobility according the Clausius-Clapeyron theory. The uniqueness of vegetation-mediated biosphere-atmosphere water flux is the volume of soil covered by the root systems of the vegetation whose “sucking potential” is governed by the leaves on the canopy. The amount of water stored in the volume of soil column is much higher than the surface, even if the soil moisture content is low. For example, a loamy soil volume (porocity ~50%), having an average volumetric water content of 0.25 that is integrated by a root system as deep as 1m, the total amount of water available for transpiration is as much as 125mm. On bare soil surface (even if it is wet) The resultant effect is that most of the Rn in vegetated landsurface is channelized via LE rather than H or G.

Figure 2: The “reed diffuser” analogy of vegetated landsurfaces where the vegetation via their root-shoot-leaves system accelerate the hydrological cycle by enhanced evapotranspiration flux. Thus, it is postulated that for a given meteorological condition, the evapotranspiration is much higher on vegetated landsurfaces than from unvegetated water bodies such as lakes. In arid ecosystems, it is hence reasonable to store water in large tanks without much evapotranspiration loss as long as deep rooted vegetation remains scanty.

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Another important reason for higher LE fluxes in vegetated landsurface as opposed to open water body is its higher surface conductance as opposed to that of a lake. The surface conductance of water vapour (the ease with which a molecule of water can move between the biosphere and the atmosphere) is primarily controlled by two factors. [1] Aerodynamic conductance (which is implies the roughness of the surface) which governs how well a surface is "coupled" with the atmosphere and [2] Stomatal Conductance which is the physiological ease with which water molecules can pass from the biosphere to the atmosphere. The total conductance of a vegetated land surface is much higher than that of an open water body and is "less coupled" with the atmosphere [12, 13]. Consequently, LE on open water body is lower than a vegetated land surface. Thus, vegetation can be considered as a strong catalyst for mass-energy transport (as latent heat flux) between the biosphere and the atmosphere. I call it as a "reed diffuser" analogy. Vegetation acts as "reed diffusers" and facilitate the strong coupling of the biosphere and atmosphere for water transport, which otherwise is "decoupled" from the atmosphere. This means that that transpiration is the biggest contributor of ET than evaporation and the role of ET in terrestrial hydrology is well known. Thus, vegetation has a greater role in terrestrial hydrology than what it is currently perceived and a land surface without vegetation has very less ET contribution even if it is wet and receives adequate energy and the atmospheric demand is high (similar to ocean surfaces).

We have discussed that vegetation plays a great role in accelerating the hydrological cycle on the Earth's landsurface by facilitating an enhanced latent heat flux via the evapotranspiration process even more than that of an open water body where the energy is mainly used to heat the water column. Thus, in my opinion, evapotranspiration-based water loss from open water bodies (lakes and reservoirs) is not significantly higher than that of a scenario where the landscape is vegetated. This postulate is valid under conditions of zero-advection (no horizontal wind). However, if there are vegetation present at the edges of these lakes and reservoirs, evapotranspiration losses will be significant. Thus, in arid and semi-arid contexts, we should be

