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Research papers and articles

Current Contributions on Cork Production and the Fight Against Forest Decline in Andalusia (Southern Spain)

Vicente Jurado Doña, María Socorro Serrano Moral, Fernando Díaz del Olmo & Rafael Cámara Artigas

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ABSTRACT

This paper provides an updated analysis of cork production and its relationship to forest decline in Andalusia, southern Spain. It examines the ecological, economic, and environmental importance of cork oak forests, while evaluating the impacts of climate change, prolonged drought, wildfires, and pathogens on productivity. Based on literature reviews, historical archives, and cork extraction data from 1998 to 2023, the study identifies a sustained decrease in yields, highlighting a moderate correlation between environmental stress factors and the decline in production, indicating that socioeconomic factors modulate cork extraction and trade. Results underscore the urgent need for innovative management strategies, ecological restoration, and international cooperation to safeguard these Mediterranean ecosystems and their socio-economic benefits.

Keywords: cork oak, *ouercus suber*, forest decline, cork production, mediterranean ecosystems.

Classification: LCC Code: SD387.C67, SD146, GE170

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RESUMEN

Este artículo ofrece un análisis actualizado de la producción de corcho y su relación con el decaimiento forestal en Andalucía, sur de España. Examina la importancia ecológica, económica y ambiental de los alcornocales, a la vez que evalúa el impacto del cambio climático, la sequía prolongada, los incendios forestales y los patógenos en la productividad de este ecosistema mediterráneo tan singular. Basándose en revisiones bibliográficas, archivos históricos y datos de extracción de corcho de 1998 a 2023, el estudio identifica una disminución sostenida de la producción, destacando una moderada correlación entre los factores de estrés ambiental y el declive de la producción lo que indica que hay factores socioeconómicos adicionales que modulan la extracción y el comercio del corcho. Los resultados subrayan la urgente necesidad de estrategias de gestión innovadoras, restauración ecológica y cooperación internacional para salvaguardar estos ecosistemas mediterráneos y sus beneficios socioeconómicos.

Palabras clave: alcornoque, *quercus suber*, decaimiento forestal, producción de corcho, ecosistemas mediterráneos.

I. INTRODUCTION

European forests constitute one of Europe's most important renewable natural resources, occupying more than 43.5% of the EU's land area and generating a vast array of ecological, economic, and environmental functions, making them essential for the health and well-being of European citizens

(European Commission, 2021). Sustainable forest management is key tools for sustainably maintaining this multiplicity of functions, which are also demanded by an increasingly environmentally conscious European citizenry.

There is no Community forestry policy as such, but a series of forestry implementation measures are included in the current CAP (2023-2027) related to forest fires, reforestation, and species conservation. Some Directorates-General of the European Commission generate Directives and Regulations that affect and modulate the forestry sector itself, which accounts for an average of approximately 2.5% of EU GDP (European Commission, 2021). It should be noted that the forestry sector in a broad sense, including livestock activities related to forest uses, constitutes an important source of employment throughout Europe and tends to diversify over time.

Much of the Iberian Peninsula, including part of Portugal, is subject to the Mediterranean climate, whose environmental constraints (mainly the limited availability of water during the period of highest temperatures) prevent the high profitability of forest products. The forest landscape It is characterized by a great diversity due to different ecological, edaphic and tectonic factors (Quézel, 1985; Ibáñez et. al., 1997; Blondel et al., 2010) including the variety of land uses that have been exploited for millennia by human communities. The configuration of the current Mediterranean landscape derives from the dynamics of the plant communities themselves, from biotic interactions as well as from climatic influence (abrupt climate changes during the last 1.8 million years) and from human activities in the organization of the territory. Intense disturbances such as grazing, fire and scrub clearing have led to evolutionary adaptations in relation to the regeneration capacity of Mediterranean species (Pons and Quézel, 1985; Ibañez et. al., 1997; Pausas & Keeley, 2009).

In the Mediterranean Basin, human activities in the territory (at least during the last millennia) together with the movement of livestock and the use of fire have constituted a potential agent transforming the composition and cover of Mediterranean vegetation (García Novo, 1984; Blondel and Aronson, 1995; Valladares et. al., 2004; Blondel et al., 2010). The forest history of much of the territories of the Iberian Peninsula differs little from other Mediterranean countries such as Italy or Greece (MaB , 1977).

Slow-growing species (holm oaks, cork oaks, gall oaks, junipers, etc.) native to the Mediterranean Basin do not usually offer very high economic returns compared to other European forest species. However, they do generate other non-timber resources of great importance for maintaining populations in rural areas, such as cork, pastures and livestock, honey from beehives, mushrooms, and hunting. Maintaining these Mediterranean ecosystems, well adapted to the climate and soil, also has clear positive impacts on the physical environment, human health, and socioeconomic structures. The Mediterranean Basin is considered a hotspot for climate change due to the decrease in precipitation and the expected increasing occurrence of extreme events (Giorgi and Lionello, 2008; Costa et al., 2020). However, in the case of the Iberian Peninsula, the scenarios predicted by climate change are expected to have a serious impact on the dynamics of forest ecosystems (especially in the center and south of the Peninsula) and a probable increase in the intensity and severity of forest fires in the natural environment with all the enormous associated economic and social losses.

One of the objectives of this article is to present an updated overview of the cork oak forest, a plant formation characteristic of the western Mediterranean Basin that offers notable ecological and economic value. It also analyzes the cork sector in Andalusia in general and in the Los Alcornocales Natural Park in particular and attempts to correlate the loss of this resource with tree death (forest decline) due to both biotic factors (presence of pathogenic microorganisms in the soil, attack by defoliating insects) and abiotic factors such as prolonged droughts in relation to climate change and socioeconomic crises.

II. METHODOLOGY

We have basically used one approach: obtaining theoretical information from research articles and reports on cork oak forests and cork in Andalusia (from the last 25-30 years). In addition, we reviewed data from various archives dating back to the mid-20th century and consulted the Annual Reports on Resource Management of the Los Alcornocales Natural Park since its establishment in 1990. We focused on the period 1985-2015 because we had a long series of data (30 years) at the local level on several climatological factors that we believe are important in cork production. Specific climatological data for certain towns are difficult to obtain because automated weather stations are unavailable. Finally, we organized and analyzed cork extraction data in Andalusia for the period 1998-2023, a sufficient time window to understand the cork production process and the current difficulties it faces. The statistical analysis and graphs were produced using Python, a programming language with artificial intelligence capabilities for data analysis.

Study area

The Aljibe and Campo de Gibraltar mountain ranges

Under the prism of the repercussions of current Climate Change, which is causing long periods of drought and intense heat waves like the one that much of Europe is experiencing this summer of 2025,we have focused on the province of Cádiz (southern Spain), where there are areas largely dominated by a mixture of *Quercus* species, mainly holm oaks (*Quercus rotundifolia*) and cork oaks (*Quercus suber*), forming pure stands and/or mixed with conifers and subject to a greater or lesser extent to a process of forest decline that has not yet been well evaluated scientifically.

The Aljibe and Campo de Gibraltar mountain ranges cover a large part of the province of Cádiz and part of the border area of the province of Málaga. They are protected as the Los Alcornocales Natural Park, with an area of 1,750 km2 (Figure 1). From a geological perspective, the Los Alcornocales Natural Park consists of a group of mountain ranges consisting primarily of the so-called Aljibe sandstones, of Oligocene-Miocene age, resting on clayey materials. The geological structure is complex, and these mountain ranges constitute rugged reliefs with steep slopes (despite not exceeding 1,092 meters in altitude), giving the area a distinctly rugged feel that stands out from the surrounding gentle hills and plains. The resulting soils are acidic and poor in nutrients, acting as a limiting factor for plant formations.

This extensive rural area is located in the Campo de Gibraltar region, just 14 km from the African continent. It has high rainfall (1,000–1,300 l/m2) and great soil and biological diversity (Marañón et al., 1999) with a dense forest appearance quite distinct from the rest of the dehesa landscapes of Andalusia. Here, cork oak forests are the predominant forest formation, covering over 72,000 ha (720 km2), making it the most important vegetation formation of this species in Europe and, along with the Mamora Forest in Morocco, in the world (Figure 2).
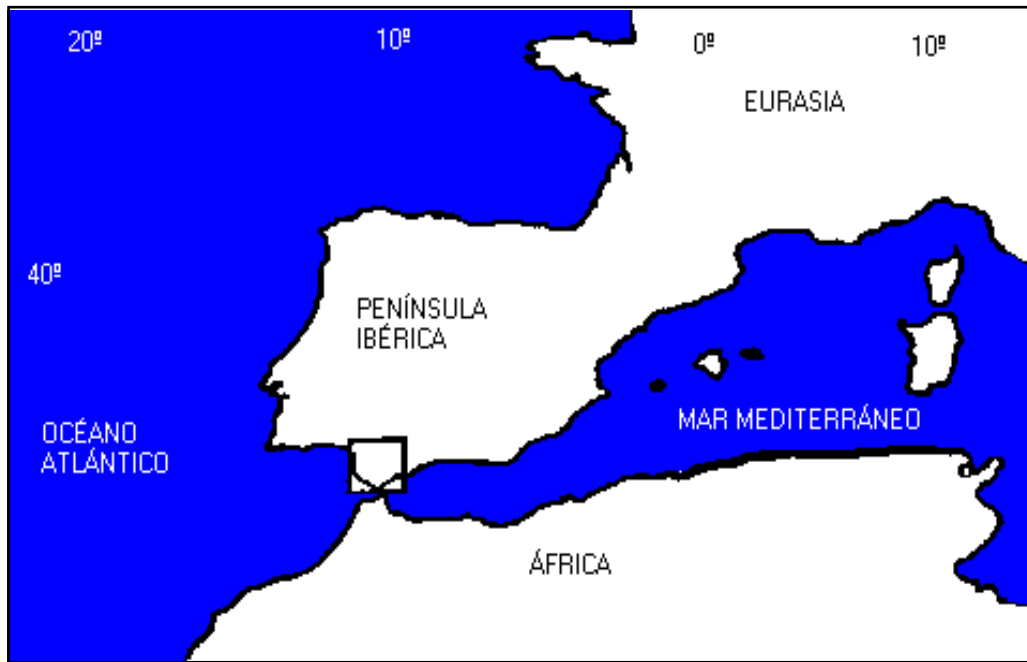
Fig. 1: General location map of the Sierras del Aljibe and Campo de Gibraltar (next to the Strait of Gibraltar, Andalusia, Spain).

Fig. 2: Panoramic view of the Sierras del Aljibe and Campo de Gibraltar where cork oaks (*Quercus suber*) predominate.

The cork oak forest as a forest community

The cork oak forest is a highly humanized Mediterranean ecosystem whose wise exploitation has allowed for centuries the maintenance of rural economies closely dependent on forest resources. The predominant tree is the cork oak (*Quercus suber*) which belongs to the *Fagaceae* family , which is an important family of hardwood trees and some shrubs, widespread in both temperate and tropical regions. This family also includes the holm oak (*Quercus rotundifolia*), oaks (*Quercus* sp .), beeches (*Fagus sylvatica*) and chestnut trees (*Castanea sativa*). It comprises about 800 species grouped into 7 genera that have deciduous, evergreen or marcescent leaves.

The cork oak in Andalusia generally occurs mixed in masses with holm oaks and gall oaks (*Quercus faginea* and *Quercus canariensis*), but in the study area it usually forms notable monospecific stands and in humid enclaves it forms mixed forests with the Andalusian gall oak (*Quercus canariensis*). It is distributed exclusively in the western Mediterranean: Portugal, Spain, France, Italy, Morocco, Algeria and Tunisia (Pérez-Latorre et al., 1993). However, its wide potential range has been reduced in recent centuries, mainly due to human action: logging, extraction of tannins for the leather tanning industry and overgrazing (Jurado Doña, 2002; Kim et al., 2017). Along with the physical environmental factors (precipitation, temperature and soil), human intervention should also be considered as a limiting and determining factor in its current distribution (Jurado Doña, 2002, Figure 3). The ecological niche of the cork oak has been expanded at the expense of the Andalusian gall oak, which supports the evidence that humans have induced strong changes in the composition of *Quercus forests* in the Mediterranean basin (Urbieta et al., 2008).
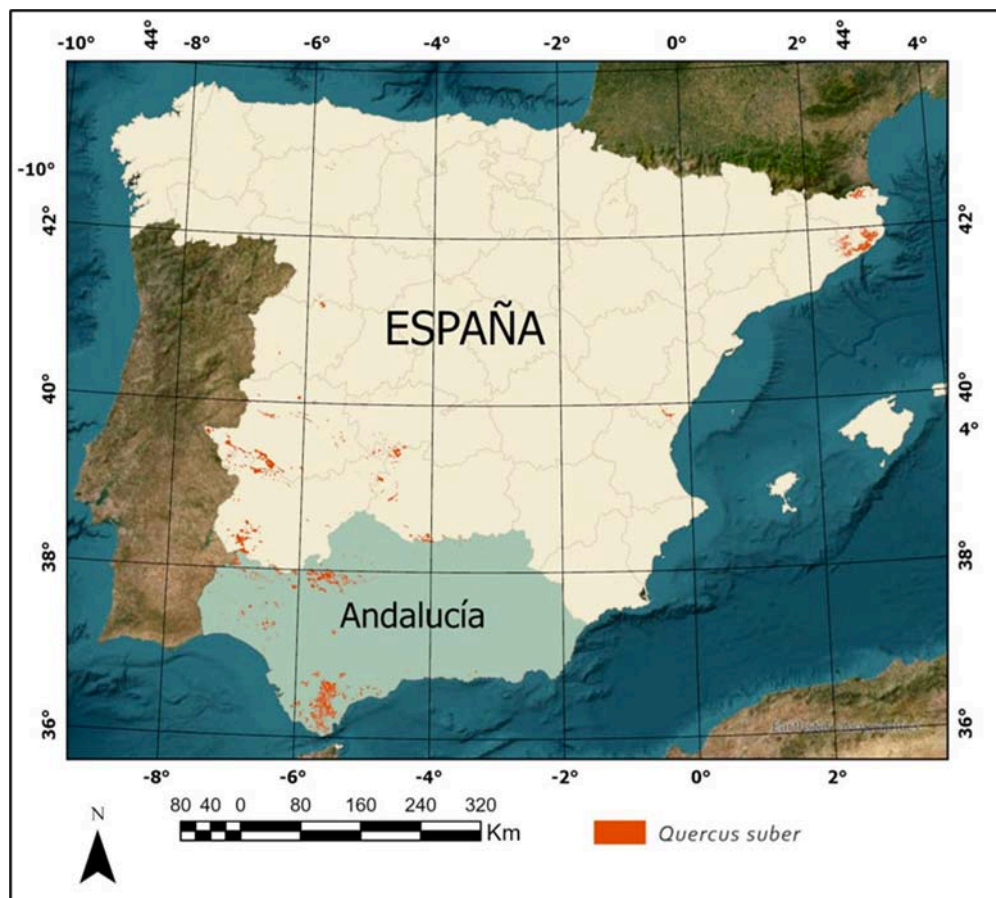
Fig. 3: Current distribution of the cork oak (*Quercus suber*) in Spain (in red).

At the end of the 20th century, cork oak forests occupied around 1,157,000 ha in the Iberian Peninsula, of which approximately 488,000 ha corresponded to Spain and 669,000 ha to Portugal. According to the II National Forest Inventory (1998), it would occupy 503,000 ha and currently covers an area of approximately 574,248 ha, after Portugal where there are 736,775 ha of cork oak forests.

The surface area of both countries represents nearly half of the world's estimated area of approximately 2.5 million hectares. This figure would represent only 28% of the 8.4 million hectares that cork oak forests appear to have reached in modern times, according to FAO data. Table 1 shows the cork oak forest area of the four largest countries in the world from 1956 to 1991. In the case of Andalusia, the area is estimated to be between 183,000 and 205,000 hectares, most of which is privately owned. In all these mountain ranges of the Los Alcornocales Natural Park, as in other areas of Andalusia, the main body of cork oak forest has been dedicated primarily to the extraction of cork . This logging, carried out every 9-10 years, has modified the natural forest, favoring the cork oak to the detriment of other species (Jurado Doña, 2002).

Table 1: Evolution of the cork oak forest area between 1956 and 1991

COUNTRY	1956(1)	1964(1)	1971(1)	1989(2)	1991(3)
Portugal	800,000	740,000	600,000	669,000	750,000
Spain	500,000	330,000	330,000	488,000	500,000
Morocco	400,000	320,000	300,000	350,000	340,000
Algeria	440,000	440,000	200,000	-	410,000

Cork is a non-timber natural resource, characteristic of the Mediterranean forests of a significant part of the Iberian Peninsula, especially Andalusia, Extremadura, part of Catalonia and much of Portugal. It covers the trunk and branches of cork oaks and is made up of dead cells impregnated with suberin, a biopolymer that gives it high elasticity and low conductivity, giving the tree good resistance to
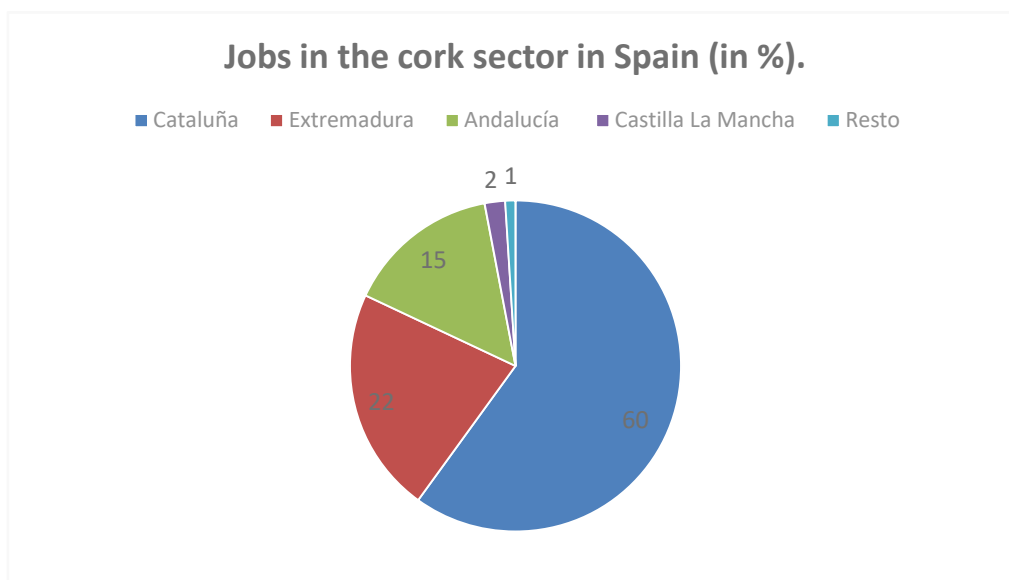
Fig. 4: Job creation in the cork sector at national level (2002-2003).
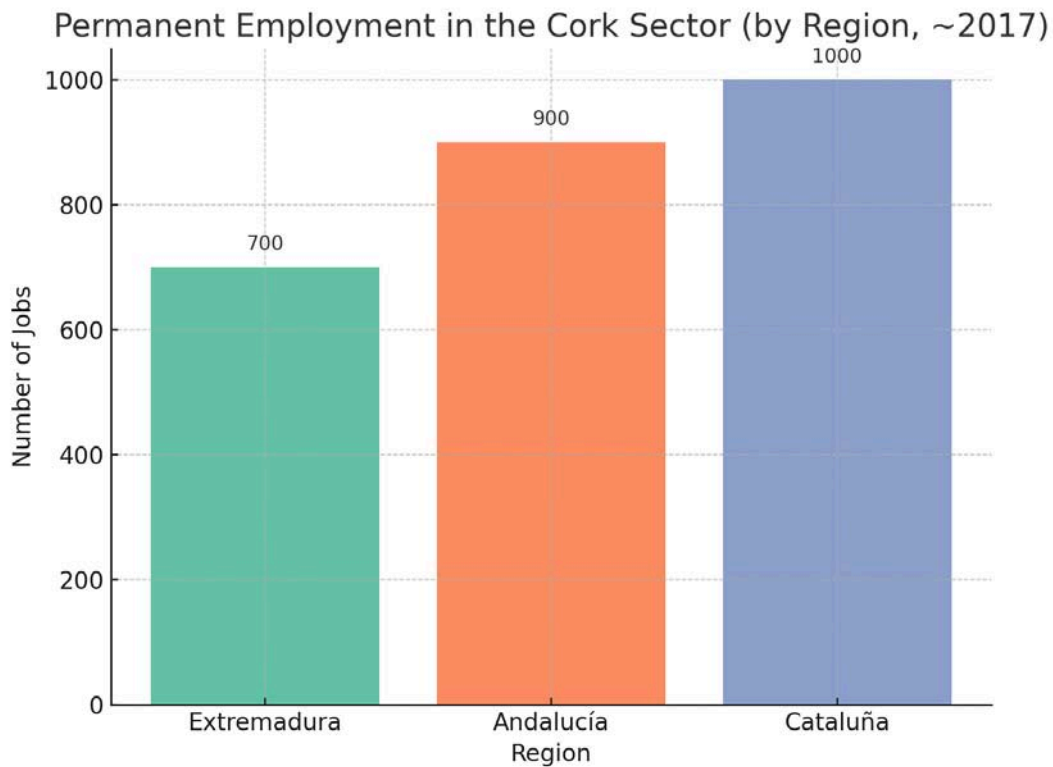
Figure 5: Permanent jobs in the cork sector in 2017.

forest fires and also partially protects it from fungal and insect attacks. The exploitation of these forests in Andalusia dates to the beginning of the 19th century, although it had already begun previously in Catalonia (NE Spain) and in France (Jurado Doña and Benítez, 2008).

Cork quality varies, even within a single geographic region, and is a very important aspect to produce good corks. Maintaining good prices for the product currently depends on the buoyant demand from the cork industry derived from the large production of sparkling wines (cava/champagne) and other quality wines, since no better substitute has been found for closing bottles, once the problem of TCA, which caused some organoleptic alterations in the wine, was resolved (TCA, or trichloroanisole, is a molecule that can contaminate wine and cause the well-known "cork flavor" or "cork taint and reduces its quality). The wine industry is a great ally for the permanence of this Mediterranean ecosystem.

The economic and social profitability of the cork oak forest has not, however, promoted its regeneration, demonstrating that the market alone does not allow the conservation of the resource but that it is necessary for public administrations (regional and national) to subsidize reforestation with cork oaks on public land and also on private property in common agreement with the owners.

Currently, global cork production is estimated at around 400,000 tons per year, of which Portugal accounts for around 50% and Spain for just over 20%. At the end of the 20th century, there were 285 cork processing companies in Spain, dedicated to the preparation of planks and agglomerates, which together processed between 60,000 and 80,000 tons of cork annually. Andalusia has 49% of the cork oak forest area, produces 56% of the raw material, but only houses 19% of the cork industries, which occupy 15% of the total jobs generated by this industry in Spain (2002-2003), although these data must be taken with caution because there is great volatility in terms of the cork industries and jobs, given that these small companies dedicated to the transformation of cork can suffer sudden changes due to

the current economic situation and the monopoly situation of some companies in Portugal specially Amorim.

The decline of the trees

The main forestry problems affecting cork oak and holm oak forests in much of Andalusia are the worrying lack of regeneration and the obvious degree of damage caused by the "Quercus drought," which has been causing tree death since at least the 1980s (both in groups and scattered trees). The holm oaks in the El Andévalo region of Huelva are currently severely affected. We have also seen tree death in southern Portugal, as well as damage to some shrub species.

The most important parasite that contributes to the development of this disease is the oomycete *Phytophthora cinnamoni* a species introduced into Europe probably from the Papua New Guinea-Celebes Islands and detected in Spain in the late 1980s (Brasier et al., 1993; Sánchez et al., 2002).

However, mortality due to "the Quercus drought" is not a new phenomenon (there are outbreaks in several Andalusian provinces, with varying degrees of affectation) but it appears and disappears and its evolution involves predisposing factors, which are permanent and gradually diminish the health and vigor of the trees (their old age, wounds and scars from bark stripping) and triggering factors such as forest fires, the attack of insect pests such as *Lymantria dispar* (Lepidoptera) and *Periclista andrei* (Hymenoptera) and climate change, which has been causing long periods of drought in recent decades, interspersed with short periods of waterlogged soil that encourage infections of tree roots by fungi and oomycetes, causing intense physiological imbalances in the trees and their death (de Sampaio et al., 2013; Serrano et al., 2021; Camarero et al., 2024; Jurado Doña et al., 2025).

Currently, data confirm that the pathogen *Phythopthora cinnamomi* It is spreading throughout both Portugal and Andalusia (Brasier et al., 1993; Tuset, 2004; Caetano et al., 2007; Gómez-Aparicio et al., 2012; Gutiérrez-Hernández et al., 2017) causing severe water stress in trees. The microorganism itself produces certain molecules called elicitins that evade the tree's defense system (Coelho et al., 2021). Along with the presence of various oomycetes in the soil, the disease is probably due to several interrelated factors, (Navarro Cerrillo, 2025) including the loss of tree vigor in previous centuries due to the ancient extraction of tannins, which is fatal to trees, and the extraction of cork in adverse weather conditions, which can damage the producing mother layer (Jurado Doña et al. 2022). Cork harvesting on *Quercus suber* trees leads to phellogen destruction and regeneration, but the relationship between harvesting intensities and tree resilience remains unclear (Oliveira and Costa, 2012).

The sometimes-sudden mortality of adult cork oaks and holm oaks will likely have a cascading impact on the plant and microbial communities in the soil and the implications for the regeneration of trees (Ávila et al., 2018) and will lead to a slow replacement of species such as cork oaks and holm oaks with more xerophilous ones such as wild olives and mastic trees. Furthermore, it is highly likely that the death of thousands of cork oaks in recent decades is compounded by a lack of recruitment of young individuals due to various factors, including the high herbivory pressure in the Park Natural (Rodríguez-Sánchez et al., 2018).

The accelerated loss of our cork oak and holm oak forests represents a major setback for the livestock farming associated with them and has serious far-reaching economic repercussions for the products associated with the dehesa and cork oak forests.
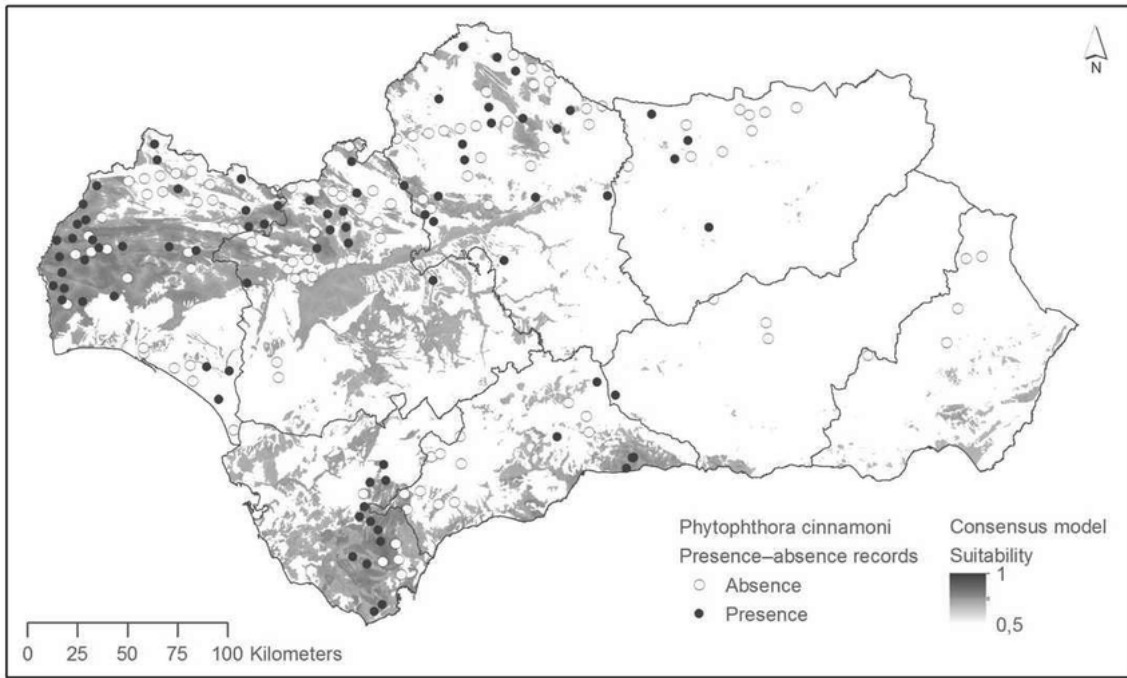
Figure 6: Presence-absence map of Phytophthora cinnamomi in Andalusia (Oliver-Hernández et al., 2017)

We cannot overlook the importance of forest ecosystems such as net carbon sinks and, therefore, their essential role in mitigating the rise of greenhouse gases at this crucial time in the fight against climate change. The Paris Agreement of December 2015, signed by 195 countries and the European Union, the first binding global climate agreement, expressly refers to the need to protect and enhance forests in line with their role in combating global warming.

Fig. 7: Stand of trees (*Quercus suber*) affected by drought in the Montes de Propios de Los Barrios (Cádiz) (top) and Tarifa (Cádiz) (bottom)

III. RESULTS AND DISCUSSION

Los Alcornocales Natural Park

In all these mountain ranges of the Los Alcornocales Natural Park, the main cork oak forest has been used primarily for cork production since the late 19th century. This logging carried out every 9–10 years, has modified the natural forest, promoting cork oaks to the detriment of other species such as Andalusian gall oaks (*Quercus canariensis)* (Jurado Doña, 2002; 2006; Urbieta et al., 2008).

In this study, we analyzed the relationship between annual cork production and certain climatic variables (average annual temperature, March precipitation, and total annual precipitation) in two very important cork-producing municipalities in Los Alcornocales Natural Park: Alcalá de los Gazules and Los Barrios. In the first municipality (Alcalá de los Gazules), the multiple regression model shows a statistically significant relationship (R^2 = 0.297, p = 0.0215): The average annual temperature shows a positive and significant correlation (p = 0.011), March precipitation presents a moderate negative correlation (p = 0.038), and the total annual precipitation is not significant (p = 0.320). For Los Barrios, the model is not significant (R^2 = 0.148, p = 0.221), and none of the climatic variables show statistical significance, the closest being March rainfall (p = 0.094). These results suggest greater sensitivity of production to climatic factors in Alcalá. In Los Barrios, other factors not included in this analysis could play a role.

We have also used the Thornthwaite method to estimate potential evapotranspiration (PET) and calculated an annual aridity index (precipitation / PET) for each municipality and year. Including the aridity index in the regression models improved explanatory power slightly:

- In Alcalá, R^2 increased from 0.297 to 0.334. The model remained significant (p = 0.027), although the aridity index itself was not statistically significant.
- In Los Barrios, R^2 increased from 0.148 to 0.239. While the overall model was still not statistically significant (p = 0.117), the aridity index came close to significance (p = 0.089). These results suggest that the aridity index may play a relevant role in cork production variability and deserve further investigation, especially in areas with more extreme climate patterns or limited water availability.

Our results show that for the chosen period (1985-2015) production has suffered significant fluctuations (graph 8). The observed decline in cork production correlates strongly with ecological

stress events, particularly drought and economic crisis. The aridity index and, ultimately, the limited availability of water during long periods of drought appear to play a moderately significant role not only in the physiological decline of trees (Allen et al., 2010; Gentilesca et al., 2017) but also in the loss of cork production (Jurado Doña et al., 2022).

These pressures weaken the trees, reduce growth rates, and increase susceptibility to pests. In turn, this has led to reduced bark quality and lower harvest volumes (Jurado Doña et al., 2018; Camarero et al., 2024).

These events appear to coincide with significant declines in production, suggesting a possible relationship between climatic and biotic factors and cork production. Added to this are the unique characteristics of the business process of selling and distributing the product (socioeconomic factors).
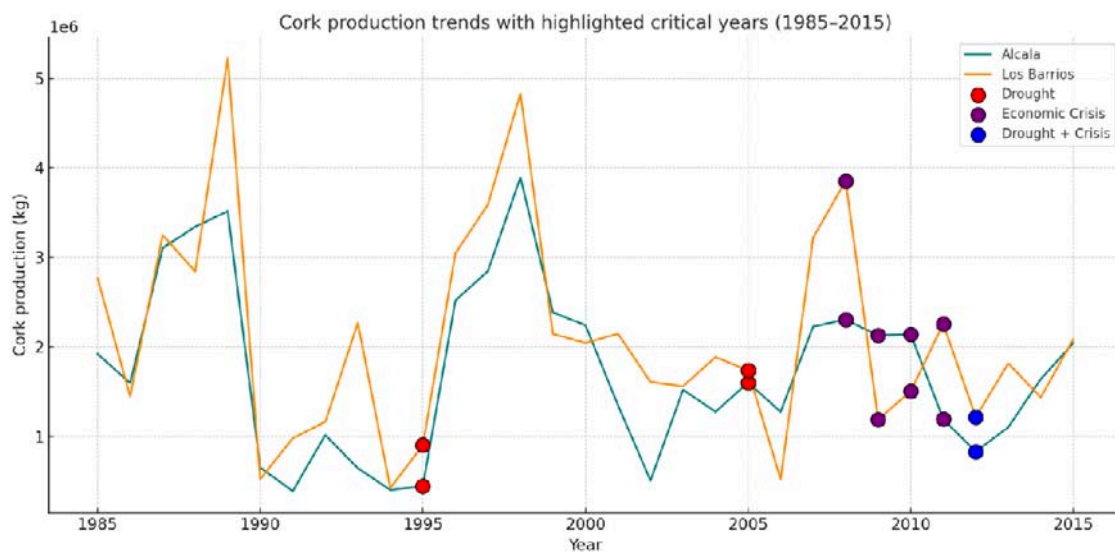
Figure 8: Relationship between cork production and specific events in two municipalities in Los Alcornocales Park for the period (1985-2015).

Andalusia

As seen in Figure 9, there is a downward trend in cork production in Andalusia, with years of decline likely due to the combined action of the aforementioned factors: prolonged drought, lack of vigor and tree death, and also commercial fluctuations.
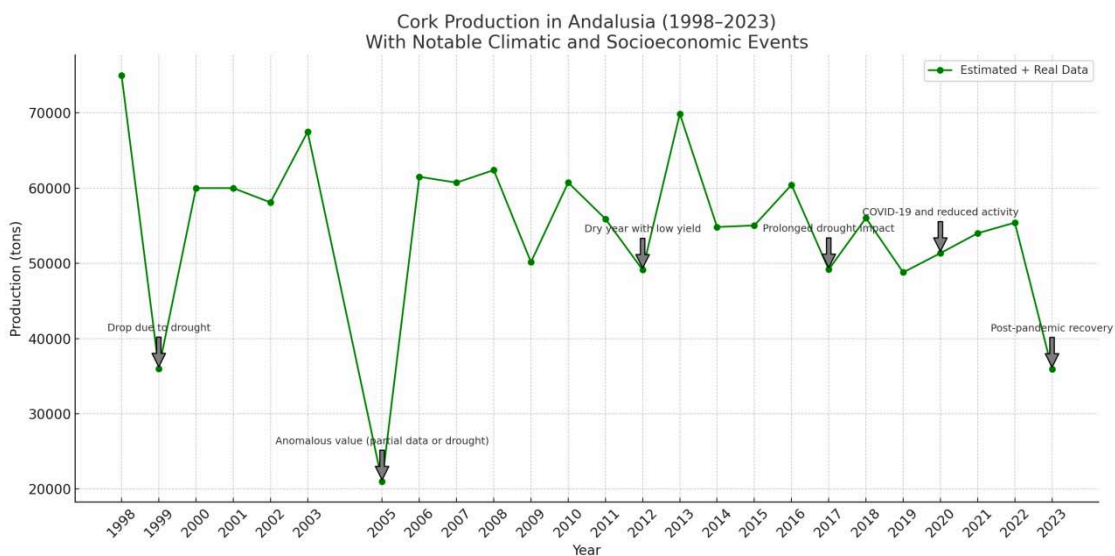
Figure 9: Correlation between cork production in Andalusia and certain biotic and socioeconomic events.

From 1998 to 2004, cork production in Andalusia remained relatively stable around 70,000–73,000 tons. Beginning in 2005, a steady decline became evident, falling to approximately 44,000 tons by 2023. This drop aligns with intensifying climate stress and biological threats to cork oak ecosystems. Recurring drought episodes, particularly in 2005 and 2022, resulted in significant water stress for cork oaks, reducing bark growth and increasing tree vulnerability.

Mass mortality events and weakening of cork oak populations have been documented due to a combination of drought and soil degradation, leading to loss of productive trees (2010, 2017 and 2021).

Outbreaks of pests such as the ambrosia beetle and defoliating caterpillars have become more frequent and intense, (2007, 2013 and 2018) often following drought years, damaging cork quality and tree health.

Large fires during these years caused direct loss of cork oak stands and long-term ecosystem disruption, particularly in areas of Cádiz, Huelva, and Málaga (2004, 2012 and 2022). The 2004 forest fire devastated more than 34,000 hectares in the provinces of Huelva and Seville and significantly affected cork and holm oak forests in several regions, causing a significant impact on cork production in small industries located in the area.

IV.   FINAL CONCLUSIONS

The cork sector is going through difficult times. The synergy of biotic and abiotic factors is very worrying and is seriously affecting part of the trees in the southern Iberian Peninsula. For all these reasons, we urgently need to implement a Plan to Combat Forest Decline that, using appropriate technologies and the most up-to-date ecological and forestry models, establishes an innovative work program that addresses the precise inventory of trees, the taking of soil samples in plots distributed throughout the selected areas, and establishes future lines of research. It is important to implement these measures in collaboration with citizen, scientific, and environmental associations, who are highly knowledgeable about territorial issues. The economic value of cork in some autonomous communities, such as Andalusia and Extremadura, as a natural product with a clear economic and social component should be highlighted. Other associated sources of income include livestock farming, honey,

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mushrooms, and hunting. Furthermore, cork oak forests perform various environmental services (protection against forest fires, control of soil erosion, safeguarding biodiversity, etc.) that cannot be ignored, acting as a shield against the undeniable advance of desertification. Cork production in Andalusia has suffered a sustained decline over the last two decades. This trend reflects increasing climate stress, insect damage, and forest degradation. Active forest management and ecological restoration are critical to reversing this decline and protecting the region's cork industry.

Finally, it seems advisable to interact and share the studies being carried out by universities and research centers, and ultimately, to launch joint actions between Spain and Portugal (and also other countries in the Mediterranean region such as Italy, France, and Turkey) to support and safeguard our Mediterranean forests and dehesas.

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How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

Dr. Vasyl Oryabko

ABSTRACT

Space is a material structure, a container of material objects densely enveloped in energy. The main function of space is to ensure the vitality of the Universe in the process of interaction of objects of matter on the basis of intellectual and informational support of its basis - objective reality. The task of the latter is ensuring the failure-free execution of all processes of interaction, what is the basis of the vitality of the space of the Universe as a whole. The existence and development of subjective reality on the basis of biological life on our planet is based precisely on the vitality of objective reality and the intellectual and informational properties of space. Subjective reality is the consciousness of the life process, which is created as a result of the total process of life as a whole throughout the entire period of its existence. The body in which the process of life of a certain individual takes place is a material shell of the primary vitality based on the vitality of objective reality. The main function of subjective reality of biological life is to create a product that goes beyond the capabilities of objective reality. The main function of subjective reality of biological life is to create a product that goes beyond the capabilities of objective reality. First of all, it is the process of creating and circulating specific biological energy resources that are provided by living organisms themselves or their foetuses in the form of food. This is necessary to ensure the viability and stable functioning of renewable bioenergy.

Keywords: space, substance & energy, vital capacity, consciousness, force interaction, work of energy, mathematical sequence.

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Space is a material structure, a container of material objects densely enveloped in energy. The main function of space is to ensure the vitality of the Universe in the process of interaction of objects of matter on the basis of intellectual and informational support of its basis - objective reality. The task of the latter is ensuring the failure-free execution of all processes of interaction, what is the basis of the vitality of the space of the Universe as a whole. The existence and development of subjective reality on the basis of biological life on our planet is based precisely on the vitality of objective reality and the intellectual and informational properties of space. Subjective reality is the consciousness of the life process, which is created as a result of the total process of life as a whole throughout the entire period of its existence. The body in which the process of life of a certain individual takes place is a material shell of the primary vitality based on the vitality of objective reality. The main function of subjective reality of biological life is to create a product that goes beyond the capabilities of objective reality. The main function of subjective reality of biological life is to create a product that goes beyond the capabilities of objective reality. First of all, it is the process of creating and circulating specific biological energy resources that are provided by living organisms themselves or their foetuses in the form of food. This is necessary to ensure the viability and stable functioning of renewable bioenergy. Nature itself, possessing all the prerequisites, cannot change itself, since it is not able to create the necessary conditions for this. Nature itself, possessing all the prerequisites, cannot change itself, since it is not able to create the necessary conditions for this. Nature is able to provide all the processes of creating and ensuring jet motion, but it is not able to create a jet engine. Due to this, the activity of subjective reality has radically changed the natural conditions on earth. The vital capacity of space, possessing an extremely high level of intelligence, is provided by the intellectual and informational capacity of objective reality, which is the basis of the subjective reality of the Universe. Extremely important in this context is the mathematical interpretation of energy transfer processes in space, which are mathematically described by a mathematical sequence with the performance of work. The method of mathematical analysis, which significantly expands the possibilities of mathematical interpretation of energy transfer processes, provides the opportunity of creating an universal formula for interaction in space.

Keywords: space, substance & energy, vital capacity, consciousness, force interaction, work of energy, mathematical sequence.

I.   INTRODUCTION

The problem of studying the concept of space in general, its physical content and philosophical essence occupies one of the leading places in the study of the environment, its nature and especially from the point of view of the place and role of human civilization and the existence of life. Despite the recognition of the concept of space as fundamentally important for understanding the philosophical essence of the Universe, the definition of the physical nature of space itself remains uncertain.

Hypothesis: *Whatever the size of the Universe, whatever its nature, it is space that is primary, since it is the container of everything, with the entire integral material world. Based on this, it is unacceptable to associate space with geometric volume. Nothing in the world can exist outside of space, since only space is the basis of the foundations of the existence of matter. This makes space a material substance in the form of a single energy body of the Universe, which consists of material objects, densely enveloped in an ocean of energy. Energy, due to its ability to act by means of force, is the main and only driver of interaction in space.*

There is no Universe, even an infinite one, that can be more infinite than space, since space itself is the container of the Universe, matter, including life. Therefore, space and the Universe are concepts that are correlated in size, physical nature and philosophical essence, and represent a single whole in the form of a united energy body of the space of the Universe. Space, being a highly intellectual structure guided by the laws of nature, ensures the execution of all processes at an exceptionally high intellectual and informational level. Nature in the form of an objective reality does not make mistakes. Due to this, all the laws of nature and processes in space occur unerringly in accordance with the cause-and-effect relationship, which is the fundamental basis and physical essence of the natural analogue of time. The measure of compliance of physical processes is the sequence of performing an action by force and performing the work that is the consequence. Chronometers and the time reference system, artificially created by humanity for its own use, practically do not affect events in space, especially outside our planet. Space successfully coped with all the problems on its own long before humanity created a system and tools for its reference. Nothing, even theoretically imaginable, can exist outside of space. Space is self-sufficient and, acting in accordance with the cause-and-effect relationship based on its own intelligence, creates all the conditions for effective functioning. It is space that is the repository of information about all processes, all events and their information support. including consciousness.

As a container of material objects, space is primarily a material structure capable of ensuring the existence and implementation of all processes of vitality occurring in its environment. Life is not something exceptionally special in the Universe, but is one of the forms of existence of matter. Therefore, space is a material structure with all the signs of vitality, the function of which is to maintain the level of intellectual and energy capabilities of life support at all levels of its existence. Signs of vital capacity are:

1. The presence of a high level of intelligence.

2. The presence of a high level of organization of interaction processes.

3. The ability to intellectually and physically communicate with the environment.

4. The ability to act as a basis for performing intellectual and physical work. The effectiveness of work performance.

So, space is a structure with vital capacity and a multi-level organization of the life support process. It also creates both a physical and social environment - connections, personal space and everything necessary to ensure this phenomenon. Biological life as one of the forms of existence of highly intelligent matter has been successfully working on our planet. for billions of years.

The main physical content of space is to ensure the interaction of individual objects of matter on a permanent basis. The interaction between them occurs exclusively with the help of Newton's force, which is the universal unit of the Universe. It is the force, combined into energy flows, creating pressure, that provides both energy and intellectual and informational support for all processes. The carriers of force are elementary particles of energy, which, interacting with each other, ensure the functionality of the viability of space.

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How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

18   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

In this context, the mathematical interpretation of the processes of space functioning is extremely important. Energy plays the main executive role in ensuring the implementation of all processes. Energy is a sequence of forces, the combination of which, when united in flows, creates pressure, thereby ensuring the performance of work. Mathematically, the process of energy transfer is expressed by mathematical sequences, with the help of which their subjective interpretation takes place.

II. PURPOSE AND OBJECTIVES

Throughout the existence of the Universe, all its processes occur in space according to their own laws, undoubtedly in accordance with the laws that are referred to in the scientific community as the laws of nature. This is absolutely obvious and, to a large extent, subject to observation, scientific analysis, and corresponding conclusions. But "Homo Sapiens", or representatives of other life forms with limited capability of their consciousness, are unable to comprehend the processes, let alone directly influence, taking place in space. That is why the philosophical essence of life itself, and even more so the vital capacity of space as a material unit with an extremely high level of intelligence, is questioned. Sometimes even completely denied. However, the existence of biological life in space, devoid of intelligence, would be impossible, primarily due to the impossibility of any communication. The body of a living organism is so complex that the secrets of its structure and functionality will probably never be understood by "Homo Sapiens". Nevertheless, it works surprisingly effectively, primarily thanks to communication with the environment. The subjective reality on Earth, created by biological life, has the exceptional ability to subjugate the extremely powerful intellect of objective reality, manipulating it to use its capabilities for its own purposes. This is extremely necessary for the creation of living conditions. Mathematical modelling is one of the powerful tools of communication. Their mathematical analysis is extremely important for facilitating the study of these processes.

The space of the Universe is a highly organized structure, therefore all processes in the Universe, as well as in space, occur at an extremely high organizational level. This indicates the presence of a powerful intellectual basis by means of which clear and unerring control of processes occurs. Despite the vastness of the spaces, there is not even a hint of chaos. Throughout the existence of the Universe, all its activity unerringly occurs according to its own laws, which in scientific circles are called the laws of nature. This is the work of consciousness of a high intellectual level. The external similarity to the automatism of processes indicates precisely their conscious implementation. The problem is that such technologies are not available to humans.

Matter exists in the form of objects of matter, connected to each other by intellectual, force connections, thus forming integral material objects of various sizes - from microscopic elementary particles to galactic formations of gigantic sizes. All material objects are in a state of constant force interaction between their individual objects, which is subjectively perceived by the senses and can be recorded by devices. Being objectively invisible, force interaction is perceived as a feeling of force in its various manifestations and the performance of work to change the state of the environment.

Space, thanks to its intellectual capabilities, supports a cause-and-effect relationship, which, being a natural analogue of time, is the primary basis of its functional ability. The functional ability of space is provided by force, the carrier of which is an elementary particle of energy.

The causal relationship is the fundamental basis of time - a theoretical and philosophical unit, which is widely practiced in the economic and everyday practice of human society. In objective reality - the reality of the objective functioning of all natural processes - time as a physical, actually existing structure does not exist. It is a chronological reference system, against the background of which both purely natural and socio-production processes occur. This system is extremely important in the activities of mankind. But it does not have any influence on the objective processes occurring in nature.