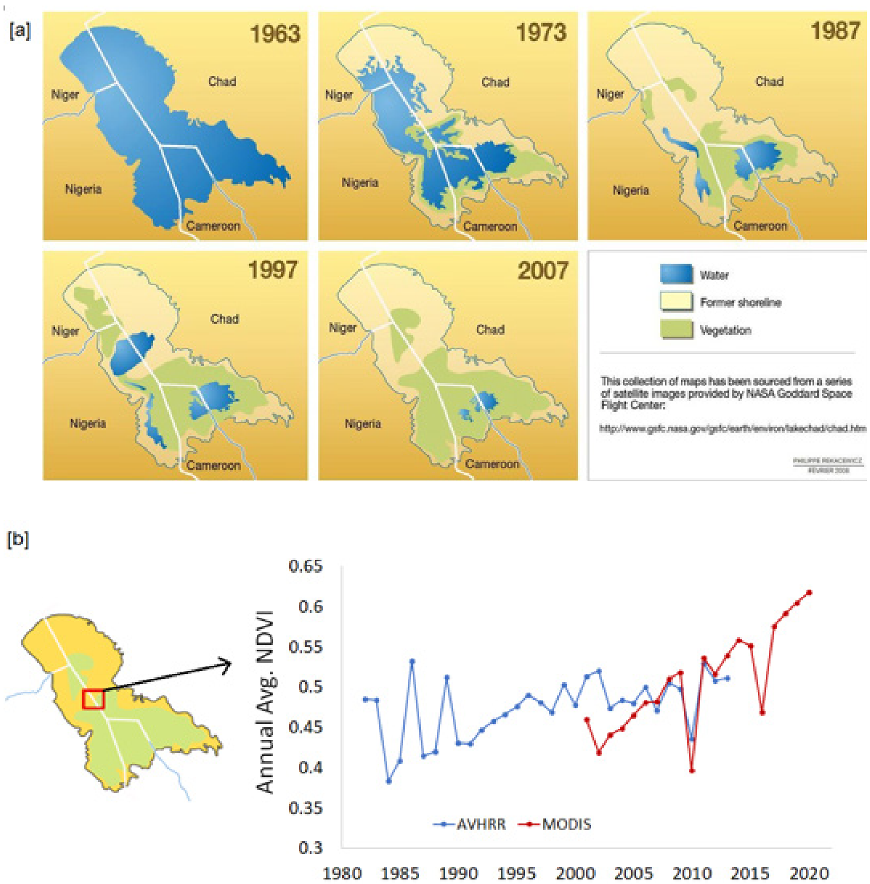

Figure 3(A): An illustration of the role of vegetation proliferation that accelerates the drying of a water body (Lake Chad) under a changing climate. This illustration supports the thought presented in this paper. This illustration was prepared by Philippe Rekacewicz, February 2006 and accessed from https://www.grida.no/resources/5593

(B) Long-term interannual variability of the annual average NDVI (indicating vegetation proliferation) at a location that was dried up in the Lake Chad (red box in the inset map), as obtained from AVHRR and MODIS.

careful about introducing vegetation around lakes and reservoirs if water conservation is a priority issue. This is particularly applicable in oasis-based crop cultivation in desertic area. As pressure on food production is increasing and as oasis agriculture is also getting prominence in desert context, irrigated oasis agriculture is proliferating. Excessive increase of irrigated cultivation in the desert will rapidly decline oasis beyond recovery. Thus, policies have to be in place to regulate sustainability of oasis. International alliances such as the Sustainable Oases Initiative (SOI) to safeguard, protect and develop oases ecosystems that as launched by the government of Morocco during the COP22 in Marrakech in 2016 have to seriously consider this aspect while making guidelines on oasis sustainability [14]. Under the SOI, the aspiration is to have a better recognition of the oases ecosystems and their unique vulnerable nature and implementation of concrete action plans to protect the oases heritage in terms of biodiversity and livelihood. In doing these, we have to have guidelines on how much greener we make an oasis by enhancing its vegetation enhancement has to be carefully considered in terms of its long term sustainability. A similar topic is the death of big lakes in the arid regions and its links to increased vegetation proliferation vis-à-vis lake water level declining due to anthropogenic reasons (crop cultivation nearby) or climate change (lack of precipitation and hence the decline of lateral water fluxes that feeds these lakes). This role of vegetation evident from an multi temporal satellite data analysis of Lake Chad that the shrinkage of the Lake Chad is correlated with an enhanced vegetation abundance on the edges as the water dries due to upstream crop cultivation that is accelerated with climate change. This also may be related to enhanced nutrient fluxes from the nearby areas. The enhanced vegetation (and the associated ET losses) by almost 30% [15] during the last two decades might have accelerated the rapid drying process in the arid climate in Sahara. Similar situation might explain the rapid death of Aral Sea in the Uzbekistan-Kazakhstan border. The decline of water from the rivers (due to enhanced use for irrigation of cotton fields upstream) reduced the influx of water in the Aral Sea. The proliferation of small salt tolerant wild vegetation along the edges of the lake might have accelerated the drying process in the recent years under a changing climate that exacerbated the process [16, 17, 18].

If recreation and parks development is a priority around the edges of large water bodies in arid and semi-arid contexts, it is important that we introduce vegetation with shallow root systems such that LE fluxes are minimized. Similarly, we also need to think carefully while doing large projects such as urban greening or planting trees in naturally arid regions to create a nice microclimate. The establishment of such tree saplings in the initial phases can be assured only if there is an abundant source of irrigation because of high latent heat fluxes that can quickly deplete the naturally existing soil moisture.

Conclusion

Vegetation significantly accelerates the hydrological cycle on Earth's land surface by facilitating enhanced latent heat flux via the evapotranspiration process. While evapotranspiration-based water loss from open water bodies is not significantly higher than in a vegetated landscape, significant losses can occur at the edges of lakes and reservoirs. In arid and semi-arid contexts, it is crucial to be cautious when introducing vegetation around lakes and reservoirs for water conservation. This is particularly relevant in desertic areas where irrigated agriculture is proliferating, leading to rapid decline of oasis ecosystems. Policies like the Sustainable Oases Initiative (SOI) should consider this aspect when implementing projects to protect oases' biodiversity and livelihood. The death of big lakes in arid regions may be correlated to increased vegetation proliferation due to anthropogenic or climate change factors. To ensure long-term sustainability, recreation and parks development should prioritize vegetation with shallow root systems and consider large projects like urban greening or tree planting in naturally arid regions.

Acknowledgement

None.

Conflict of interests

No Conflict of Interest.

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