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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Humanity, as a result of its activities, has the ability to really influence the causal relationship in nature, since it is an active component of nature. But it does not have the opportunity to actually perform these processes, since all natural processes occur regardless of the will of man. Space is a perfectly balanced system. A human, like all living biological objects, is not the manager of even his own organism, even his own life. The vast majority of objectively existing processes in one's own body from conception to death occur in the vital interests of a person, but almost without his direct participation. A person can influence how the processes of breathing, digestion, conception and fetal development occur to a very limited extent, since all processes in the body are carried out on the basis of a cause-and-effect relationship, and not chronometers or his own will. A person can create, manufacture and use equipment, weapons of various powers, tying all this to the course of the created time tracking system, but the operation of a jet engine or the explosion of a nuclear charge will occur on the basis of a cause-and-effect relationship, without any influence on this process of the operation of chronometers.

In the scientific theory of relativity, time is closely related to the structure of space-time. But the theory of relativity itself is a mathematical interpretation of processes that have no real basis. The main drawback of this theory is that the speed of movement of 300,000 km/s does not exist in nature. This is a mathematical value of the speed of energy transfer by means of pressure force, these are completely different processes. The speed of movement of EC energy is only a few meters per second, which is emphasized by engineering studies.

The limited influence of chronometry makes the influence of time on objective natural processes even on our planet insignificant, compared to their course according to the cause-and-effect relationship. Outside the Earth, this influence is reduced to the very minimum, while the influence of the natural cause-and-effect process plays one of the decisive roles in the activity of the space of the Universe as a whole. Space is an extremely complex machine, for the control of which the cause-and-effect relationship is of the utmost importance. All interaction processes in it occur on a constant basis. As a result, the cause of the next process inevitably arises, which is a consequence of the previous one, which is signalled by a decrease or increase in pressure indicators in the interaction zone. The reaction is unambiguous and irreversible. Pressure directs its action there or there, the effective value of which is always the magnitude of the dynamic force, since the system is always directed to a state of equilibrium. Thus, causality can be modelled as an information-theoretic model. The presence of a cause necessarily leads to a consequence in the form of work performed. In objective reality, only one cause with one effect can occur in a process. The continuation of the interaction is a completely different process, the cause of which can be the effect of the previous one. This excludes the possibility of chaos in objective reality. The action in the process of interaction is always directed in the direction of the force vector. The multidirectional movement of individual material particles is caused by the action of individual forces, each of which performs only its work. A set of unidirectional forces is combined into energy flows, creating pressure, which most often occurs in nature. Multidirectional movement cannot be interpreted as chaos, because this is a process of interaction. In subjective reality, there may be a multitude of causes without any consequence. Especially since the consequence may appear to be obvious falsification and manipulation of facts.

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

20   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

Picture 1: Alive Space

However, in the practice of subjective reality, time plays an extremely important role. Therefore, it is extremely important to deepen the study of subjective reality and its difference from the properties of objective reality. These are different forms of life ability, which in many cases are closely intertwined.

Control over the activity of processes in space is carried out using a force that induces action, and as a result of the work performed according to formula 1. (1)

$$W = Fl \tag{1}$$

Where: W- work done, F – available amount and direction of force action, ℓ- modulus of the magnitude of displacement.

Time has no physical basis and can in some hypothetical way exist only at a certain moment of the action performed exclusively in the process of the cause-and-effect relationship. While the past and the future have meaning exclusively in the subjective reality of the existence of humanity. The action of objective natural processes occurs on the basis of the cause as a set of many natural factors, force and its intellectual support for performing the work of committing the action. All these processes occur outside the will of man without any influence of chronometers and depend solely on the energy and force balance supported by force. It is the presence of the amount and direction of the force that dictates the course and sequence of work at each point in the Universe.

The environment of existence of matter is space, a sample of which is shown in Fig. 1. Space is a living, constantly operating organism of colossal size, which consists of material bodies of various sizes, energy states and configurations. All material bodies are enveloped in a dense energy shell that provides control of all processes occurring on the basis of the laws of nature, as well as ensuring their interaction with each other at a high intellectual and organizational level of all components. The area of space illustrated in Fig. 1 clearly demonstrates the close relationship between all its segments. It is quite obvious that there are no boundaries between individual structural units of the Universe, such as galaxies, subgalaxies, individual star systems, up to an individual cosmic dust particle the size of a molecule or atom. This clear and comprehensive interaction is provided by a holistic

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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Volume 25 | Issue 11 | Compilation 1.0
21

material-energy-information complex operating at an extremely high intellectual level, which includes ensuring the interaction of all real components existing in nature. An example is the television-radio communication that has been going on for decades between artificially created by the genius of mankind spacecraft such as Voyager and control systems on Earth. Compared to the size of the illustrated area of space in which the device is located, the size of the spacecraft is more than insignificantly small. But the colossal and amazing perfection of the activity of space allows us to see these devices, communicate with them and receive perfect information about the state of the environment around them. The only information source that can exist there is space. Thus, "Homo Sapiens", thanks to their own intellectual genius, have already created and are increasing the possibilities of direct communication with nature. This became possible thanks to the creation of an algorithm for communicating with space, and the creation on this basis of an intermediary - artificial intelligence. A Human has an exceptional ability to communicate with the intelligence of space directly, but such opportunities are quite limited.

The basis, the foundation of the vital ability of space is Objective Reality, which is manifested in the vital activity of the so-called inanimate nature. But it is precisely Objective Reality that is the carrier of the most powerful intellectual and informational complex of the Universe, the complex of laws of nature to which everything is subject, which make for some reason it to be the most alive structure. The pinnacle of the vital essence of space is Subjective Reality (Oryabko V 2025), created in the process of vital activity of biological life. However, it should be especially emphasized that subjective reality, being the pinnacle of the perfection of the Universe, was created in the information space of objective nature and is the part of it and in some aspect's user the manager of this intelligence.

A phenomenal property of Objective Reality is its complete subordination to the will of Subjective Reality. It is well known how flawlessly and precisely automated systems created by human labour work. This is explained by the fact that in the life hierarchy of space, objective reality is the executor of the will of the Summit of Subjective Reality of the Universe. That is why subjective reality performs the administrative and command function of managing all processes of the Universe. Objective reality, on the other hand, performs all executive functions with surprising accuracy and perfection to ensure the life process of the Unified Energy Body of the space of the Universe. Therefore, it is unacceptable to separate biological life from the living space of the Universe, since biological life is only one part of life as a whole and is entirely based on the laws of objective reality.

Space is capable of self-improvement and learning through the acquisition of its own experience. This is based on the vital capacity of vital components, which is simply amazing. An atom of a trace element of calcium or magnesium in its natural state has certain physical and chemical properties. However, getting into the body of a biological organism, passing through the digestive and selection system, each component undergoes a process of adaptation to the conditions of the part of the body to which it is sent, because the functions that the calcium or magnesium atom will perform as part of a living organ, in DNA or RNA cells will be completely different from the functions of the natural state. A living, even the simplest organism, is an informational-intellectual complex of an extremely high intellectual level. Therefore, it is extremely necessary for it to have a specific energy and material support of biological origin, that is, previously trained. Getting into the body, these natural components undergo a specific learning process, which is manifested by the pumping of information, knowledge and experience about the functional duties that must be performed in interaction with all components of the body. On average, it is usually considered normal for the process of adaptation and learning to last 12-15 days. It is extremely necessary for living organisms in this sense to replenish biological resources to support biological life at the expense of food components of biological origin. This is precisely because that kind of food is the high degree of intellectual saturation. Simple material food and energy from natural sources of the environment cannot satisfy the needs of biological life.

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

22   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

If the learning process is imperfect, it manifests itself in the body as diseases of the so-called allergic nature. With more significant deficiencies, an information failure occurs, which is accompanied by the development of foreign cancer cells. Therefore, it is obvious that each atom has information about the interaction with all components of the body. All this information is analysed, converted and transmitted by biological energy generated in the body of the organism. This energy is extremely specific and information-rich and is extremely different from an ordinary electrical or thermal energy in nature. It differs precisely in the information component, although it often uses the same primary sources.

A Human can see its own movements, controls the course of his thoughts and actions, completely not possessing the technologies of these processes. The process of its own life is not at all subject to a human, because the life is a level of intelligence that is unattainable for human understanding. Therefore, the body lives by itself, and the life of this body simply uses its services, without even having an idea of everything that happens in it. The body itself is a combination and cooperation of the lives of a huge number of individual living organisms that are closely interconnected and coordinated by a single control system.

Therefore, biological life, which is the basis of subjective reality on our planet, is entirely based on the vital capacity of objective reality, or the intellectual and informational basis of the so-called inanimate nature. As already noted, the vital capacity of biological life is created by two life-giving factors. This is a material shell that, in the form of a body, provides the functionality of the vital capacity of a biological organism, and the process of the life itself as an element of subjective reality. It is in the functional abilities of the body that the basis of the vital capacity lies. There is no doubt about the obvious fact that all processes in the body occur on the basis of the laws of nature. The body consists entirely of material components of natural origin, the individual organs of which are united by neurons and connected by material systems of communication and interaction. After death, the body degrades to its natural state, and the process of life self-destructs.

No matter how perfect the technological processes developed by human genius are, no matter how powerful the scientific and technological capabilities of their developments are, the direct execution of the processes themselves will always be exclusively the skill and genius of nature. Humans are able to control processes, create technologies, technological processes, but it is precisely the processes of boiling water or melting metal that are subject exclusively to the genius of nature. That is why the direct execution of the process of functioning of the body of the organism itself will always be performed by nature its own intellect. And a human was, is and will be ever a user. In this regard, it would be interesting to compare the intelligence of nature in the body of a human organism with the mental abilities or intellectual capacity of consciousness of one mentally developed individual. Obviously, that all information that a human has learned in its entire life could be placed on the single modern medium-capacity flash drive.

If it were possible to describe all the information about the process of life of one person on electronic media, then without a doubt all the means that exist at the disposal of mankind in our time would not be enough. That is why the intellectual ability of human consciousness in comparison with the mental ability of the life process is incomparable. However, the advantage of human consciousness is the ability to control the processes.

Therefore, the body of the organism must be considered as a material object of the shell of life of a high intellectual level, the function of which is to provide all its needs, including protective functions. In other words, the body is a biological machine that, based on the vital capacity of matter, ensures the existence and functionality of consciousness as the basis of the life process. It is consciousness that

is a manifestation of life as the basis of the Subjective reality created in the process of life of living biological organisms.

In the process of its development from the moment of conception, extremely intensive processes of learning and intellectual-informational development of its vital life ability take place in the body of the organism. This is manifested in the development and adaptation to a full life of all material components, with each molecule and atom inclusive. All these components are composed of hereditary information up to the colour of the eyes, as well as about all life processes. which then occurs in the so-called automatic mode. However, this entire automatic mode occurs thanks to and under the strict control of the intellectual ability of nature. It is the only nature that knows how to provide the living process. Consciousness is a user of the body's work with signs of supremacy in managing nature, and nothing more. Consciousness has a very limited influence on the functionality of processes in the body. The total amount of information that a human has acquired throughout their life is insignificant, especially when compared to existing artificial intelligence. It may only amount to a few dozen gigabytes. Therefore, consciousness has a very limited influence on the functionality of processes in the body. However, having the ability to exercise general control, it has the exceptional opportunity to manage both vital and objective natural processes and exploit them in its own interests and at its own discretion.

Thus, nature in the form of objective reality is the basis of life, a life-giving structure that provides intellectual-informational, energetic and functional support for the vital capacity of the subjective reality of the space of the Universe based on the intellectual properties of matter. The pinnacle of the Subjective Reality of the Universe is the Universal Intellect, whose activity serves to ensure the management of all processes of the vital capacity of space from the Elementary Particle to the integral life-giving organism of the Single Energy Body of the Space of the Universe.

III. CONSCIOUSNESS

So, the life of a biological organism is consciousness, and the body is a shell that serves this consciousness. Consciousness does not possess the information of life, even the processes of conception and reproduction. This function is performed by the material life space, isolated in the body shell. This space is completely material, which is beyond doubt. Therefore, life consciousness, being the product of the intellectual activity of all components of life, united into a single system of isolated space, makes this system a living material structure. This system, being autonomous, has a high ability to interact with the environment due to the presence of specific organs of consciousness, capable of directly communicating with the consciousness of the environment. The organs of vision, for example, are the internal consciousness of the organism, which is capable of communicating with a similar system in the environment. These are organs that are capable of communicating with the corresponding intellectual system of the life space of the environment and perceiving and analysing images at considerable distances. The internal consciousness of the organism is an intellectual system that is able to communicate only at the level of intelligence. That is, what we see with our eyes is a reflection of intellectual information received from space. If there is no information, we simply will not see anything, which happens on a dark night. The eyes perceive information. This is clear evidence that space is an intellectual information structure with a specific vital capacity.

The organs of consciousness are not able to directly contact images, which are sometimes located at great distances. However, these organs are able to see through space. That is, it is space that is able to prepare information for the organs of vision in a form or format in which visual consciousness is able to use it. Therefore, space must have the appropriate intellectual capabilities and physical ability to process and transform information into the required format. With a deep analysis of events and life possibilities of the life capacity of space, it becomes quite clear that everything around is arranged

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

24 Volume 25 | Issue 11 | Compilation 1.0

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precisely in such a way that biological life is possible and at the same time comfortable. A Human does not know how he sees, but he can see, just as he does not know how his stomach or liver works. For a Human, it is important that these organs work, but how exactly is not really important.

This is not about specific material objects located at considerable distances, but about their energy-informational interpretation, which, when in contact with visual consciousness, creates a clear visual-informational picture of the contact space to ensure orientation. At the same time, visual consciousness is not able to perceive sounds, smells and all other sensations. This means that the internal system of visual consciousness finds and communicates with the corresponding energy of the external system. That is, information exchange occurs. This, in turn, especially emphasizes the presence of a high intellectual level of the external system. In some engineering aspects, this is called the level of resolution. It is the resolution that is an analogue of the vital capacity of space, with the help of which selective selection and exchange of information occurs. Adjacent systems communicate with each other. This is a distinctive feature of biological life, which consists in the activity of a highly intellectual material isolated space with its ability to interact with the environment.

So, the consciousness of life is a product of the material space, the result of its activity, which occurs on a material basis and is work performed on the basis of the laws of nature, the laws of objective reality. It follows from this that consciousness is a product of the activity of a high level intellectual energy systems, which are converted into the process of life. With the onset of death, the shell of the vital space of biological life is destroyed, the information space degrades to the level of objective reality. All components of the previous life, as a result of biological decay (rot), lose the acquired knowledge and skills, as well as the corresponding physical properties, and turn into a source of biological energy in the form of food for certain types of living organisms. In this deep philosophical sense, the notorious struggle for the existence of individual biological individuals is reduced to creating the basis of biological energy-material support for the existence of subjective reality, which in earthly conditions is provided by biological life. All living things need food, and in a timely manner. This is at a time when the source of food is biological life itself, which, thanks to the energy-informational support of space, ensures the continuity of the process. The death of a single individual brings a chance for the continuation of the life process to another but living one.

Conclusion: *Consciousness is a product of the activity of the material life space; therefore, it has a completely material nature. Consciousness is reality, a real reflection of the processes of interaction in space, which are perceived, analysed and used for the needs of the life space of a living organism. A living organism has all the necessary intellectual capabilities and tools in the form of neural systems that provide effective communication.*

Most theories of the origin and evolution of life that exist to this day boil down to an oversimplified, if not more, judgment that it, life, arose somehow by chance. However, none of these theories even allows that life is one of the forms of existence of matter, the key to their diversity. Each of the known forms of existence of matter meets the criteria of viability, the basis of which is the presence of intelligence. However, these theories do not even assume the participation of the intelligence of nature in these processes. Allegedly, somehow the structures themselves, absolutely worthless in intellectual terms, founded their own structures, but already with signs of intelligence. Although it is absolutely obvious and quite well studied that all living structures are connected by energy-informational structures in the form of DNA/RNA or any other living structures - structures of the highest intellectual level. The creation of life on the basis of natural components, "deprived" of the intellectual component, is nonsense.

IV. ALIVE SPACE

All material objects depicted in the Image 1 of space are densely enveloped in energy. Black colour denotes energy in its pure form without any material inclusions, owing to which interaction occurs between existing material objects. This is how our visual consciousness perceives it. Multi-coloured objects are an informational reflection of material objects, depending on the physical and chemical properties of their components.

The picture in the photograph is an interpretation of how information from the depths of the Universe is recorded, digitized, adapted to the appropriate standards by artificial intelligence, passing through the tool of vision in the body. Intellectual processing reaches consciousness in this form. The system of interaction of different systems and the results of its work are obvious. There is a complete mutual understanding between individual systems. The body of the organism is nothing more than a biological machine, the function of which is to ensure the needs of consciousness. All systems in the body are extremely perfect, and are equivalent in perfection to the systems of objective reality. They easily communicate with each other, and consciousness receives adapted information that is perceived by it exactly as we see it. Thus, consciousness is freed from unnecessary rough, albeit intellectual work. This is an example of an algorithm for communicating with nature with the assistance of artificial intelligence. However, our consciousness is not capable for deeply understanding these processes. "Homo Sapiens" is an active component of the intelligence of the Universe. Therefore, its scientific assessment is unacceptable, separated from the intelligence of the vital capacity of space as a whole. The principle scheme, "nature - body - consciousness", works in a single complex. If at least one link in the chain is inoperative, you are either blind, deaf, or barren.

As careful observations show, life as a whole is not the property of the living organism that is its carrier. It is, as it were, given to the owner for use. The essence of life itself, its purpose and role in the vital capacity of the space of the universe, goes beyond human perception. Its provision in no way depends on the will of consciousness, which is the user of its own body. The body performs its functions in an autonomous mode, performing all the necessary actions to maintain comfortable conditions for the existence of consciousness. From its inception to the very end, consciousness is practically unable to control the course of its own body's existence. Moreover, the consciousness of life itself goes far beyond the existence of its own body. To ensure the full functioning of consciousness, the body is provided with a considerable number of tools with which consciousness is able to go beyond its own body. Thanks to these tools, consciousness has the opportunity to communicate surprisingly effectively with the environment, thus receiving a huge amount of information necessary for its own functioning. Moreover, thanks to its special ability to circumvent the laws of nature, consciousness creates for itself a huge number of auxiliary tools outside its body, using and exploiting the exceptional capabilities of nature. With the help of artificial intelligence and other scientific inventions, consciousness has the opportunity to exploit the intellectual capabilities of objective reality and even manipulate them. It is thanks to the auxiliary science-intensive tools created by science in recent decades that enormous opportunities have been created for the exploitation of the intelligence of objective reality. Thanks to the collective use of information, both by its own innate tools and artificially created ones, humanity has created a fairly effective structure for the functioning of human civilization. This structure has become the dominant link in subjective reality on planet Earth, displacing all competitors from the animal world, even those who far exceed humans in strength.

Artificial intelligence is a system developed by man but with the direct participation of intelligent systems of artificial intelligence itself from the very beginning of its inception. It has become one of the extremely powerful tools at man's disposal, with the help of which man has gained the opportunity to directly influence both scientific research and achievements and purely natural processes. Artificial intelligence does its work independently, without needing any support from human consciousness,

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

26   Volume 25 | Issue 11 | Compilation 1.0

except for command and administrative support. Therefore, the machine must receive a command in a language it understands. It is at this stage that the redistribution is obvious - who is who. It does not matter what name is given to the intelligence of nature. It is important that it does its work extremely effectively, correctly and without fail. 70-100 years ago, such technologies were not even discussed. This became possible precisely because humanity began to talk to nature in its language, the language of zeros and ones, which nature, through force impulses, perceives as impulses of an energy flow of information. That is why all computers need energy, which nature perfectly understands and perceives accordingly. With the help of zeros and ones, nature has already mastered most of the world's languages by means of artificial intelligence.

It is in this aspect that the correct understanding and interpretation of the properties of objective and subjective realities is extremely important. The consciousness of objective reality is radically different from the consciousness of subjective reality. However, the body of a biological organism functions exclusively thanks to the intelligence of nature. That is why it is so obedient and unfailing to the will of the organism's consciousness. The organism's consciousness is command, while the consciousness of the organism's body carries out executive functions. This is the issue that requires a more thorough and comprehensive study.

Based on the above analysis, an assessment of the mechanism of interaction between the intelligence of the consciousness of "Homo Sapiens" and the intelligence of the consciousness of objective reality is provided. No matter how powerful the intelligence of nature is, a human has innate abilities to control the consciousness of nature.

The perception of the world order by consciousness occurs figuratively, through the creation of certain images by energy-information flows. Human consciousness is unable to comprehend the elementary structure of, say, a giant planet, as well as a miniature atom, since the amount of information would be too large and immeasurable for consciousness. This information would not fit either in the organ of vision or through resolution. However, this does not mean that complete information about these objects does not exist at all. It even exists in detail. However, in a format accessible to the biological life of subjective reality, it is filtered by the organs of perception. In space, it creates conditions for the formation of an image that is sufficient for consciousness to assess the situation. This factor clearly demonstrates the intellectual basis of the matter of the Universe. The ability to communicate in terms of mutual exchange of information is provided by energy, which emphasizes the material nature of both information and consciousness. Both information and consciousness, having one source, are carriers of real physical material content. Information is the main means of consciousness. Therefore, the ability to use the capabilities of artificial intelligence, to observe and analyze space, use information is a fundamental property of space. If the organs of vision cannot see a material object at accessible distances, this means that such an information image does not exist in space at all, or at least in a state accessible for information exchange.

These organs are able to communicate with the corresponding intellectual system of the living space of the environment and perceive and analyse images at considerable distances. However, these organs are not able to contact directly with images, which are sometimes at great distances. Therefore, these organs are seen as a means of space. That is, it is space that is able to prepare information for the organs of vision in a form or format in which visual consciousness is able to use it. This means that the space has the appropriate intellectual capabilities and physical ability to process and convert information to the required format. With an in-depth analysis of events and life opportunities, the vital capacity of space, it becomes quite clear that everything around is arranged in such a way that biological life is possible and even comfortable. Humans do not know how they can see, but they see,

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

©2025 Great Britain Journals Press   Volume 25 | Issue 11 | Compilation 1.0   27

just as they do not know how their stomach or liver works. It is important for them that these organs work, but how they themselves are not important at all.

An object that does not exist in reality in the material aspect is not material. Such objects include the so-called realistic objects. An artistically created painting or photograph at a high level can create a realistic image, a real natural interpretation of which, however, does not really exist. Real in this sense will not be a realistic image, but the material body on the basis of which this image is created. Realism in terms of reality that is objectively existing in the material-informational plane is false. A realistic image of any picture does not provide any information about the image itself but is a subjective reproduction of a real image. Not to mention that both portrait images and intellectual information can appear to be true, but in fact be a fake. Realism is a falsehood that claims to be true but is not as such.

Therefore, the philosophical formation, being a realistic reflection of the sequence of the objective process of being, is not an objective reality. Events that occurred centuries ago can be realistically depicted. However, they are not real. Information about them as objects of objective reality does not exist, since they are only a subjective reflection of processes that once occurred. But in the present, such processes are not elements of objectively active processes. Therefore, real time can only be a cause-and-effect relationship in nature, which connects the progressive process of interaction in nature. The subjective realism of past, present, future times, conditionally existing states of all categories do not have a physical basis, material, energy-informational support, are not carriers of the living space of the corresponding intellectual-informational level and are non-existent. That is why the correct understanding and appropriate interpretation of processes from the point of view of objective and subjective reality is extremely important. Attempts to recreate prehistoric mammoths or others like them are impossible. Even if it is possible to recreate a copy that is outwardly similar, it will not be mammoths. These will be artificially created objects of artificial intelligence created by "Homo Sapiens". Because life is not a body. It is intelligence. An artificially created life shell will be the beginning of a new kind of life at the expense and on the basis of the existing one at the time of creation. It is impossible to restore the intelligence of a mammoth, or any other, since information about the past mammoth does not exist in space.

In the absence of planets or their satellites with the appropriate level of intelligence in our solar system, biological life is impossible there due to the lack of suitable conditions. These conditions must be created there, which is impossible with the capabilities of human civilisation. For the existing subjective reality of a higher level in space, there is obviously no need to create it. Therefore, at the moment, the conditions for the existence of biological life exist exclusively on planet Earth.

Intellectual-power interaction of energy flows of space

In the absence of integral material bodies in space, the function of its physical filling is performed by energy in the form of bodies of elementary particles of energy (EPE) - photons and quants - electrons, which are physical carriers of the force of interaction. "There are various kinds of scientific, well-founded hypotheses that all material bodies, depending on their chemical composition and physical structure, are 90-98% quantitatively composed of energy." (Oryabko V., 2024)

Energy is a conglomerate of EPs of the thermal and electromagnetic spectrum of extremely diverse power and other characteristics. Precisely of that they do not compete with each other. The property of energy is interaction as a means of force action. It is precisely because of this phenomenon that the law of conservation of energy operates. Energy cannot be created or utilized, because it already exists in quantities sufficient for the full functioning of the Universe as a whole. Interacting with each other, space, thanks to energy, is a generator and at the same time a conductor for transmitting information

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

28   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

over infinite distances. Energy is the filler of space and its physical essence, filling the entire space, no matter how immense it may be. By combining into thermal and magnetic flows, energy flows create force structures, the driving force of which is the force of the pressure created by it. If individual forces act in a specific given direction, then a huge amount of EP of energy acting simultaneously creates pressure which in a static position acts in all directions. It is this factor that makes the action of force a universal acting unit of space.
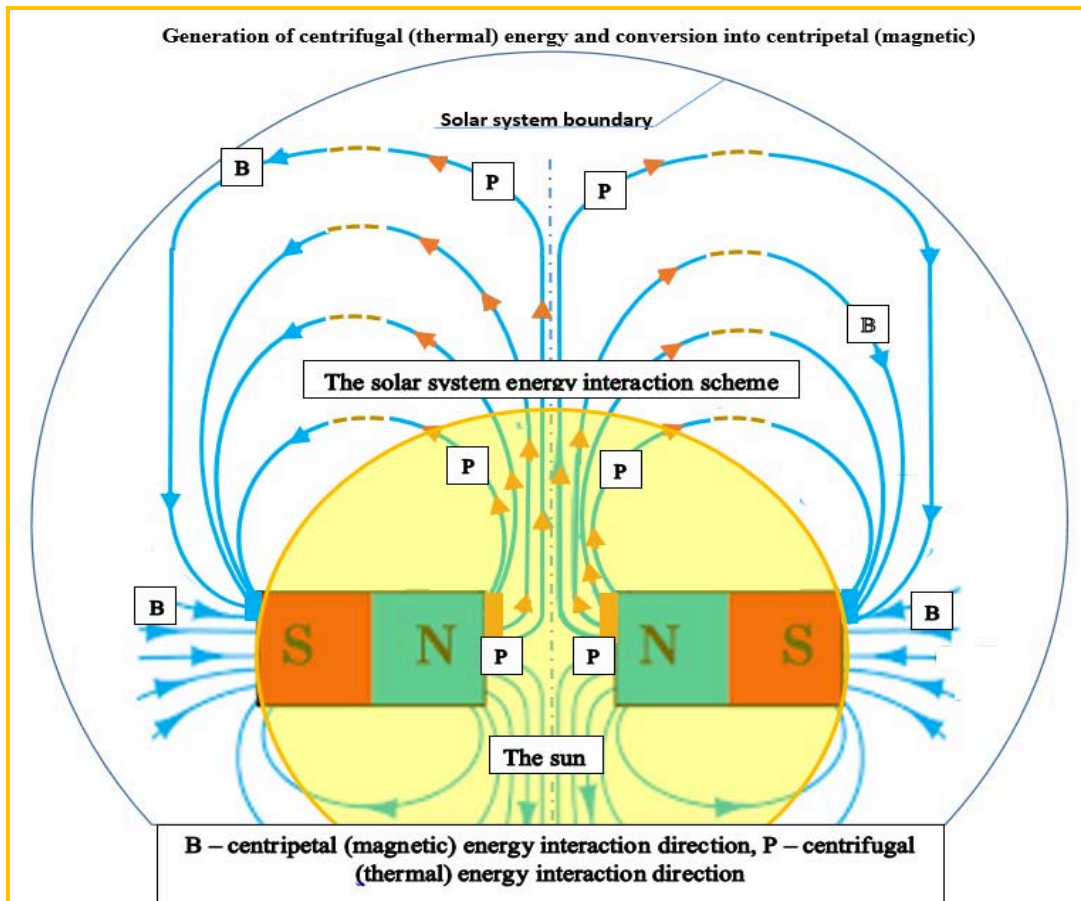
Figure 1: The principle of converting centrifugal (thermal) energy into centripetal (magnetic) one in the Solar system

Energy has a unified unique nature and differs only in the direction of the forces that create pressure. An illustration of the principle of converting centrifugal (thermal) energy into centripetal (magnetic) energy in the Solar System is shown in (Figure 1). The Sun is an energy generator and operates on the principle of an energy pump, in which the body of the Sun plays the role of the rotor. Through the magnetic poles along the magnetic axis, a flow of magnetic energy with a pressure of B_0 is pumped into its body (Figure 4). Under the action of centripetal pressure, the flow of magnetic energy creates conditions for sustaining a thermonuclear reaction. This leads to the release of a certain (large) amount of heat in the form of EM thermal energy, the carriers of which are photons (Figure 2). By all indicators, the sun should explode. But this does not happen, primarily because in the body of the rotor, the magnetic flux changes the direction of action to the opposite by which energy is carried outside the body of the Sun. This occurs due to the rotational movement of the sun's body, which acts as the generator's rotor. The principle of operation is the same as that of an electric generator, and especially a centrifugal water pump. If in a water pump centrifugal acceleration is imparted to water molecules, then in the case of the sun it is an avalanche of plasma full of energy.

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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It should be emphasized that water molecules consist of more than 90% energy, which is the binding component between individual components in molecules. There are various scientific, well-founded hypotheses that all material bodies, depending on their chemical composition and physical structure, consist of 90-98% energy. Clear evidence of this can be seen in nuclear and thermonuclear explosions involving a small amount of explosive material, which result in uncontrolled processes of decay or, conversely, synthesis of atomic nuclei. With a small amount of explosive material, a tremendous amount of energy is released, which can only be calculated approximately. But most importantly, only neutrons can cause the destruction of atomic structures. Being neutral, neutrons are carriers of mass, i.e., objects of matter. All other components of nuclei are energy.

The plasma energy flow is ejected under enormous pressure into the atmosphere of the sun. Material components settle on the surface, and photons of thermal energy under pressure propagate in the space of solar energy. Thermal energy of photons has no temperature. Therefore, outer space is cold. The equivalent of temperature in space is the EP of thermal energy - a photon that is a carrier of Newton's force. Acting with the force of pressure on an air molecule in the atmosphere, a photon increases the volume of the molecule, which is subjectively felt by life as thermal comfort. The EP of energy of photons does not go beyond the boundaries of the solar system. Having performed their work and centrifugal force, photons gradually change the direction of force and move on to the return path in the centripetal direction. (Figure 2) Naturally and structurally, they remained photons - carriers of force. But the powerful gravitational force of the sun forces some of them to return back, changing the direction of force. But material bodies react to the centrifugal action of photons as a force of magnetic attraction, while centrifugal as a force of repulsion. Thus, the law of conservation of energy is ensured. All the energy of the solar system is its property, since it is the equivalent of mass. Outside the system, for communication with other spatial systems, information is transmitted by means of the pressure force.[1] The speed of movement of EP of energy is several meters per second, while the speed of force transmission is 300,000 km/s. It is thanks to the transmission of information at such a speed that the force mechanism of interaction is extremely sensitive and effective. The work according to the received information is performed by completely different photons, that is, those that are in the interaction zone. The essence of the process does not depend on the name of EP of energy, but on the nature of the interaction.

The essence and physical nature of phenomena and processes that objectively occur in nature do not depend on the terminology and symbolism used to define and designate them in scientific practice. Processes in nature occur objectively, strictly in accordance with its nature, laws. But for unknown reasons in the case of radiation or magnetic energy, the concept of force is replaced by the concept of energy flows or power of flows. The concept of energy flow is correct and is a unifying force structure. This is the combination of the VP of energy forces into an energy flow, which fully corresponds to Pascal's law.

$$P = F/S \qquad (2.1)$$

The pressure of light was experimentally confirmed by Lebedev P 25 years after Maxwell's prediction. Lebedew, P. (1901). Pressure, as a physical process, is inextricably linked with force. There is no pressure without the participation of a universal physical unit - force. In scientific practice, it is common to denote phenomena of the same type by physical nature with different symbols. But, from the definition of equivalence, it is known that "…two expressions are logically equivalent if they have the same truth value for all possible combinations of truth values for all variables occurring in these two expressions." (November 2024) That is, the expression of the pressure of the hydraulic flow, or heat flow according to Pascal P = F/S. is equivalent to the expression of the pressure of the magnetic

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[1] A good example is a conventional battery that first receives energy from the outside, then gives it back. The amount of material electrolyte in the battery remains unchanged after each cycle. The amount of force is variable

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

30   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

flow according to B=Φ/S. The logical equivalence of the above expressions is obvious; therefore, they have the same truth, therefore, they are equivalent.

$$B=\Phi/S \leftrightarrow P=F/S \qquad (2.2)$$

Therefore, it follows that such physical quantities as hydraulic pressure and, magnetic energy (current) density J = I/S, magnetic flux (July 2025), magnitude B = Φ/S; luminous flux density (intensity) I = Φ/Ω are physical quantities that characterize the distribution of the force action on the cross-sectional area of an energy body in the process of interaction of two or more isolated energy bodies. The fact that radiant energy is able to create pressure on material bodies has been confirmed experimentally and is beyond any doubt. Therefore, it is a proven fact accordingly, the quantities F = PS, I = JS, Φ = BS, Φ = ИΩ are the quantities of the pressure force acting on the cross-sectional area of a certain material body. The above conclusions do not deny, but on the contrary, agree with the already established practice of using different symbols for the same physical processes, provided that the physical nature of the processes taking place is correctly interpreted. Therefore, this should not be perceived as a denial, but rather as an agreement with the classical terminology that is already widely used in scientific practice. Provided that in the entire space of the Universe there is only force described and introduced into scientific practice by Newton.

V. PRINCIPLES OF ENERGY INTERACTION TRANSFER. HEAT ENERGY TRANSFER

Space is a material structure with a high level of organization of the vital capacity with an extremely high level of organization of all processes of interaction on the basis of the intellectual and informational capacity of energy, the carrier of which is matter.

Energy is a key element of interaction in the Universe. Interaction occurs on a clear intellectual and informational basis exclusively by means of force, one of the carriers of which is a photon. Its, photons, computer model is shown in a photograph (Figure 2) taken by Dr. Yuen B. (2024) and colleagues at the University of Birmingham. The photon, being an elementary particle of energy, is quantitatively expressed by its elementary quantitative portion.

Energy is an elastic force substance that exists in the form of a force intellectual-informational interaction between individual objects in the process of transferring force created by a force flow of pressure. Energy, as is known, has a corpuscular - wave nature. Being quantitative, energy consists of the EP of force, the carriers of which are photons. It is photons or corpuscles that are considered the smallest parts of thermal energy. One photon, being a separate unit of force, exhibits exclusively corpuscular properties, since it acts pointwise and in only direction. In a single state, a photon cannot physically exhibit wave properties.

But, being a quantitative quantity, plenty of force actions has the natural property of being combined into energy flows, which in the process of interaction and sequential action are divided into separate waves. A wave is the result of the sequential action of a set of forces combined into energy flows.

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How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

©2025 Great Britain Journals Press   Volume 25 | Issue 11 | Compilation 1.0   31
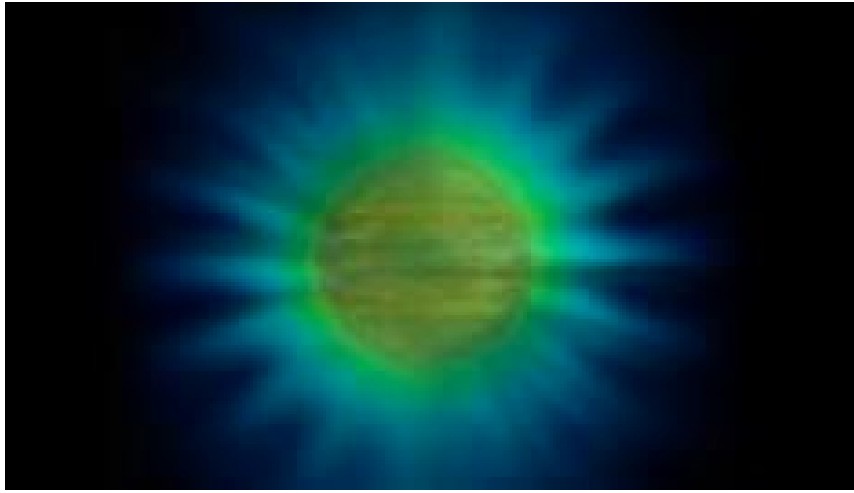
Figure 2: The shape of a single photon

Heat flux is a flow of heat carriers (EP) – photons, force carriers, acting in the centrifugal direction of interaction. Heat flux density (July 2025) is the total heat flux (Q) divided by the surface area (A) through which this flow passes,

$$q = Q/A \qquad (2.1)$$

The heat flux density is equivalent to the force of the pressure of energy flux according to the Pascal law. It is obvious that the expression for the heat flux density is equivalent to the Pascal hydraulic pressure expression, P = F/S,

$$q = Q/A \leftrightarrow P=FS \qquad (2.2)$$

The logical equivalence of the above expressions is obvious; therefore, they have the same truth, therefore they are equivalent. So, energy is a process of sequential action of pressure created by the combined action of the force of photons in the process of interaction with the performance of work in the process of interaction. Pressure P = F/S in turn is the process of transferring the action of the set of forces of interaction between material objects. Both energy and pressure have one property that unites them into a single concept, this is the property of transferring the force of interaction. In the process of transferring energy in the form of pressure, work is performed, which will certainly be accompanied by the release (absorption) of other types of energy.

Therefore, thermal energy is a sequential process of thermal interaction through the transfer of force pressure, by means of which the interaction occurs with the performance of a certain amount of work to change the state of the objects of interaction.

Formula for performing the work of the action of the energy force on changing the state of an energy body with a variable volume in isobaric processes will be

$$A= P_n(V_{n+1} - V_n) \qquad (2.3)$$

The change in volume symbolizes the change in the energy state of an isolated energy body, since it is the changes in the volumetric characteristics of the energy body that are a function of the change in the amount of EP of energy. The change in the amount of energy leads to a change in the volumetric characteristics of the space of the energy body. It should be noted here that formula (2.3) is valid for a

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

32   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

constant pressure value, i.e. for isobaric processes in thermodynamics. It is obvious that the error in the calculations will be the greater, the greater is the difference in the pressure value in adjacent sections of the energy body. Therefore, the formula A = pΔV cannot always be used, since it gives the correct result under conditions of constant pressure.

However, for an elementary small change in the pressure and, accordingly, the volume of any system, this formula can be applied to a larger difference in their values. By dividing the total volume of the energy body into a certain number of elementary volumes using integral calculus, the error can be reduced to a value that can be neglected. In this case, the formula of the work of thermal energy dissipation is the product of a fixed pressure and the difference of the elementary volumes of the energy body and will have the form of a definite integral.

The energy transfer process can be expressed in the form of a descending sequence, where the magnitude of the energy pressure (P) at each step is the difference between the initial pressure (Pn−1) and the work done,

$$P_1 = P_0 - A_1; \ P_2 = P1 - A_2 \ldots P_n = P_{n-1} - A_n; \ P_{n+1} = P_n - A_{n-1} \tag{2.4}$$
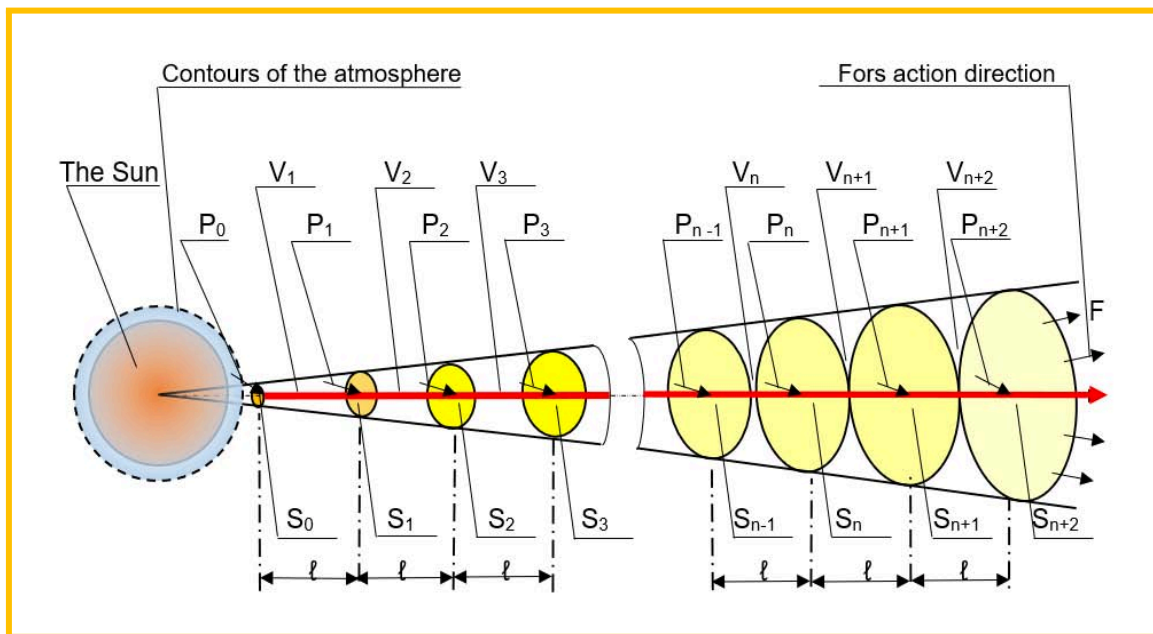
Figure 3: Principle of energy transfer of centrifugal thermal interaction in space.

The work done is expressed in the form of integral expressions,

$$A_1 = \int_{V0}^{Vn+1} P0 dV \quad A_2 = \int_{V1}^{V2} P1 dV \quad A_n = \int_{Vn-1}^{Vn} Pn - 1 dV; \quad A_{n+1} = \int_{Vn}^{Vn+1} Pn dV \tag{2.5}$$

Each term of a mathematical sequence minus the work done will be,

$$P: P_1 = P_0 - \int_{V0}^{V1} P0 dV; \ P_2 = P1 - \int_{V1}^{V2} P1 dV; \ \ldots P_n = P_{n-1} - \int_{Vn-1}^{Vn} Pn - 1 dV; \ P_{n+1} = P_n - \int_{Vn}^{Vn+1} PndV; \tag{2.6}$$

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

By substituting the value of work in the form of the defined integral into the mathematical sequence, we get a universal formula for the process of transfer of centripetal (magnetic) energy in the open space,

$$\text{E: } P_o - \int_{V0}^{V1} P0\,dV; \ P_1 - \int_{V1}^{V2} P1\,dV; \ \dots \ P_{n\text{-}1} - \int_{Vn-1}^{Vn} Pn-1\,dV; \ P_{n-}\int_{Vn}^{Vn+1} Pn\,dV \tag{2.7}$$

From here follows the formula for the momentum Pn of energy,

$$P_n = P_{n\text{-}1} - \int_{Vn-1}^{Vn} Pn-1\,dV; \tag{2.8}$$

So, the transfer of thermal energy in an open space environment close to ideal conditions is a natural process of sequential transfer of a uniformly decreasing pressure force with the performance of a certain work, which is described by mathematical sequences (2.7). The magnitude of a unit impulse in the transfer process is expressed by the difference in the pressure value taking into account the energy expenditure for performing the work due to an increase in the dissipation value due to a change in the volume value. Therefore, the change in the volume of an energetic body by its physical essence is a function of performing work on changing the energy state of the system. That is, the work is performed by energy, which by its force due to the creation of a variable pressure value leads to a change in the volume of an energetic body. That is, the change in the volume of an energetic body occurs exclusively due to a change in the pressure value of the energy flow, the force characteristic of which is the Newtonian force - the universal unit of the Universe.

VI.   MAGNETIC ENERGY INTERACTION TRANSFER

Magnetic energy, being equivalent to thermal energy, is the second part of the energy balance of the space of the Universe. Interacting with each other on a permanent basis, together they represent a boundless ocean of a united energy body of space, a container of all material bodies regardless of size, and provide all processes of interaction in space at all levels. Electromagnetic energy, which is also the basis of the gravitational energy of our planet, and on the basis of which at least half of the energy balance of the production and economic complex of the world economy is created, is the main part of the magnetic balance of the planet too.

The principle of centripetal magnetic energy transfer is equivalent to the principle of thermal centrifugal energy transfer, although they act in opposite directions in nature. Energy in nature acts as a united intellectual-informational and force complex of interaction in space. This complex acts inseparably. Only theoretically, energy can be divided into centripetal and centrifugal. But this has a significant impact on the reaction of matter to the action. A lightning strike is a vivid example of this. Being electromagnetic in nature, it causes an electromagnetic shock by connecting with the mass of the earth. At the same time, a considerable amount of heat energy is released in parallel, which always acts from the centre of the earth. This is because both magnetic and thermal flows are present in the energy body of the discharge. James Clerk Maxwell's (October 2012), in 1865, ground breaking theory of electromagnetism provided the prediction of light pressure.[2] Energy flows exist exclusively in the

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[2] In 1865, James Clerk Maxwell's ground breaking theory of electromagnetism provided not only a unification of electric and magnetic fields but also a series of profound predictions, one of which was the phenomenon of radiation pressure. Maxwell's equations implied that light, as an electromagnetic wave, could exert force on matter. This insight was theoretically extended by Bartoli in 1876, who, using principles of thermodynamics, inferred that radiation pressure could perform work, establishing light as a quantifiable force-carrier. Maxwell's formalism thus suggested that a beam of light impacting a surface could impart a minute, yet measurable,

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How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

34   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

process of transferring a directed force of energy pressure on a constant basis, thus creating an elastic medium that tightly envelops material bodies, ensuring their interaction on a constant basis.

Currently, in this section studied the electromagnetic interaction, process of transferring magnetic energy by the carriers of force, which, according to the definition of Planck M. and Einstein A. (2025), are quanta of energy. Albert Einstein "associated the "quantum" or minimal element of the energy to the electromagnetic wave itself".

The only difference between electromagnetic quanta and photons, carriers of heat energy pressure, is their centripetal direction of action. Magnetic energy quanta do not compete with photons in any way. Their task, acting simultaneously, is to ensure the interaction of individual objects of matter with each other. In scientific practice, as already noted, it is traditionally customary to use a separate symbolic notation in electrodynamics, different from the notations used in thermodynamics. Symbolism and terminology do not change the essence of physical processes, but for clarity and better interpretation, the use of different symbols for different types of energy is a better option. The physical essence of the processes described by Pascal's and Newton's laws or Ampere's laws does not change from the use of different symbols. Based on this definition, we accept the concept of magnetic flux pressure through a magnetic flux, which will have the following form.

$$B = \Phi/S, \qquad (3.1)$$

where, B - the magnitude of the magnetic flux pressure, its density, which is equivalent to Pascal pressure, Φ - the force of the magnetic flux acting in a direction on the plane S.

Considering the energy transfer scheme, it is obvious that the maximum concentration or density of electromagnetic quanta - carriers of the centripetal force of magnetic energy pressure, of which the magnetic flux consists, is located in the centre of mass of the material body. It is the EP of matter, carriers of the mass of matter, that emit energy on a constant basis to ensure its own processes of interaction. Interaction is the main property of matter - the state of its existence. This centre is the material point of the centre of interaction of forces of both magnetic and thermal energy. In the direction from this centre, energy is transferred in all directions, because energy is transferred by means *of pressure created by the total force of the interaction process*. This means that in the process of transferring centripetal magnetic energy from the centre of the system to its periphery, work will be performed to change the state of the energy body.

With a variable volume, similarly to processes in thermodynamics, the work done by the action of the energy force to change the state of the energy body will be different. The performance of elementary work to change the volume of the energy body under the action of energy pressure will be according with formula,

$$W_n = B_n(V_{n+1} - V_n), \qquad (3.2)$$

The change of the volume of an energy body symbolizes the change in its energy state, since it is the changes in the volumetric characteristics of an energy body that are a function of the change in the amount of electromagnetic energy in a certain volume. A change in the amount of EP of magnetic energy leads to a change in the volumetric characteristics of the space of the energy body.

Here again, similarly to the processes in thermodynamics, it is necessary to note that this formula is valid at a constant pressure value. Therefore, it is obvious that the error in the calculations will be greater, the greater the difference in the pressure value in adjacent sections of the energy body. However, with an elementary small change in the pressure value in the certain volume of the system, this formula can be applied for a larger difference in their values. Dividing the energy body into a

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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Volume 25 | Issue 11 | Compilation 1.0

35

certain number of elementary sections by means of integral calculus will provide an opportunity to reduce the error value to a value that can be neglected. In this case, the formula for the work of magnetic energy dissipation is the sum of elementary volumes.

The process of magnetic flux energy transfer can be interpreted by a mathematical sequence at each stage (B) as the difference between the magnetic energy pressure (Bn−1) at the beginning of the process and the corresponding work done. Each term of the mathematical sequence, taking into account the amount of work done, will have the following form,

$$B_1 = B_0 - W_1; \ B_2 = B_1 - W_2; \ \dots \ B_n = B_{n-1} - W_n; \ B_{n+1} = B_n - W_{n+1}; \tag{3.3}$$

The work done at this stage is represented by integral terms,

$$W_1 = \int_{V0}^{V1} B0\,dV \quad W_2 = \int_{V1}^{V2} B1\,dV \quad W_n = \int_{Vn-1}^{Vn} Bn-1\,dV; \quad W_{n+1} = \int_{Vn}^{Vn+1} Bn\,dV \tag{3.4}$$

By substituting the value of work in the form of the defined integral into the value of each member of the sequence,

$$\text{B: } B_1 = B_0 - \int_{V0}^{V1} B0\,dV; \ B_2 = B1 - \int_{V1}^{V2} B1\,dV; \ \dots \ B_n = B_{n-1} - \int_{Vn-1}^{Vn} Bn-1\,dV; \ B_n = B_n - \int_{Vn}^{Vn+1} Bn\,dV; \tag{3.5}$$
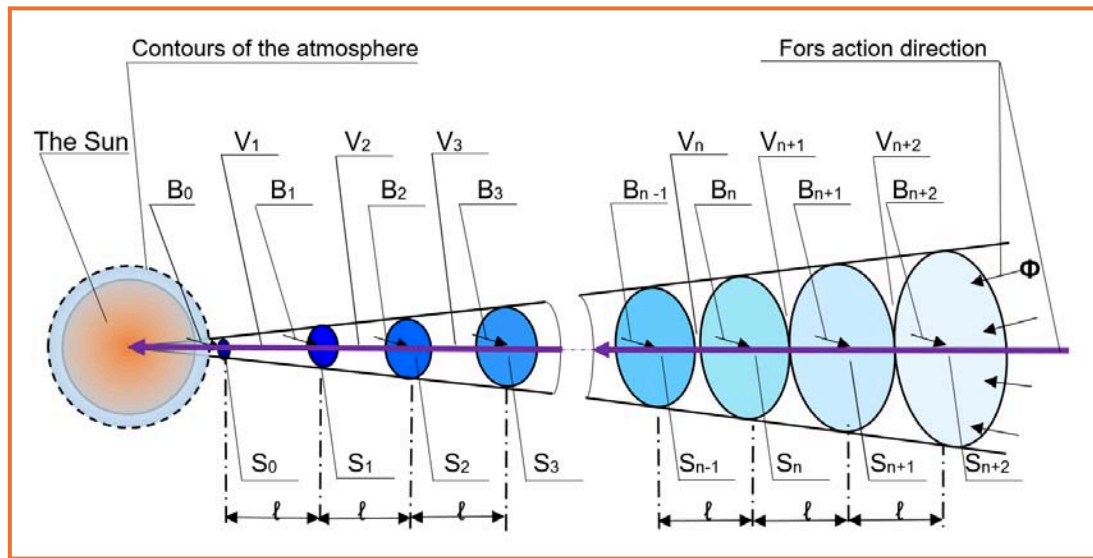
Figure 4: The principle of energy transfers by centripetal magnetic interaction in space.

we get a universal formula in the form of sequence for the process of transfer of centripetal (magnetic) energy in the open space,

$$\text{E: } B_0 - \int_{V0}^{V1} B0\,dV; \ B_1 - \int_{V1}^{V2} B1\,dV; \ \dots \ B_{n-1} - \int_{Vn-1}^{Vn} Bn-1\,dV; \ B_n - \int_{Vn}^{Vn+1} Bn\,dV; \tag{3.6}$$

From here follows the formula for the momentum Bn of energy,

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

36   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

$$B_n = B_{n-1} - \int_{V_{n-1}}^{V_n} B_{n-1} \, dV; \qquad (3.7)$$

The magnetic energy flow B will expand in the direction from the energy centre. Thus, the centripetal magnetic energy performs work W by reducing the density of its internal energy or reducing the concentration of quanta in the area of the energy body. This formula is valid for determining the process of energy transfer regardless of the direction of force action - both the centrifugal thermal flow and the magnetic flow with the centripetal direction of force action. This serves as convincing evidence that in nature there is a single energy that acts as a single complex in all interaction processes. The only difference is the reaction of material objects to the action of energy in the centripetal and centrifugal directions, which is expressed in the form of work performed.

So energy is *a sequential continuous process of transferring the pressure of interaction by means of an energy flow created by a set of elementary particles of force, the carriers of which are elementary particles of energy*. Each individual EC of force acts in one direction. But a set of elementary particles of force in a static state, uniting into flows, create pressure that distributes the action of individual forces in different directions. This provides flexibility and extraordinary manoeuvrability to all processes of interaction in nature.

If, as a result of the interaction, there is a predominance of the action of forces in a certain direction, this creates conditions for the creation of a dynamic flow. The dynamic flow created by the unilaterally directed action of part of the force is expressed by dynamic pressure. The force of this dynamic pressure creates a translational motion with a certain magnitude of the force action called velocity, which is the physical essence of the physical phenomenon of motion and speed, respectively. According to Bernoulli's formula "The dynamic part of the energy force $B_d \approx k/2I^2$ is the working part of the total energy force". (Oryabko V, 2024). It is this magnitude that is the physical nature of velocity as a moving dynamic force.

The definition of speed as the distance travelled per unit of time practiced in modern practice does not correspond to the physical nature of the process. This is for accounting. For example, the processes of take-off and landing of an airplane occur at the same speed values. But under completely different force conditions. To tear off an airplane from the ground and to land it on the ground are different physical processes that require different values of applied forces. At one time, in order to somehow level this nonsense, the first - fourth cosmic speeds were proposed, which with their dynamic force are able to overcome the energy of the Earth's gravity.

VII.   WEIGHTLESSNESS PHENOMENON

The phenomenon of weightlessness is well-known but insufficiently studied. This especially applies to the role of matter and energy in this process. It is in this regard that it is necessary to emphasize the fact that energy is one.

Hypothesis: *Energy in terms of the unity of its physical nature in the process of interaction, acting in different directions, that is the main factor in the state of weightlessness. It is thanks to the interaction of the centripetal action of the force of magnetic energy and the centrifugal action of thermal energy that the phenomenon of weightlessness occurs, which can be observed in open space or in the aquatic environment on Earth.* Energy is a unified elastic medium of space completely filled with the pressure force carriers mentioned above - thermal photons and magnetic quanta. It is thanks to the diverse directions of action of magnetic and thermal energy that the action of the fundamental law of the Universe, which we call Newton's third law, is ensured. This law is based on the interaction of all objects of matter by means of centripetal and centrifugal energy, which as a result ensures

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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relative stability and equilibrium. The interaction of two opposing energy flows, which leads to weightlessness, means the constant action of their forces on a constant basis.
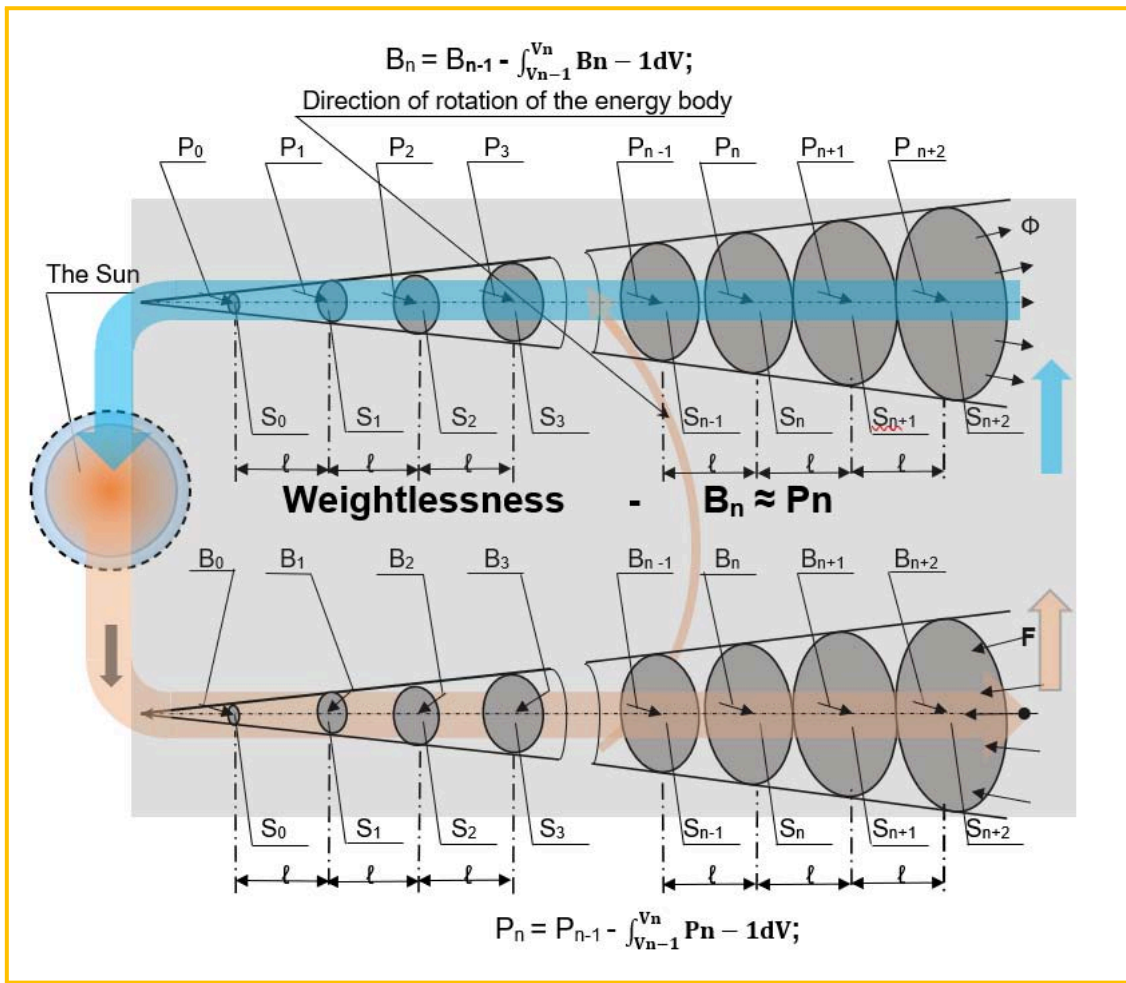
Figure 5: Illustration of weightlessness

Weightlessness is achieved due to equilibrium, and in no way lead to mutual destruction. In the depths of the oceans, at high pressure, the phenomenon of weightlessness can be observed because the opposing forces compensate for each other's actions.

$$\Phi/S = -F/S. \tag{4.1}$$

But in the conditions of open space, everything is different. The forces of attraction and repulsion are the same in magnitude. If at a certain point in open space a material point is acted upon by the force of a quantum of the magnetic spectrum of the centripetal direction B, then at the same moment the force of photons F of the thermal spectrum of the centrifugal direction will act upon this point. (Figure 7)

$$F/S - \Phi/S = 0. \tag{4.2}$$

Thus, the effect of weightlessness is created, when the interaction of all forces ultimately leads to equilibrium. Being enveloped by extremely powerful energy flows, material bodies - planets, stars and even galaxies - become weightless, which makes energy processes in space easily controllable and carried out with minimal energy losses. This phenomenon is extremely important from the point of view of managing and performing the processes of the vital capacity of the space of the Universe. The energy body of the solar system, like the system of our planet, works on the principle of an

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

38   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

electromagnetic generator, where the magnetic axis of the Sun acts as the core of the rotor. The energy body of the Solar system consists of the energy body of the Sun and the outer space of the entire Solar system (Figure 7). The Sun, rotating around its axis, rotates the entire space of its system with its powerful force, just as the Earth rotates its entire atmosphere when rotating. The entire Solar system is a single whole and is completely subject to the gravitational forces of the Sun. Rotating, the core of the generator of the Sun's axis pumps a magnetic flux of centripetal energy. The Sun's body, acting as a rotor, giving the centripetal energy additional acceleration at the exit, changes the direction of its action to the opposite. That is, the flow of centripetal energy, having received an additional charge, acquires the properties of a centrifugal direction. The speed of movement of these flows and, accordingly, their dynamic pressure is negligible by earthly standards and decreases as it moves away from the Sun's body. At the same time, the speed of pressure force transmission is 300,000km/s. Spending its own centripetal energy force from the periphery of the solar system, or having exhausted its energy, the heat flow enters the zone of magnetic centripetal influence. Changing the direction of movement to centripetal, the magnetic flows are directed to the poles of the solar body in order to support the thermonuclear reaction in the solar body with their magnetic pressure, and also to again receive additional force and pressure to become a centrifugal flow. This is a perpetual motion generator which, thanks to the constant system of circulation of the solar system's own energy, will never lose its own power. Energy cannot disappear; it can be transformed from one state to another. And thermonuclear reactions will be supported by magnetic flows on a constant basis.

The energy circulation of our planet in a miniature version occurs in the same way. The only difference is that the energy flows on the earth are significantly influenced by the flows of thermal energy from the sun. Thermal energy, being absorbed by material bodies, increases their volumes, which is subjectively felt as thermal comfort. However, this does not prevent the earth from living its own life, rotating around its own axis, producing its share of thermal energy by absorbing magnetic energy.

VIII.   CONCLUSION

Space by its nature is a structure with a high level of intellectual and organizational support with the presence of all the main signs of vital capacity. The main feature of the ability to live is the presence of intelligence as a fundamental criterion for interaction. It is the ability to interact with the environment that is the main feature of viability.

Is the process of interaction with objects of interaction that do not possess intelligence at all possible? Definitely not. This is not real; therefore, it is not possible. Non-intellectual matter, matter that exists outside the laws of nature in space, does not exist. The interaction of highly intellectual objects in space with non-intellectual objects is impossible, since the existence of such objects goes beyond the scope of objective reality. Objective reality is the basis of the vitality of space, the vitality of which is provided by the basic level of intellectual support of matter. A feature of the intellectual support of objective reality is its universality and comprehensiveness, as well as the unambiguity and inviolability of the laws of nature. Therefore, objective reality is assigned the main executive function - ensuring the functionality of the vitality of space. Without the effective functioning of objective reality, life processes in space are not possible, because it is the provider of all the necessary conditions for life support. Life is a complex of interaction between all its components.

Biological life on earth is a separate and special form of the existence of matter as a higher form of life capacity – subjective reality. It is based exclusively on the vital capacity of the material shell of the body which is the basis of biological life. Unlike objective reality, subjective reality has the inherent functions of creating and ensuring the life capacity of a system. Being deprived of the function of ensuring the functionality of all natural processes of the basic level, the function of subjective reality is

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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the command-administrative function. Therefore, the intelligence of "Homo Sapiens" is capable of creating a management and command superstructure, while using the intellectual capabilities of objective reality, with limited own intellectual capabilities. The task of Subjective Reality is to create additional conditions for better regulation of the conditions and quality of one's own living space. The physical essence of the viability of objective reality has not changed at all from the activities of Subjective Reality. Only the conditions of existence of biological life have changed. Therefore, changing the conditions of the viability of space is the main function of subjective reality.

The implementation of the laws of nature for subjective reality, unlike objective reality, is optional, which makes it possible to use nature in one's own interests by manipulating its laws. In this regard, it is extremely necessary to deeply study the problem of differentiating the course of processes in two separate realities. The system of measuring time with modern chronometers is valid in the subjective reality of modernity. The system of time measuring by the height of the sun above the horizon by the number of conventional sticks, which was used at least in certain regions of Europe 100-200 years ago, has already lost its relevance. However, nature works on the principle of cause and effect, and in no way uses time in the processes of interaction. The interaction of objectively existing space within certain time frames or its direct influence on space is questionable. However, the exception is technological processes under the guidance of human intelligence, provided that the direct implementation of the processes themselves will occur according to the laws of nature. The contemporary speed measurement system has the same shortcomings. For administrative, economic and everyday needs, in some scientific aspects this system is valuable and useful. However, in objectively existing processes, speed is associated with dynamic force. Force is in no way associated with time. That is why, in order to get around this scientific nonsense, science uses the concept of cosmic speeds in rocket and space technologies. All this calls into question the expediency of arbitrary use in scientific practice of time, the theory of relativity, since objectively the speed of light does not exist in nature at all.

As the ancients said, it is impossible to step into the same river twice... Because the next moment there will be different water there. Objectively, it is impossible to return to the past or jump into the future. First of all, in the complete absence of information. This is possible in cinema. And it is not forbidden at all. Because life, within certain limits, is given the right and some opportunities to manipulate the laws of nature. It is possible to create a movie, very realistic, but it will never be objectively real. It is essential.

It is extremely significant that humanity, thanks to its specific intelligence, using the laws of nature, has managed to change the accounting of the entire planet beyond recognition. And this is reality, not a movie at all. But, the laws of both objective and subjective reality are real. Therefore, these laws must be known, studied and used accordingly.

One of the key roles in ensuring the above-described processes is played by the process of energy transfer and transformation. Mathematical interpretation and modelling of these processes is extremely important in terms of optimizing the conditions for the use of energy resources, without which the existence of human civilization has already become impossible. It is energy as a carrier of the intellectual potential of the space of the Universe that is the basis of the vital capacity of everything, including biological life.

The law of conservation of energy reliably protects the vital capacity of planet Earth, and accordingly biological life, as part of the Subjective reality of the Universe.

How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

40   Volume 25 | Issue 11 | Compilation 1.0

Although it is quite obvious that the body is a biological machine, everything is arranged in such a way that spending one's own life with it, with all its joys, hopes, and love, is extremely pleasant and important although not without pain and loss.

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How the Universe Works: Part 4. Philosophical Foundations of Space Vitality: Energy, Consciousness, and the Mathematical Interpretation of the Processes in Space of Universe

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42 | Volume 25 | Issue 11 | Compilation 1.0

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Enhancing Digital Learning: The Role of NPC Managed Virtual Educational Environments

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INTRODUCTION

Generative artificial intelligence represents a significant opportunity, particularly in educational settings, as it has the potential to enhance the teaching, learning process. However, its use should aim to integrate and augment, rather than replace, human thought—adopting a logic of inclusion (*et, e*t) rather than exclusion (*aut, aut*) (Prencipe & Sideri, 2023, p. 99). Firstly, this approach counters the apocalyptic tendency (Eco, 1964) to reject technology—specifically, in this case, AI—on the mistaken assumption that it substitutes human intelligence and, consequently, the learning process. Instead, AI should be framed as a tool designed to facilitate human learning processes (Prencipe & Sideri, 2023, pp. 100, 102). Nevertheless, a fundamental shift must be acknowledged: learning should transition from a focus on merely identifying solutions to a practice centered on formulating well, structured questions, which, in turn, generate meaningful content—whether in the form of images, videos, text, or other media. This is the space within which educators must operate when teaching the use of generative digital tools.

Enhancing Digital Learning: The Role of NPC Managed Virtual Educational Environments

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I.   INTRODUCTION

Generative artificial intelligence represents a significant opportunity, particularly in educational settings, as it has the potential to enhance the teaching, learning process. However, its use should aim to integrate and augment, rather than replace, human thought—adopting a logic of inclusion (*et, e*t) rather than exclusion (*aut, aut*) (Prencipe & Sideri, 2023, p. 99). Firstly, this approach counters the apocalyptic tendency (Eco, 1964) to reject technology—specifically, in this case, AI—on the mistaken assumption that it substitutes human intelligence and, consequently, the learning process. Instead, AI should be framed as a tool designed to facilitate human learning processes (Prencipe & Sideri, 2023, pp. 100, 102). Nevertheless, a fundamental shift must be acknowledged: learning should transition from a focus on merely identifying solutions to a practice centered on formulating well, structured questions, which, in turn, generate meaningful content—whether in the form of images, videos, text, or other media. This is the space within which educators must operate when teaching the use of generative digital tools. In doing so, they should engage with themes of lateral and divergent thinking (Sibilio, 2014, 2016) and embrace the human creative capacity to envision and construct new possible worlds (Berthoz, 2015; Sibilio, 2017). At the same time, the challenge between the various nations is only just beginning, both in terms of the chips that can be used for computing power, and in terms of performance in the generation of multimedia content through artificial intelligence. That is why it is important for a nation to be among those allowed to use top, of, the, line technologies. In the context of increasing regulations on the dissemination of artificial intelligence (AI), the *U.S. Framework for Artificial Intelligence Diffusion*, introduced by the United States[1], imposes restrictions that may impact not only global security and the economy but also access to AI, based educational technologies. By limiting the availability of advanced models and specialized hardware, these measures risk creating a divide between countries with privileged access and those subject to restrictions, potentially affecting education, research, and innovation in the educational sector. The *U.S. Framework for Artificial Intelligence Diffusion* is a regulatory framework issued by the U.S. Department of Commerce on January 13, 2025, with the objective of managing the global dissemination of advanced AI technology through export controls. This regulatory framework aims to balance the protection of U.S. national security and foreign policy interests with the promotion of economic and social benefits derived from the responsible dissemination of AI. Key measures introduced include global licensing requirements for the export of advanced computing, integrated circuits and the "weights" of the most sophisticated AI models, as well as the implementation of licensing exceptions for low, risk destinations and end users. The regulation officially took effect on January 13, 2025. The *U.S. Framework for Artificial*

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[1] https://www.federalregister.gov/documents/2025/01/15/2025-00636/framework-for-artificial-intelligence-diffusion

Intelligence Diffusion also includes restrictions on the types of advanced chips that can be exported, particularly high, performance processors used for training and executing sophisticated AI models. The United States seeks to limit access to these chips by countries deemed high, risk for national security or potential military applications. Countries classified as "high, tier" (low, risk countries, among which Italy[2]) benefit from licensing exceptions, meaning they can more easily access advanced hardware and the most sophisticated AI models without undergoing lengthy approval processes. This facilitates technological innovation, research, and development without significant restrictions. Conversely, lower, tier countries may face limited access or be required to obtain case, by, case approvals, slowing the adoption of advanced technologies and putting them at a disadvantage compared to nations with fewer restrictions (Clifford Chance, 2025; Rand Corporation, 2025).

The *U.S. Framework for Artificial Intelligence Diffusion* could also affect AI, related educational software in three main areas: 1) Access to Advanced AI Models (if an educational software application relies on advanced AI models for virtual tutoring, content generation, or personalized learning, it may be subject to restrictions if these models require advanced hardware or neural network weights that fall under export controls); 2) Availability of Hardware for Training (schools, universities, and startups in restricted countries may face challenges in accessing GPUs and advanced chips necessary for research and development in the educational sector. This could limit the adoption of AI, based educational tools or slow down the development of new applications); 3) International Collaborations and Exchanges (if a country is not classified as "high, tier," obtaining licenses to use state, of, the, art AI software and hardware may be difficult. This could impact global educational projects, such as Massive Open Online Courses (MOOCs) or advanced e, learning platforms that leverage AI). In modern education this will have a strong impact, due to the fact that digital technology plays a crucial role in enhancing learning experiences.

II.   NPC: THE STATE OF THE ART

Non-Player Characters (NPCs) are characters within a game that cannot be directly controlled by the player. They can be neutral, allies, or adversaries, and they can exhibit different interactions or behaviors based on variables such as the environment or interactions with the player character. The first definition of NPCs (West N., 1996) describes them as non playable characters specifically created by the Game Master in a role, playing game, thus originating as functional elements for creating interactions alternative to player, to, player interactions. The potential arising from the creation of this type of player, game interaction can be expressed in multiple aspects of a game, from the more superficial, related to specific functions for game progression, to the deeper, related to the immersiveness of the game itself. The dual objective of functionality and immersiveness remains even with the increasingly widespread application in video games. What changes with the new application context is rather the management of NPCs. While in role, playing games it is the game master, or

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[2] Tier 1 encompasses the United States and 18 key allies and partners, who face no restrictions on imports or chip sales. This flexibility enables jurisdictions with robust technology protection frameworks and aligned national security interests to benefit from seamless large-scale acquisitions. The Tier 1 countries include Australia, Canada, Japan, Taiwan, South Korea, New Zealand, Norway, the United Kingdom, and ten of the 27 EU member states: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Spain, and Sweden. Tier 2, comprising the majority of the world, includes 120 nations that maintain significant trade and security relationships with the United States, such as Israel, Singapore, Saudi Arabia, the United Arab Emirates, Romania, Morocco, Turkey, Luxembourg, the Czech Republic, Brazil, and Poland. These countries may receive exports only through companies participating in the data center authorization program or by obtaining individual licenses. Tier 3 includes countries such as China and Russia, which remain subject to stringent restrictions aimed at preventing the transfer of advanced AI chips to arms-embargoed states, mitigating the risk of theft and unauthorized use of AI model weights, and slowing the development of cutting-edge AI capabilities by U.S. competitors. Obviously, the list may be subject to changes as it was issued by the previous U.S. administration.

sometimes the players themselves, who trigger NPCs through random events like dice rolls or player decisions, in the case of video games, the automated management of NPCs effectively becomes a programmer's problem. This problem is solved from the outset thanks to the application of a theory that computer scientists had known long before the 1980s, namely that of finite state machines (FSM). An FSM contains a set of states and conditions that allow the machine to transition from one state to another. The FSMs that are assigned to NPCs allow them to behave accordingly based on their current state, and when a condition is met, the machine can transition to another state (Uludağlı, M. Ç., & Oğuz, K., 2023). The solution strategy proposed by FSMs is still used today for a large portion of the NPCs present in video games, however, the intrinsic limitations of the theoretical model continue to require a progressive effort in the search for alternative solutions. In order to keep the number of transition states low, which grows exponentially with respect to the number of states, there is a tendency to reduce the number of states, often causing anomalous or approximate behaviors compared to what a player expects. Naturally, as in reality, most individual interactions with the environment can be well approximated by an FSM model. An example of this is all those people with whom we have disposable interactions. Conversely, in a small part of our relational system, a much higher number of different interactions are concentrated. An example of this is the teachers we had during our school period. These cases, therefore, even if smaller in number, are of greater importance. In other words, to improve the level of immersiveness, it is necessary that some NPCs can satisfy multiple functionalities and realize multiple interactions with the player. As it results from a much more extensive literature than that relating to FSM, based NPCs, the most versatile and widely discussed theoretical model is decision trees. A tree, defined as an acyclic and connected graph (Harju, T., 2011), lends itself easily to modeling the action, consequence schemes that regulate the behaviors of NPCs. In fact, each NPC always possesses a default behavior, usually associated with the base of the tree called the start node, a set of conditions structured hierarchically and associated with the intermediate nodes, and a set of final behaviors associated with the leaves that are realized based on whether or not the previous conditions are met (Millington, I., 2019). In addition to identifying characteristics common to all NPCs, the new model proves to be much more expressive than the FSM model, as each action of the NPC occurs as a result of one or more series of events or paths of the tree. The different paths, on one hand, efficiently address the need to have the NPC perform certain actions or functionalities, on the other hand, they highlight the problem of repetitive action typical of, for example, early fighting video games (Lie and Istiono, 2022). The player who has identified a certain strategy, therefore an effective path for a certain response from the NPC, will tend to apply it in subsequent times as well, risking in the short term to deprive themselves of part of the gaming experience and in the long term to lower the level of engagement. This phenomenon, which is certainly the primary enemy of companies that develop video games as it could lead to a drop in sales, also has an impact on the quality of the player themselves, increasingly tending towards sterile automatism and less competent regarding the game. The resolution of this problem plays a central role in the introduction of Artificial Intelligence, based methods in video games. The works in the literature that deal with the application of AI in video games are numerous. In this contribution, however, we will focus on a particular class of NPCs that are equipped with AI methods in order to improve their own credibility, understood as similarity to the human being in expressive and social capabilities. Particularly in cases where the purposes of the game are educational, AI regulates the behaviors of NPCs not to oppose the player's strategies in an adaptive way, but rather to cooperate for the educational experience proposed to the student or, more generally, to the player. The work of Cassel, J. et al. (1999) is one of the first to present an NPC of this type. Real Estate Agent, simply called REA, has a human, like face and body, gestures, is able to interpret the audio and video information provided by the player, and produces responses based on functions that make the conversational module versatile. In the work of Mateas, M., & Stern, A., (2003), the emulation of a daily life scene is proposed where multiple interactions are possible in a virtual environment shared with a couple of NPCs. The interactions, and in particular the text typed to

communicate with the NPCs, constitute the information processed by an abstract entity that manages the course of the storyThe NPC described in the work of Poggi, I. et al., (2005), although it may seem rudimentary in some respects today, contains multiple key components of communication. In fact, the generated responses can be enjoyed both by reading and listening to the respective audio file; furthermore, the phonemes present in the audio file constitute part of the input of a module that modifies the facial expression of the NPC in a manner consistent with the potential emotional state of the NPC. The emotional component, in fact, remains one of the main objects of research, as evidenced by the article by Rowe, J. et al., (2009), in which the group investigates a strategy that can make NPCs dynamic also with respect to the player's emotional state. In the virtual environment presented, the dialogues of the NPCs are not static but are generated in a manner consistent with the character's characteristics, the narrative context, and the NPC's own communicative objectives. Over the years, the potential of these tools has sparked the interest of an increasing number of application contexts, with the development of NPCs verticalized on increasingly specific tasks. The research group of McCoy, J. et al. (2011) presents a social simulation game for adolescent students in which AI is used to manage the evolution of social relationships between the player and the various NPCs, while the edugame developed by Yunanto, A. A. et al., (2019) is designed for a much younger student audience. In this case, the highly cartoonized NPCs use a Natural Language Processing model to analyze English grammar questions and respond from among the possible alternatives before the player. In the serious game proposed by Tato, A. et al. (2020), the player must overcome 5 levels, and in each level, there are various NPCs who can help in reflecting on the social issue proposed in the level. The video game detects emotion through the analysis of facial expressions, but this information does not influence the type of interactions with the NPCs, who can express agreement or disagreement with what the player has typed only through the appearance or absence of a downward, pointing arrow. An example for a type of adult student comes from the serious game developed by Panopoulou, E., Aversa, D., & Vassos, S., (2023), where the virtual experiences are of interest to Law Enforcement Agencies, such as police officers.

III. NPC VS HUMAN TEACHING TRAINER

One innovative approach to education is the integration of digital assets, such as videos and 3D objects, into virtual educational environments managed by Non-Player Characters. These environments offer new opportunities for interactive and personalised learning, catering to different learning styles and increasing accessibility (Yannakakis & Togelius, 2018). By leveraging curated digital resources within virtual spaces, educators can create engaging, flexible, and collaborative educational experiences that adapt to students' needs and preferences (McCoy et al., 2011).

Recent meta-analytic evidence on Virtual Digital Human Pedagogical Agents (VDHPAs), a category that also includes NPCs equipped with human-like interaction capabilities, confirms their significant pedagogical potential in immersive Virtual Reality contexts. The analysis conducted by Zhang and Mo (2025), based on a synthesis of 36 empirical studies published between 2013 and 2023, reveals that although VDHPAs do not lead to a significant reduction in cognitive load, they foster a moderate yet significant increase in students perceived social presence. This finding aligns with the definition of social presence as the degree to which a learner perceives themselves to be in the company of another intelligent and attentive interlocutor (Biocca et al., 2003). Research in immersive virtual environments (Kyrlitsias & Michael-Grigoriou, 2022) indicates that high levels of social presence contribute to stronger engagement, increased trust, and more collaborative learning behaviours. Such effects are amplified when NPCs or other pedagogical agents employ non-verbal cues, such as simulated eye contact, synchronous gestures, and expressive intonation, that enhance the sense of co-presence and emotional connection with the learner.

Even more noteworthy is their positive impact on learning-related variables such as knowledge retention, the transfer of skills to new context, and other assessment outcomes.

From a technological perspective, an educational NPC relies on artificial intelligence modules capable of processing multimodal input (text, voice, and gestures) and delivering adaptive responses (Cassell et al., 1999; Poggi et al., 2005). Machine learning algorithms, particularly in the domains of Natural Language Processing (NLP) and Dialogue Management, enable the NPC to interpret student queries, retrieve relevant information from structured knowledge bases, and tailor explanations to the learner's profile (Rowe et al., 2009). Through speech synthesis and embodied conversational agents, the NPC can present information in a human-like manner, using voice modulation and gestures to enhance engagement (Mateas & Stern, 2003). Indeed, the studies by Zhang and Mo (2025) also highlighted how agent design features, such as gestures, facial expressions, and human-recorded voices, significantly moderate effectiveness, with gestures enhancing clarity and voice naturalness increasing emotional engagement. In addition to emotional engagement, these design features enhance both social presence and telepresence, the latter referring to the subjective feeling of "being inside" the virtual environment (Steuer, 1992). Studies in VR-based learning contexts (Kyrlitsias, & Michael-Grigoriou, 2022) indicate that when social presence and telepresence are both high, learners are more likely to internalise complex concepts and sustain attention over longer periods.

Embedded analytics modules allow tracking of learners' progress in real time, identifying gaps and reinforcing content where necessary, aligning with principles of adaptive learning (Panopoulou et al., 2023). In this regard, du Plooy et al. (2024) highlight that personalised adaptive learning approaches, supported by AI-driven feedback and continuous performance monitoring, can significantly improve academic performance and engagement. Their review of 69 studies in higher education reports that approximately 59% observed measurable performance gains, while 36% recorded improvements in student engagement, confirming that adaptivity is a key factor in sustaining motivation and optimising learning trajectories.

From a pedagogical perspective, NPCs excel in tasks where repetition and standardisation are essential, such as providing consistent explanations of core concepts and delivering targeted practice exercises (Tato et al., 2020). They can instantly adjust the pace and complexity of instruction according to learner performance data, thus enabling a form of differentiated instruction that is otherwise challenging for a single human trainer to achieve simultaneously across a large group (Yunanto et al., 2019).

However, the human trainer brings irreplaceable skills in emotional intelligence, improvisation, and socio-cultural sensitivity, which remain critical for fostering deep learning and higher-order thinking (Sibilio, 2014; Berthoz, 2015). One of the most significant strengths of NPC-based training lies in accessibility and inclusivity. Equipped with assistive technologies, NPCs can provide captions, real-time translations, and alternative content formats, such as simplified text, interactive diagrams, and audio descriptions, allowing learners with diverse cognitive and physical abilities to engage fully with the material (Aiello, 2024). This capability aligns with Universal Design for Learning (UDL) principles, which emphasise multiple means of representation, engagement, and expression.

Nevertheless, challenges persist. Current conversational AI still struggles with sustaining long-term contextual memory and recognising nuanced emotional states, meaning that the human element remains essential for promoting critical thinking, creativity, and socio-emotional development (Sabir et al., 2024).

From a broader perspective, the combination of adaptive instructional capabilities and the ability to simulate social presence positions NPCs as powerful facilitators of learner engagement. By reducing the

psychological distance between instructor and student, NPCs can transform remote or virtual settings into emotionally rich learning spaces, comparable in some respects to face-to-face interactions (Kyrlitsias & Michael-Grigoriou, 2022). In practice, the most effective model appears to be hybrid, where NPCs handle routine instructional tasks and adaptive content delivery, while human trainers focus on mentoring, fostering creativity, and managing complex classroom dynamics (Beatini et al., 2024).

In other word, NPCs should not be seen as replacements for human educators, but as pedagogical amplifiers, tools that extend the reach of teachers, ensure continuity of instruction, and enrich the learning experience through adaptive, data-driven strategies. Their successful integration depends on aligning technical capabilities with clearly defined pedagogical objectives, ensuring that technology support the human dimension of teaching.

IV. NON-PLAYER CHARACTER WITHIN A VIRTUAL MUSEUM

An alternative to the conventional linear approach to museum visits, often solitary experiences for visitors who may not be well, versed in the subject matter before them, can be found in multimedia and multimodal technologies. Consider, for instance, a tourist exploring a capital city who decides to visit a major museum, or a traveler on a day trip who stumbles upon a historic castle, enters, and encounters a museum filled with remarkable artworks, yet explained only through cold, static captions placed beside the objects. In such cases, digital tools such as edugames, virtual reality, and 3D printing offer valuable opportunities for engaging visitors with different learning styles. For these technological tools to be truly effective, they must be adapted to accommodate diverse cognitive styles, recognizing that each form of intelligence encompasses a set of psychological processes. The virtual environment represents a significant departure from traditional museum education, which is primarily structured around display cases and textual descriptions, relying almost exclusively on linguistic abilities. This approach does not always succeed in stimulating curiosity and interest in all visitors (Sibilio, 2024).

This potential becomes even more powerful when 3D environments feature a NPC capable of responding to visitors' questions. If properly trained using materials provided by museum directors, art historians, archaeologists, and experts, such an NPC could effectively communicate with both children and specialists alike, offering tailored and contextually relevant information. More in detail, An NPC (Non-Player Character) in a virtual museum serves as an essential tool for enriching user experience through various interactive functions. Firstly, it can act as a virtual guide, providing detailed information about artworks, exhibited objects, and the museum's history while allowing users to engage through questions and receive personalized responses. Additionally, the NPC can introduce storytelling elements by narrating historical contexts and anecdotes about artists and their works, making the experience more immersive and engaging. From an educational perspective, the NPC can facilitate learning through interactive activities and quizzes, promoting user engagement with the exhibited content. Moreover, it can offer technical support and accessibility features, such as adjusting brightness, contrast, and viewpoint, ensuring an inclusive experience for individuals with learning disabilities, special educational needs, or physical limitations; or consider intellectual disability, which is a condition characterized by significant limitations in intellectual functioning and adaptive behavior, affecting conceptual, social, and practical domains (Aiello, 2024).

The NPC can also personalize interactions by recommending artworks based on users' interests and preferences, enhancing their exploration. Finally, it can introduce entertainment and social interaction components, incorporating jokes, games, or casual conversations to make the visit more enjoyable. Overall, the presence of an NPC in a virtual museum significantly enhances the interactivity, educational value, and engagement of the user experience.

The implementation of an NPC within a virtual museum requires the integration of multiple technological components, ranging from artificial intelligence to real-time computer graphics, and extending to museum information systems management.

Over the years, the *Teaching Learning Center for Education and Inclusive Technologies – Elisa Frauenfelder* of the Department of Human, Philosophical, and Educational Sciences at the University of Salerno has collaborated with numerous museums to refine techniques for managing the virtualization process of cultural heritage. Notable examples include the *Virtual Museum of Herculaneum*, the *National Archaeological Museum of Sannio Caudino*, the *Civic Museum of Carife and Baronia*, the *Filangieri Museum in Naples*, the *Historical Museum of Villamaina*, the *Museum of Memory and Peace – Giovanni Palatucci National Study Center*, and the *De Chiara De Maio Foundation*. Theoretical reflections on how the edugame should function were inspired by numerous exchanges with the *Collège de France* and Professor Emeritus Alain Berthoz (Di Tore, Todino, Di Tore, Sibilio & Berthoz, 2023), as well as with the *University Hospitals Pitié Salpêtrière* (Beatini, Cohen, Di Tore, Pellerin, Aiello, Sibilio & Berthoz, 2024). Additionally, further contributions came from collaborations with the *Città della Scienza* in Naples and the *Cité des Sciences et de l'Indus*trie in Paris.
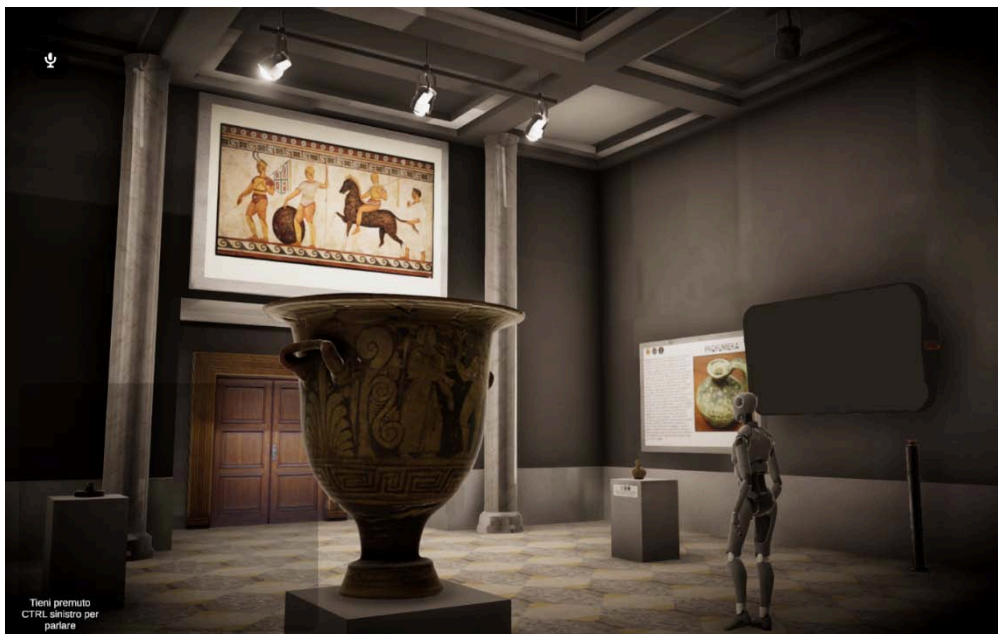

Figure 1: A virtual Museum with an NPC developed by the *Teaching Learning Center for Education and Inclusive Technologies – Elisa Frauenfelder.*

V. LOADING DIGITAL ASSETS INTO A VIRTUAL EDUCATIONAL ENVIRONMENT MANAGED BY AN NPC

In recent years, the evolution of virtual learning environments has made it possible to integrate heterogeneous digital assets, 3D models, interactive videos and multimedia repositories, into an instructional framework mediated by NPCs. This synergy between multimedia content and artificial intelligence enables the design of personalized and adaptive learning experiences that can respond in real time to students' needs, adjusting the difficulty and the mode of information delivery (Mayer, 2022). Literature highlights that diversifying input channels, visual, auditory, and kinesthetic, promotes better comprehension and retention of information, especially when content is contextualized within immersive and narratively coherent scenarios (Moreno & Mayer, 2007).

From an engineering perspective, the operation of a virtual learning environment managed by an NPC relies on a multi-layer architecture. The content layer hosts and organizes multimedia assets within a content management system (CMS) compatible with international educational standards, such as SCORM, ensuring not only interaction tracking but also granular analysis of performance and learning sequences. At this stage, external repositories and libraries of 3D objects optimized for real-time, reducing loading times and improving usability even in low-bandwidth contexts.

The processing layer constitutes the intelligent core of the system, implementing pedagogical rules and machine learning algorithms to adapt content delivery. Here, Natural Language Processing systems are employed to interpret student questions, predictive analytics models to anticipate difficulties and attention drops, and recommender systems to suggest supplementary materials based on the learner's progress and preferences. Personalization is achieved through learner profiling models that integrate historical data, real-time performance, and behavioral indicators, enabling the modulation not only of conceptual complexity but also of the NPC's communicative style.

The presentation layer manages visual rendering and interaction, integrating assets and interfaces into navigable three-dimensional environments developed with graphic engines such as Unity or Unreal Engine, and enriched with embodied interaction elements and multimodal interfaces. In this context, the NPC acts as an interface orchestrator, managing procedural animations, lip-sync, gestures, and emergent behaviors to enhance realism and presence.

Figure 2: An NPC schema of functioning within a virtual museum environment involves the interaction with multimedia files for training purposes and the subsequent presentation of these materials to users visiting the virtual space

VI. CONCLUSIONS

Within this ecosystem, the NPC serves as an intelligent instructional mediator. In addition to selecting and presenting the most relevant content based on the learner profile, it provides immediate feedback, guides learning through targeted exercises, and fosters metacognitive reflection. Recent studies indicate that the presence of conversational agents in VR environments can significantly increase social presence and telepresence, elements strongly correlated with sustained attention and intrinsic motivation (Zhang & Mo, 2025).

From an interoperability standpoint, adopting semantic standards such as CIDOC CRM and the Europeana Data Model allows the integration of resources from different institutions, ensuring broad reusability and enriching the shared educational heritage (Doerr, 2003). These standards can be combined with security protocols and privacy-by-design approaches to ensure personal data protection, a fundamental requirement in international educational contexts.

The use of NPCs in digital asset management also opens significant prospects for educational inclusion. Features such as automatically generated audio descriptions, real-time adaptive captions, and voice-controlled interfaces can make the learning experience truly universal. Despite technological advancement, the literature agrees that the role of the human educator remains indispensable, as a bearer of emotional competence and critical judgment that AI, at its current state, is not yet able to replicate (Sibilio, 2014).

Looking ahead, the convergence of digital assets, immersive environments, and advanced NPCs could redefine the concept of the virtual classroom, transforming it into an open, adaptive, and culturally rich space where physical distance is no longer a barrier but an opportunity to expand the boundaries of learning and foster truly global and connected education.

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A Review on Innovative Nanocellulose Solutions for Wastewater Treatment and Reusability of Nanocellulose

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ABSTRACT

About 14,000 individuals lose their lives every day as a result of exposure to certain toxins in the environment. Reducing these pollutants to acceptable levels using existing methods including adsorption, biodegradation, oxidation, precipitation, reverse osmosis, and photocatalysis is costly, energy-intensive, and unsustainable. A novel method of cleaning up these chemical pollutants combines biosorption with nanotechnology. Nanocellulose (NC) has been widely utilized to cleanse water. According to reports, nanocellulose may be utilized to eliminate various contaminants from water systems, such as dyes, heavy metals, medications, pesticides, medicines, and microbiological cells. There is a lot of interest in wastewater management globally in developing practical treatment methods to guarantee the supply of clean water. The abundance of -OH groups that allow nanocellulose to bond with heavy metals, dyes, and other pollutants and high aspect ratio are its specializations for this specific application. This review summarizes the application of nanocellulose in wastewater treatment, namely as heavy metal, oil, salts, and dye adsorbents and as membranes for filtering other pollutants, such as microorganisms. The effectiveness of nanocellulose over conventional methods towards wastewater treatment is also reviewed.

A Review on Innovative Nanocellulose Solutions for Wastewater Treatment and Reusability of Nanocellulose

Gatawa Biswalo Gatawa

ABSTRACT

About 14,000 individuals lose their lives every day as a result of exposure to certain toxins in the environment. Reducing these pollutants to acceptable levels using existing methods including adsorption, biodegradation, oxidation, precipitation, reverse osmosis, and photocatalysis is costly, energy-intensive, and unsustainable. A novel method of cleaning up these chemical pollutants combines biosorption with nanotechnology. Nanocellulose (NC) has been widely utilized to cleanse water. According to reports, nanocellulose may be utilized to eliminate various contaminants from water systems, such as dyes, heavy metals, medications, pesticides, medicines, and microbiological cells. There is a lot of interest in wastewater management globally in developing practical treatment methods to guarantee the supply of clean water. The abundance of -OH groups that allow nanocellulose to bond with heavy metals, dyes, and other pollutants and high aspect ratio are its specializations for this specific application. This review summarizes the application of nanocellulose in wastewater treatment, namely as heavy metal, oil, salts, and dye adsorbents and as membranes for filtering other pollutants, such as microorganisms. The effectiveness of nanocellulose over conventional methods towards wastewater treatment is also reviewed. Applicability of cellulosic nanomaterials in wastewater treatment as well as aspects of nanocellulose as an adsorbent for diverse water contaminants are highlighted in this review. The broad application of materials based on nanocellulose as adsorbents and catalysts is made possible by the commercial processing of cellulose. The membrane technologies' longevity and efficacy in separating materials have been demonstrated. Recent advancements in the creation of innovative membranes or adsorbents promote the use of cleaner technologies based on NC for treatment of wastewater. Future research prospects of nanocellulose composites for wastewater treatment are also discussed, along with the difficulties and possibilities of nanocellulose-based composites in these fields.

Keywords: desalination; heavy metals; modification; membrane; nanocellulose; reusability; water treatment.

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I. INTRODUCTION

Water, which makes up around 71% of the Earth's surface, is necessary for all life systems. The universe's water content is maintained. Nonetheless, water consumption has been rising at a rate that is more than twice as fast as the whole population. Because of the substantial increase in water utilization, problems like water pollution, and water scarcity, clean water has emerged as a crucial concern of the twenty-first century. In order to provide the basic needs of industrial and household water, wastewater treatment is a necessary technology. A sustainable solution may be provided by cellulose-based polymers, which might address issues including the buildup of oil reserves, plastic pollution, and carbon emissions. As a result, cellulose synthesis is crucial. Water treatment [1], ultraviolet protection [2], and biomedicine [3] have all made extensive use of cellulose-based products.

They provide environmentally friendly purifying methods. Both with and without substrates, they work well as materials for membrane-based technologies [2].

Water sources across the world have been revealed to comprise a diversity of contaminants, such as organic dyes, heavy metals, medicines, and petroleum products [4]. They are extremely dangerous to persons and other alive things because of their poisonousness and bioaccumulation [5]. Therefore, it is now urgently necessary to remove them from the seas. Reverse osmosis, filtration, solvent extraction, precipitation, adsorption, ion exchange, and coagulation are just a few of the methods that have been used throughout the years to remove these contaminants [6]. Nevertheless, the majority of these techniques are quite costly, have poor clearance rates, and need further treatments [7]. However, adsorption appears to be receiving a lot of attention amid these technologies due to its simplicity of use, high economic values, ability to remove contaminants at low concentrations, high accessibility and efficiency, to a variety of adsorbents, for example carbon nanotubes (CNT), composites, and tiny-particles [8]. Compared to their non-biological adsorbent equivalents, biomaterials such as chitin, starch, cellulose, chitosan, alginate, and gelatine have the benefits of being non-toxic and biocompatible when applied to eliminate contaminants from water. Cellulose is superior to these biomaterials due to its relative plenty in nature, renewable properties, non-toxicity, and the presence of OH functional groups that are employed in a number of instigation activities [9]. In spite of its many advantages, cellulose's limited adsorption capacity and weak hydrophilicity, and its low chemical and physical steadiness, are its drawbacks in water remediation [10]. To boost cellulose's adsorption capacities, this disadvantage can be addressed by turning it into a nanosized substance [11]. A cellulosic substance with a single dimension in the nanometre range, nanocellulose (NC) has excellent mechanical strength, stability, and surface area [12]. Nanocellulosic material can be classified as cellulose nano-crystals (CNC), cellulose from bacteria (BC), or nanofibrillated cellulose (NFC) based on how it was isolated [13]. Nanocellulose's exceptional qualities have made it a perfect reinforcement for a variety of nanocomposites, including ceramics, graphene oxides which are reduced, CNT, and non-metals, which are used in water remediation [14]. Examining several nanocellulose-based composites that are employed to adsorb different harmful chemicals from water is the goal of this review. There is also discussion of the problems that exist now, potential remedies, and potential future developments.

Recent advances in nanotechnology have produced a range of innovative materials based on nanocellulose (NC) that show promise for wastewater reduction and purification [15]. Numerous inexpensive sorbents have been shown to be successful in removing dye from both industrial and agricultural wastewater [16]. To fulfil this need for industrial scalability, nanocellulose (NC) may be utilized to provide an ecologically friendly and economically viable solution [17]. The probability of turning cellulose into small scale materials utilizing several physicochemical techniques has unlocked up a novel area for researchers to examine the characteristics and probable applications of this nanomaterial in the wastewater treatment. Nanocelluloses are favored over small-dimensional materials for efficient elimination of pollution because of their large surface area and nano-dimension [18]. Surface alterations allow the backbone of cellulose to be refined and adapted for a particular purpose because of the diversity and ease of incorporating functional groups into the structure of NC [19]. There are exponential increases in the publications number over the year on the utilization of NC in water treatment as seen in Figure 1 [2].
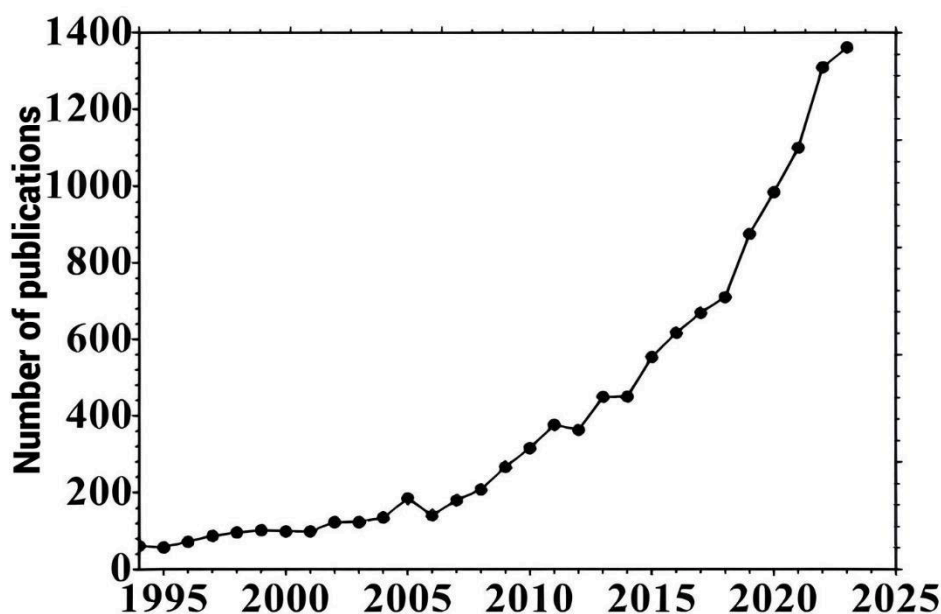
Figure 1: Scientometric investigation of cellulose in water treatment centered on publications number [2].

The first section of the review provides a concise overview of current approaches used in purification of water. The specific characteristics of nanocellulose that forms the prerequisites for an adsorbent is examined. The subsequent section discusses the modification of nanocellulose for water treatment. Also the applications of nanocellulose to eliminate a diversity of pollutants from water, comprising bacteria, heavy metals, oil, hazardous textile colours and viruses, are highlighted. The reusability of nanocellulose based materials is reviewed and then the current challenges and research opportunities, emphasizing the significance of enhancing nanocellulose production methods and looking at its potential for widespread usage in real-world wastewater treatment applications is discussed in this review paper.

II.   THE EFFECTIVENESS OF NANOCELLULOSE OVER CONVENTIONAL METHODS TOWARDS WASTEWATER TREATMENT

Nanocellulose, resulting from renewable materials of plants, has arisen as a favorable solution in treatment of wastewater because of its unique characteristics, including biodegradability, mechanical strength, as well as high surface area. As industries progressively face strict regulations regarding quality of wastewater, the requirement for sustainable and effective treatment technologies is more demanding than ever. NC can significantly improve the effectiveness of conventional wastewater treatment procedures by acting as a flocculant, enhancing the exclusion of pollutants and allowing the recovering of treated water [20]. Furthermore, the economic profits of consuming NC in treatment of wastewater are noteworthy. Different studies have revealed that its incorporation can lead to cheap operating costs by depressing consumption of energy and usage of chemicals [21]. For example, the utilization of NC can improve the settling characteristics of sludge, reducing the volume of mud created and reducing dumping costs [22]. As per industries attempt for sustainability while handling costs, NC offerings a viable substitute that not only increases treatment efficacy but also grants significant economic benefits. This dual benefit positions NC as a key player in the future of wastewater treatment. Precipitation, biodegradation, bio-sand, reverse osmosis, adsorptive filtration using ion exchange resins, photocatalysis, iron oxide and active alumina are a few of the traditional water treatment techniques that may be employed to remove impurities [23]. Nevertheless, only certain chemical pollutants may be eliminated from water using some of these methods. Potable water has long been

purified using a variety of techniques, including membrane separation, chemical oxidation, liquid extraction, electro-dialysis, electro-coagulation, electrolytic treatment, electrochemical treatment, adsorption onto activated carbons, and membrane technologies, even though adsorption–filtration is frequently the preferred approach [24]. The primary issues with these techniques are insufficient precipitation and the fabrication of substantial quantities of sludge, which are subsequently challenging to filter out for disposal. The expensive price of activated carbons, particularly those that experience material loss during regeneration after usage, is another barrier to their widespread adoption. Adsorption has been acknowledged as a desirable method for eliminating chemical pollutants since it is easy to use, doesn't produce any byproducts, and is less expensive than alternative techniques [25]. Through physical forces like weak forces known as van der Waals forces as well as electrostatic attraction, or through covalent bonds formed amid molecules of the oppositely electric adsorbate and the surface of adsorbent, adsorption enables pollutant molecules to adhere to the adsorbent's surface [26]. Nevertheless, the adsorbent's quality deteriorates after wards several rounds of usage, and the column of adsorption requires periodic cleaning also maintenance [27]. All adsorption-based methods, however, are not capable of functioning across extensive levels of pH which are important to the surroundings. In addition to pH, adsorption capacity is also significantly influenced by extra condition factors including duration of contact, operating temperature, and concentration of contaminant [28]. Ideal adsorption materials for contaminants must generally have the subsequent characteristics: (i) be affordable; (ii) be structurally and mechanically sound enough to sustain water flow over an lengthy duration; (iii) exhibit a great adsorption capability at a great rate; (iv) have a great specific surface area; as well as (v) be capable of regeneration utilizing economical approaches [29]. Materials based on nanocellulose are frequently utilized to remediate wastewater because they meet all of these criteria. NC's easy processability and inexpensive raw material costs may also make it more affordable than other nanomaterials like graphene and ceramics. With the remarkable adsorption capability of cellulose nanocrystals (CNC) and the significant potential to replace activated carbons, there are numerous approaches to producing appropriate, reasonably priced adsorbents from derivatives from industries and agricultural activities [30].

Recent advances in material science offer an extensive diversity of raw materials for the membranes creation. The majority of membrane materials utilized in filtration of water and wastewater today are polymeric. The main drawbacks of the majority of these membranes, however they are severe fouling brought on by their nature of hydrophobicity that negatively impacts flow, membrane lifetime, and separation efficiency. However, because of their high running costs and brittleness, inorganic membranes have a restricted range of applications [31]. The availability, renewability, and biodegradability of nanocellulose materials, along with their remarkable qualities of great water penetrability, outstanding mechanical capabilities, and expanded surface area, make them very intriguing for use in water filtration technologies. The many kinds of nanocellulose-based membranes that are used in water filtering are shown in Table 1. The removal capability of the specific pollutant and the water permeation flux are the main factors influencing the filtering effectiveness of membranes based on nanocellulose [32].

Table 1: Various categories of membranes based on nanocellulose for filtration of water

Materials	Filtration Method	Sample	Performance	Ref.
Cellulose nanocrystals and TOCNF coated polyethersulfone (PES) membrane	Membrane filtration	Water	Better antibacterial and antifouling qualities	[33]
Composite membrane of NC/filter paper	Ultrafiltration	Oily wastewater	Up to 97.14% retaining rate; 46,279 $L\,m^{-2}h^{-1}$ flux	[34]

Cellulose triacetate and novel thin film composite	Forward osmosis	Desalination	Cleaning by hand was more effective.	[33]
NC metalized with Ag and Pt	Forward osmosis	Wastewater, urea, and nanopure water,	High solute rejection and water flux with sample of wastewater	[35]
Carbon nanofiber (CNF)/cellulosic membranes	Forward osmosis	Desalination	15 L m^{-2}h^{-1} water flux	[36]
Cellulose acetate membrane	Ultrafiltration	Wastewater	Permeability of pure water, 207.32 L m^{-2}h^{-1}; flux recovery ratio, 90.56%	[37]
Biocellulose nanofibers membrane	Nanofiltration	Emulsified oily wastewater	99% effectiveness in separation; >94% permeate flux retrieval ratio	[33]
Cellulose acetate/copper oxide nanoparticles	Ultrafiltration	Wastewater	Better water penetration, separation of BSA, antifouling activity, and hydrophilicity	[38]
Nanocellulose as modifier for hollow fiber	Ultrafiltration	Dye	Rejection rose from 96 to 99%, whereas permeability increased by 1.5 times.	[39]
Cellulose membrane	Membrane filtration	Oily wastewater	99% of oil from peanut and pump nanoe mulsions are rejected.	[15]

III. EVALUATION OF NANOCELLULOSE IN WASTEWATER TREATMENT

Nanocellulose has bring in attention in treatment of wastewater because of its exceptional characteristics, including non-toxicity, biodegradability, and high surface area, making it an attractive choice for eliminating contaminants such as organic dyes and heavy metals. Its exceptional structure permits for enhanced filtration and adsorption proficiencies, contributing to more effective processes for wastewater treatment. Additionally, NC can be integrated into composite materials, improving the effectiveness of purification systems. Nevertheless, challenges continue concerning the scalability of production of nanocellulose and its cost-effective achievability in large-scale utilization [40]. While studies highlight the efficiency of NC in enhancing traditional wastewater treatment techniques, further research is essential to evaluate its long-term performance, sustainability, and overall effect on the environment.

3.1. Advantages of Nanocellulose in Waste water Treatment

Nanocellulose presents numerous benefits in treatment of water, mainly because of its sole chemical and structural properties. Its high surface area-to-volume ratio increases adsorption capability, making it operative for eliminating pollutants including dyes, heavy metals, and organic contaminants. Being non-toxic and biodegradable, NC offerings an eco-friendly substitute to conventional materials, decreasing environmental effect. Its capability to form aerogels and hydrogels permits for the effective retention and capture of impurities, enabling easier separation practices [32]. Additionally, NC can be simply modified to improve its functionality, for example through the introduction of groups which are

reactive that rise its affinity for particular contaminants. The lightweight nature of NC also adds to lower consumption of energy in treatment procedures related to traditional materials. Moreover, it's prospective for renewal and use again brands it economically feasible for long-term utilizations in systems of wastewater treatment. Largely, the multifunctional characteristics of NC position it as a favorable material for proceeding sustainable water treatment technologies, contributing to further effective and conservational solutions. One of the significant advantages of using nanocellulose is its biodegradability, which contributes to sustainability in wastewater treatment. Pollutants removed by nanocellulose do not pose the risk of secondary pollution, thereby promoting environmental safety [18].

3.2. Disadvantages of Nanocellulose in Treatment of Wastewater

Regardless of its promising utilizations, NC offers some shortcomings in treatment of water that must be spoken. One major challenge is the scalability of its fabrication; recent techniques can be expensive and energy-intensive, which restricts extensive adoption in large-scale wastewater treatment facilities. Furthermore, while NC is biodegradable, the potential discharge of microplastics in the course of treatment increases concerns about secondary contamination, predominantly in aquatic settings. There are also issues associated to the consistency and steadiness of NC in numerous water conditions; its performance can be affected by aspects for instance ionic strength, pH, and the existence of competing pollutants that may decrease its effectiveness. Also, the discharge of chemical additives utilized during the processes of modification can cause additional environmental hazards. Addressing these drawbacks through further research and novelty is critical to increase the potential of NC in sustainable solutions of water treatment [41].

IV. MODIFICATIONS ON NANOCELLULOSE TO IMPROVE FILTER EFFICIENCY

Once the filter membrane operates utilizing the affinity system, surface functionalization is a crucial step that can be accomplished through various strategies that encompass the chemistry of OH function [42]. Nanocellulose can be modified through a variety of processes, including esterification, etherification and oxidation that lead to introducing new functional groups on the material. Additionally, prior study has demonstrated that nanocellulose can be modified by the addition of compounds including quaternary compounds, aldehyde, antibiotics, citric acid, activated carbon, and tiny materials. Let's say, aldehyde groups are attached onto NC by oxidation utilizing oxidants including periodate Na and 2,2,6,6-teramethylpiperidinyloxy (TEMPO). This process places TEMPO on the nanocellulose's surface in aqueous settings, while the OH group at the C6 location of NC can be changed into aldehyde and carboxyl functional groups. In addition, quaternary compounds with low toxicity and no harm to the environment, for instance polyglutamic acid, poly(N,N-dimethylaminoethyl methacrylate), anionic polyelectrolytes, and amines, can be utilized to quaternize NC and increase effectiveness of nanocellulose as membrane filters because they can develop an electrostatic affinity for microorganisms. Both grinding and high-pressure homogenization might be used in this quaternization procedure. Several instances of NC functionalized employing quaternary chemicals for elimination of virus uses are shown in Figure 2. Since the majority of viruses and some microorganisms have polar charges on their surfaces, altering the nanocellulose's surface charge would enhance the material's electrostatic contact qualities, leading to excellent filtering efficiency [43].
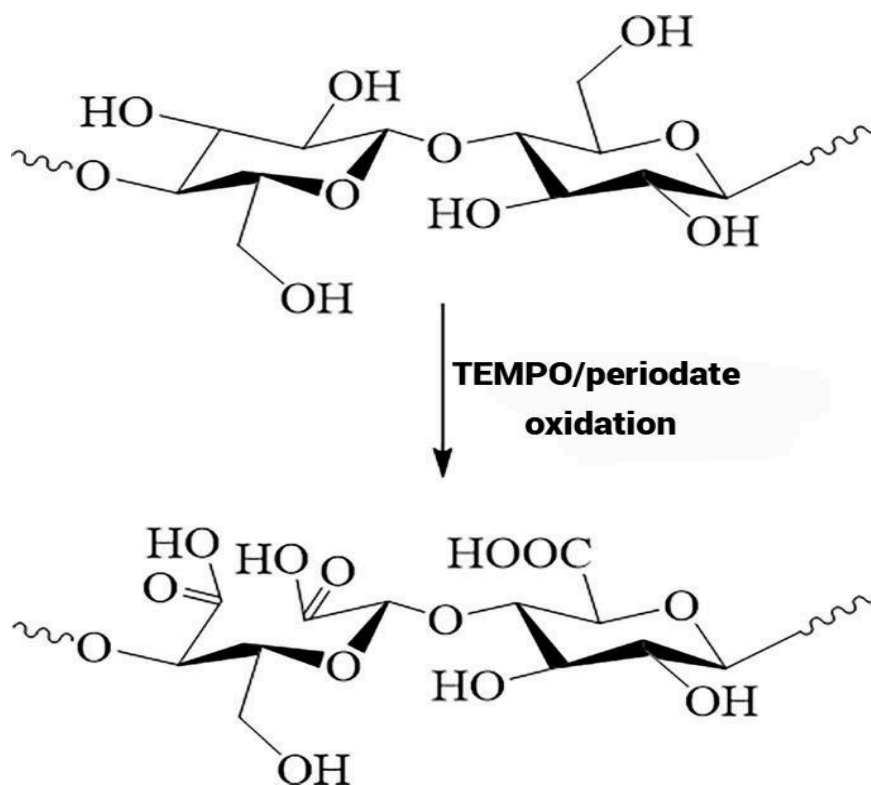
Figure 2: Functionalization of nanocellulose by TEMPO/periodate oxidation [43].

4.1. Potential Risks and Environmental Impacts of Nanocellulose Modifications in Water Treatment

The modification of NC for the purposes of water treatment offerings potential dangers and environmental effects that deserve careful concern. Although modifications can improve the adsorption properties of material and specificity to numerous pollutants, they frequently involve the usage of chemicals that may introduce harmful substances into the environment. For example, particular additives utilized in functionalization processes of surface may leak into treated water, causing risks to aquatic ecologies as well as human health. Also, the energy-intensive practices necessary for the production of NC and modification can add to carbon radiations and environmental deprivation. There is also a regard concerning the steadiness of modified NC in diverse water chemistries; changes in temperature, pH, or ionic strength may change its performance and lead to the discharge of microplastics [42].

V. APPLICABILITY OF CELLULOSIC NANOMATERIALS IN WASTEWATER TREATMENT

It is possible to modify nanocellulose to display new and markedly enhanced chemical and physical characteristics. Small diameter, high surface-to-volume ratio, plenty of OH groups enabling simple functionalization, outstanding mechanical qualities, and superior chemical resistance are some of nanocellulose's distinctive qualities. Nanocellulose is a very promising option for wastewater treatment because of these superior qualities. High aspect ratio and large surface area of NC create an ultrafine, 3-D network structure in an aqueous environment, which may be used to remove and absorb different types of water contaminants. The hydrophilic characteristic of cellulose has led to its usage as an antifouling hydrophilic covering to boost membrane flow. After being appropriately chemically modified on its surface to include molecules with elementary groups, especially those which are rich in N, O, and S, cellulose tends to show a high adsorption capacity for contaminants [44]. Because of their inherent plenty, structural variety, and easiness of functionalization, cellulose nanofibers have been the subject of much research [45]. In the areas of pollution prevention, treatment, and cleanup,

nanotechnologies have been hailed as having enormous promise to lower costs and increase efficiency [46]. By way of an active sorbent material for pollutants and in place of a stabilizer for other particles that are active, nanocellulose has sparked attention in this field. Nanocellulose's readily functionalizable surface enables the addition of various chemical moieties which might improve the adsorption also binding effectiveness contrary to water contaminants including colours, hazardous heavy metals, etc. Due to their low cost, high natural abundance, intrinsic environmental inertness, and high surface area-to-volume ratio, cellulose nanoparticles hold great promise as an alternative adsorbent. Additionally, the readily functionalizable surface of CN makes it possible to add chemical moieties that might improve the contaminants' ability to attach to the CN. The most extensively researched technique for enhancing CNs' sorptive ability is carboxylation. Modified CN matrices have also been shown to be effective at sorbing organic pollutants. To increase the material's affinity for hydrophobic chemicals, CNs' intrinsic hydrophilicity might be decreased. It is possible to manipulate the CNs' surface chemistry by adding inorganic as well as organic functionalities. Fast advancements in the nanosciences, particularly in the area of nanocellulose, present a promising new material type for application in treatment of water in the form of tiny particles. Incorporating both organic and inorganic functions into nanocellulose might alter its surface chemistry, potentially making it a H_2O repellent which can eliminate oils which have been dispersed on the surface of water. Water treatment microfiltration membranes based on nanocellulose have lately fascinated a lot of attention. Membrane construction for treatment of water may take use of nanocellulose's strength and characteristics. Membranes can benefit tremendously from nanocellulose's high strength. NC can raise the polymer membranes' stretchy strength by up to 50 percent at modest loadings of a few weight percentage when loading nanocellulose is low [47].

VI. ASPECTS OF NANOCELLULOSE AS AN ADSORBENT

As was already noted, nanocellulose's intriguing qualities have made it a material that may be utilized in a diversity of ways. NC is a great material as an adsorbent of chemical pollutants because it can functionalize its surface chemistry. Nanocellulose may be easily functionalized to add the needed functionality and create extremely efficient flocculants thanks to the hydroxyl groups, on its cellulose backbone [48]. The cellulose's chemical structure is seen in Figure 3, where hydroxyl groups are abundant. Aside from that, nanocellulose has several intriguing properties, such as the capacity to desorb and adsorb repeatedly, very high specific area, high permeability with good pore interconnectivity, great biodegradability, small weight, also a structure that resembles a rod or ribbon [49]. The importance of these distinctive characteristics of nanocellulose in its use as an adsorbent is summed up in Table 2. [1]
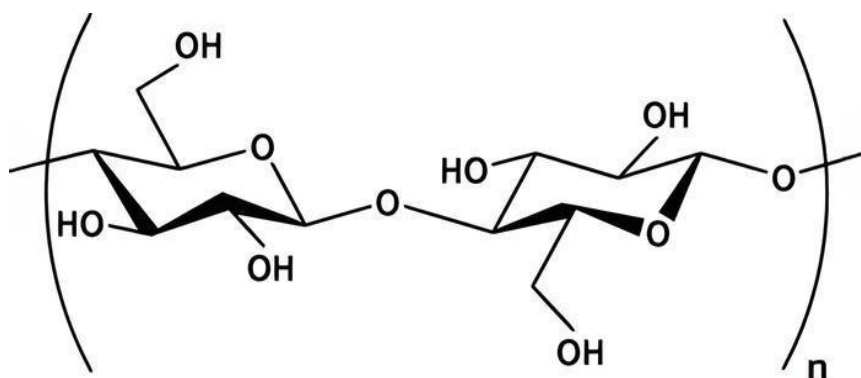

Figure 3: Chemical structure of cellulose.

Property	Benefits	Ref.
Refillable/desorption	The capacity to desorb and adsorb pollutants repeatedly. NC just needs a straightforward regeneration process which doesn't impair its ability to adsorb substances.	[50]
High mechanical properties	The adsorbent's mechanical qualities are enhanced by the high stiffness and cohesiveness of nanocellulose. This demonstrates an adsorbent's potential for renewal.	[51]
Good surface tension properties	Facilitating water-induced wetting of nanocellulose	[52]
Surface functionalization	Able to undergo grafting, silylation, etherification, esterification, oxidation, and addition to become surface functionalized. The adsorption capacity rises as a result.	[42]
Biodegradability	It decomposes naturally. Therefore, it doesn't hurt the environment.	[50]
Renewable	Economical in contrast to active carbon. able can be utilized from a diversity of feedstock	[30]
Stable in water	Nanocellulose's high hydrophilicity can lessen organic and biofouling. Because of nanocellulose's high crystallinity, the adsorbent is impervious to both chemical and biological corrosion in water.	[53]

VII. POLLUTANT REMOVAL MECHANISMS BY NANOCELLULOSE

NC reveals exceptional characteristics that brand it an operative an effective material for removal of pollutant in wastewater. Its surface chemistry unique as well as structure enable numerous molecular-level interactions with contaminants that can be classified into flocculation, electrostatic interactions and adsorption.

7.1. Flocculation Mechanisms

NC functions as a natural flocculant, accumulating suspended particles and contaminants through two key processes. These processes are described as follows: (i) Charge Neutralization: Adjustment of NC can change its surface charge, permitting it to neutralize contaminants which are negatively charged. For example, Aguado et al. (2023) found that cationic NC efficiently eliminated anionic dyes through charge neutralization, leading to the creation of larger collections which can be simply settled. (ii) Linking mechanism: NC fibers can physically bridge several particles together, improving sedimentation. This linking effect is critical for eliminating colloidal materials and suspended solids [54]. According to Mohd et al. (2017), the linking mechanism permits for the effective elimination of fine particles, enhancing general water clearness [55].

7.2. Adsorption Mechanisms

Polar impurities including heavy metals and dyes can be removed by materials which form hydrogen bond with them. NC comprises abundant hydroxyl groups that support hydrogen bonding with these polar contaminants. For instance, Liu (2021) verified that the OH groups on NC can successfully adsorb cationic dyes through hydrogen bonding, increasing elimination effectiveness. Moreover, the nanocellulose's porous structure and high surface area enable strong Van der Waals interactions with hydrophobic contaminants [41]. As reported by Abdelhamid et al. (2024), the adsorption capability for organic compounds which are non-polar considerably rises because of Van der Waals interactions that are crucial for the elimination of certain industrial contaminants [56]

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7.3. Electrostatic Interactions

There are several charged pollutants in water. These pollutants can be removed with materials through electrostatic interaction. The nanocellulose's surface charge can be modified to improve interactions with numerous charged contaminants. Cationic nanocellulose can be utilized to adsorb negatively charged contaminants including heavy metals and anionic dyes. By introducing cationic functional groups, NC can efficiently adsorb these contaminants. A study by Xiuping et al. (2017) revealed that cationic NC demonstrated significantly enhanced adsorption capabilities for anionic pollutants because of strong electrostatic attractions [57]. On the other hand, anionic NC adsorb contaminants which are positively charged. This adaptability makes NC appropriate for an extensive range of wastewater treatment applications [54]

VIII.   REAL-WORLD APPLICATIONS AND PILOT STUDIES OF NANOCELLULOSE-BASED WASTEWATER TREATMENT TECHNOLOGIES

NC has revealed significant potential in laboratory sites for treatment of wastewater, and there are developing real-world applications, pilot studies, and field trials that show its potential. The fabric industry is recognized for producing significant wastewater laden with chemicals and dyes. Many companies have initiated incorporating NC into treatment systems to improve dye elimination efficiency. For example, a pilot study done in India revealed that NC flocculants could decrease concentrations of dye by over 90%. Wastewater treatment technologies based on NC are gradually being discovered in real-world utilizations and pilot studies, indicating their potential for effective contaminant elimination. For instance, model projects have efficiently make use of NC composites for treating wastewater from industries, where they efficiently adsorbed organic dyes and heavy metals, showcasing important enhancements in discharge quality. Also, NC has been used in biofilters for treatment of municipal wastewater, improving the elimination of pathogens and nutrients whereas upholding low energy consumption. These uses highpoint the adaptability of NC in numerous treatment processes, such as filtration, and adsorption, as a support medium for bacterial biofilms. Furthermore, studies specify that NC can be incorporated into present treatment systems, providing an ecological and sustainable alternative to conventional materials. The positive results of these model studies highlight the practicality of scaling up NC technologies, paving the way for wider implementation in both industrial and urban wastewater treatment practices [58].

IX.   REMOVAL OF VARIOUS POLLUTANTS FROM WATER USING NANOCELLULOSE-BASED MATERIALS

Proteins, starch, chitosan, alginate, and cellulose are among the several biopolymers that have been utilised recently to treat wastewater [59]. Because of its unique structure, wide availability, and biodegradable nature, nanocellulose is one of the practical options for eliminating different pollutants from water. Desalination, oil removal, dye removal, and metal ion removal from water and wastewater have all been accomplished with nanocellulose. This section discusses several contaminants for which cellulose has been used as an adsorbing material [60].

9.1. Nanocellulose for Removal of Dyes

In recent years, the paper, textile, food, and pharmaceutical sectors have used synthetic chemical dyes much more often that has headed to the discharge and buildup of industrial effluents comprising colours into water systems. According to the literature, there are an estimated 7×10^5 to 1×10^6 tonnes of dyes produced year globally, and there are more than 1×10^5 different kinds of commercially obtainable dyes [61]. Due to their intricate aromatic structures, the majority of dyes are difficult for standard waste

treatment procedures to remove and are resilient to light, ozone, biological activity. One of the utmost effective means to extract textile colours from H_2O is via adsorption.

Materials made from nanocellulose have been used to industrial effluent to remove dyes. The colour that has been extracted from wastewater using nanocellulose the most frequently researched is methylene blue. Recently, cellulose nanocrystals with a high carboxylation content were prepared utilizing Fe (II)/H_2O_2 in an easy and environmentally friendly manner. With a removal effectiveness of up to 95.6%, the produced cellulose nanocrystals demonstrated a superior adsorbing ability for methylene blue from wastewater [62]. Luo and colleagues (2020) used a lignin/hemicellulose mix to create films generated from nanocellulose. The films had better mechanical qualities. The study also noted that hybrid nanocellulose films with lignin/hemicellulose solution showed outstanding methylene blue elimination efficiency (ranging from 192 to 429 mgg^{-1}) [63]. Utilizing nanowhiskers cellulose-based tiny-fibrous microfiltration membranes through adsorption, Ma et al. (2012) stated the elimination of crystal violet colorants. They applied TEMPO oxidation on the cellulose nanowhiskers' surface. A nanofibrous mesh which is cross-linked with an extremely great surface-to-volume ratio was produced by soaking cellulose tiny-whiskers into the poly(acrylonitrile) (PAN) electrospun scaffolding to create the nanofibrous microfiltration membrane based on cellulose nanowhiskers. The formed membrane for adsorption of crystal violet (CV) dye was found to have a maximum adsorption capacity 16× more than that of the commercially accessible membrane GS0-22, as seen in Figure 4. This occurred because the surface of the cellulose nanowhiskers had extremely negative carboxylate groups and protonated CV molecules that were strongly attracted to each other electrostatically [61]. In order to eliminate anionic dyes from aqueous solutions, Jin et al. (2015) produced a unique NC-based tiny-composite microgel and amphoteric polyvinyl amine (PVAm) using a 2-step process. Because the produced microgel protonates amino groups, it was shown to be efficient in removing anionic dyes in acidic environments. According to absorption tests, the produced microgel revealed a great adsorption capability of 1469 mgg^{-1} for Congo red dye [64].
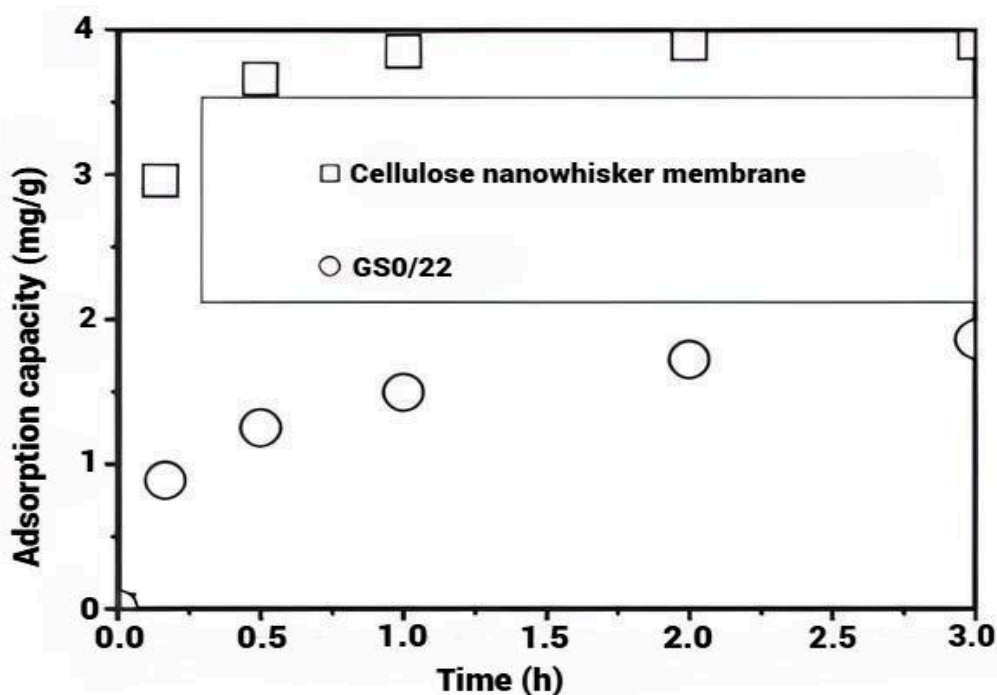

Figure 4: Adsorption capability towards CV dyes of membrane based on cellulose nanowhisker and GS0.22 against time [61].

9.2. Nanocellulose for Filtration of Microbes

When microorganisms contaminate water, it can lead to major epidemics of waterborne illnesses including cholera, giardiasis, cryptosporidiosis, and gastroenteritis. *E. coli*, *Legionella sp.*, *Campylobacter jejuni*, *Vibrio cholera*, in addition *Shigella dysenteriae* are the most often implicated bacteria in these epidemics [65]. However, gastrointestinal disorders such as cryptosporidiosis and giardiasis are brought on by protozoa or tiny parasites, specifically *Cryptosporidium sp.*, and *Giardia duodenalis* respectively [66]. Due to drinking tainted water, an estimated 485,000 persons each year pass away from diarrhoeal illness (WHO 2019). Therefore, before being released into bodies or courses of water, effluent that has been microbially polluted has to be treated. With small pore sizes ranging from 1 to 100 nm, nanocellulose has several special qualities that make it a favorable material for utilize as a high-performance membrane filter which can efficiently eliminate microorganisms from air or liquids. These qualities include high surface area, great strength, chemical inertness, and hydrophilic surface chemistry [67].

A citric acid cross-linked NC-based paper was created by Quellmalz and Mihranyan (2015) for size-exclusion nanofiltration. The cellulose nanopapers were cross-connected with citric acid to improve the wet strength of paper. According to their particle retention tests, tracer particles as tiny as 20 nm might be eliminated by the produced paper. In order to create paper-based sterile (virus) elimination filters, they came to the conclusion that cross-linking nanocellulose with citric acid was advantageous [68].

9.3. Nanocellulose for Absorption of Oil

Large ship oil leaks are a major cause of oil contamination, but additional types of pollution also contribute to the problem, releasing extra oil into the sea overall. When oil builds up on the water's surface, a number of negative consequences may arise. The oil spreading across the water's surface is the most frequent result. Oil spreads across the water's surface when it spills because it is often less thick than water. Water for drinking and other uses can get contaminated by oil effluence, which can also damage ecosystems that support animals as well as plants. Cleaning up oil spills in water is crucial. Research has been done to create materials that are strong, reusable, floating, ecologically benign, and capable of quickly absorbing vast amounts of oil without absorbing water. These materials may also be burnt together with the oil they absorb [47]. A functionalized cellulose nanofibrils-based materials was shown by Korhonen et al. (2011). Cellulose is natural, renewable polymer, also most abundant. By vacuity freeze drying microfibrillated cellulose hydrogels, they created extremely porous nanocellulose aerogels, as seen in Figure 5. They demonstrated how the hydrophobic titanium dioxide oleophilic covering functionalizes the aerogel's natural cellulose nanofibrils, allowing them to preferentially absorb oils from water. As seen in Figure 6, the low density of the surface-modified aerogels and capability to absorb oils as well as non-polar liquid up to nearly their full original volume allow them to remove organic contaminants from the surface of water. They revealed that, depending on the liquid's density, the adsorption capacity based on mass ranges from 20 to 40 (wt/wt), and that the absorption was nearly equal to the total volume of aerogel (80% to 90% vol/vol). According to their findings, aerogels based on nanocellulose show promise as oil absorbents for upcoming environmentally friendly uses [69]. The enhanced manufacturing and capabilities of oil absorption of super-hydrophilic reused cellulose aerogels were reported by Feng et al. (2020) They used chemical vapour deposition to cover the reused cellulose-based aerogels with methyl/trimethoxy silane (MTMS), which produced outstanding capacities of oil absorption up to 95 gg^{-1} with the 0.25 weight percent cellulose-based aerogel and highly steady super hydrophobicity for over 5 months. It was demonstrated that the generated cellulose aerogels' capacity to absorb oil is highly influenced by the initial concentration of cellulose fibre. They came to the conclusion that among of the utmost favorable sorbents for cleaning up oil spills would be the super-hydrophobic recycled cellulose aerogels that were shown [52].
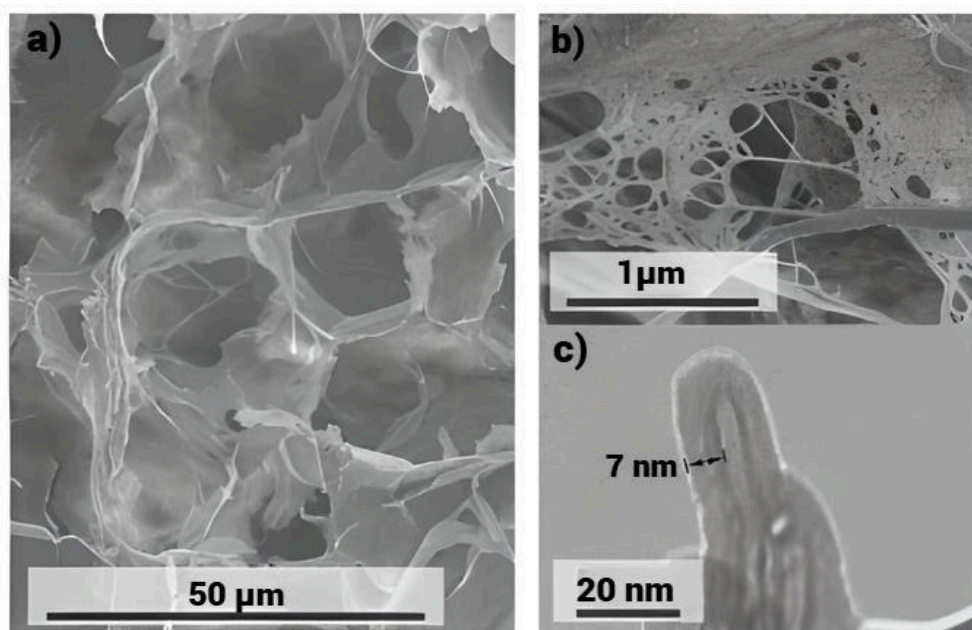
Figure 5: Microscopic structure of innate NC aerogels. SEM micrographs of (a) freeze-dried NC aerogels with fibrils packed into sheets, which are linked to make an open, porous aerogel structure, and (b) an intensification of a sheet, which is composed of fibrils forming the structure also nanoporous. (c) TEM micrograph of a nanocellulose fibril with an even 7 nm titanium dioxide coat [70].
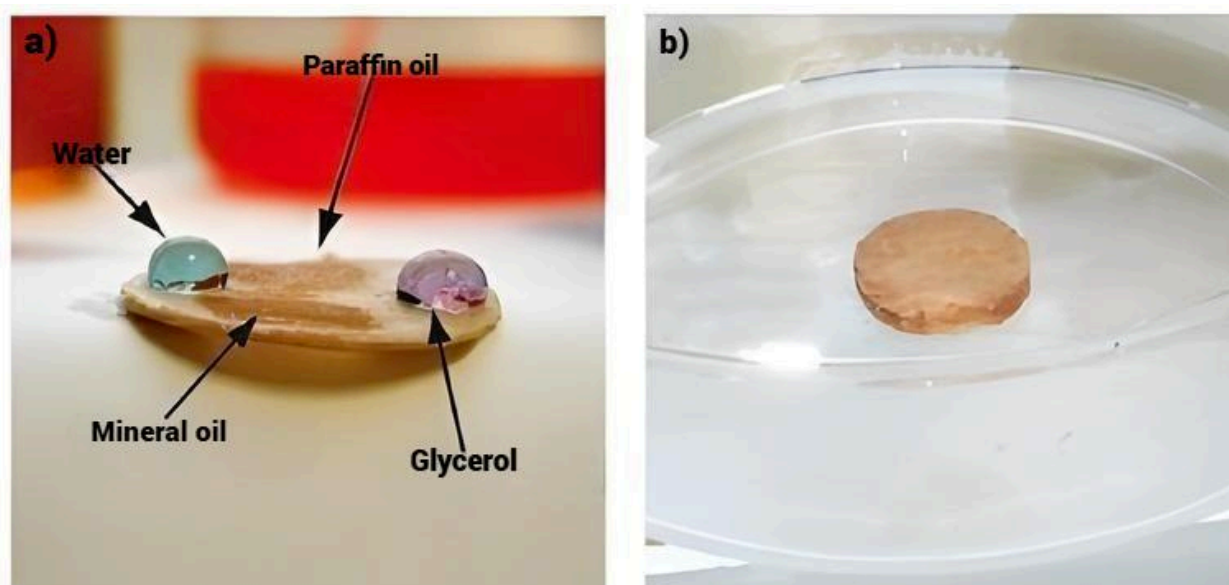
Figure 6: (a) Aerogels coated with TiO_2 are oleophilic also hydrophobic: the H_2O and glycerol stay as droplets, while mineral oil and paraffin oil are readily absorbed. (b) Coated aerogel floating on H_2O [70].

9.4. Nanocellulose for Heavy Metal Adsorption

Cadmium, lead, arsenic, copper, mercury, and chromium are examples of heavy metal ions that have been a hazard to aquatic and human life. According to [71], the majority of heavy metal ions that are released into the environment come from various sectors, including metals, batteries, fertilizers, electroplating operations, oil and gas, and dyes. According to Pan et al. (2016), the limited mobility,

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non-biodegradability, and bioaccumulation of heavy metals make them extremely detrimental to the ecosystem [72]. Heavy metals can be found in wastewater from a diversity of businesses, together with the pesticide, paper, and metal plating industries. The effects of heavy metal pollution are severe since these metals are not biodegradable and have a tendency to build up in alive things [73]. A number of techniques, including chemical precipitation, the use of ion exchange resins, and coagulation, have been proposed for the elimination of heavy metals out of water [74]. Adding a secondary chemical to the H_2O is one of these techniques for getting rid of heavy metal ions. Therefore, in order to produce potable drinking water, this secondary component needs to be eliminated from the water [73]. Centered on the sorption procedure, the elimination of hazardous heavy metals from H_2O has remained regarded as a potential method. Globally, investigators are becoming progressively interested in finding economical, effective bio-based materials that have improved sorption and stability while lowering the dosage of biomass. Because of its chirality, hydrophilicity, and reactivity, nanocellulose has emerged as a viable sorbent material for the elimination of hazardous heavy metal ions out of wastewater [75].

For the elimination of copper (II), cadmium (II), and lead (II) from solution of contaminated water, Zubair and colleagues stated a simple production of acrylic acid attached CNC derived adsorbent utilizing the hydrothermal method; the results showed a maximum of 872, 898, and 1026, mgg^{-1} for copper (II), cadmium (II), and lead (II), respectively, from aqueous solutions which are acidic; the isothermal, kinetic, and thermodynamic investigation demonstrated that the adsorption phenomenon was very well fitted with the Freundlich isotherm model and pseudo-second-order [60]. Another intriguing study was conducted by Wang and colleagues (2013). They reported used PVAm grafting on cellulose nanofibers to eliminate Cr (IV) from the H_2O. The high number of amine groups in PVAm-grafted cellulose nanofibers produced positive charges in the pH¼7 solution, which made it easier for Cr (IV) ions which are negatively charged to be adsorbed from the aqueous solution. They discovered that the membrane of PVAm-CNF, as illustrated in Figure 7, exhibited capacity of adsorption of 100 mgg^{-1} against chromium (IV) ions from the solution [76]. Karim et al. (2016) used multilayered nanocellulose membranes to effectively eliminate silver (I) copper (II), and iron (II)/iron (III) ions from mirror manufacturing discharges. They used cellulose nanofiber solutions that had been vacuum-filtered, then CNC having carboxyl or sulphate surface groups were dip-coated to create the membranes. The tensile strength of CNF coated using carboxyl surface-grouped CNC was high (95MPa). Additionally, they proposed that by adjusting the drying conditions and acetone treatment, structure of the pore, the specific surface area, water flow, and membranes' wet strength that were displayed could be customized [77].
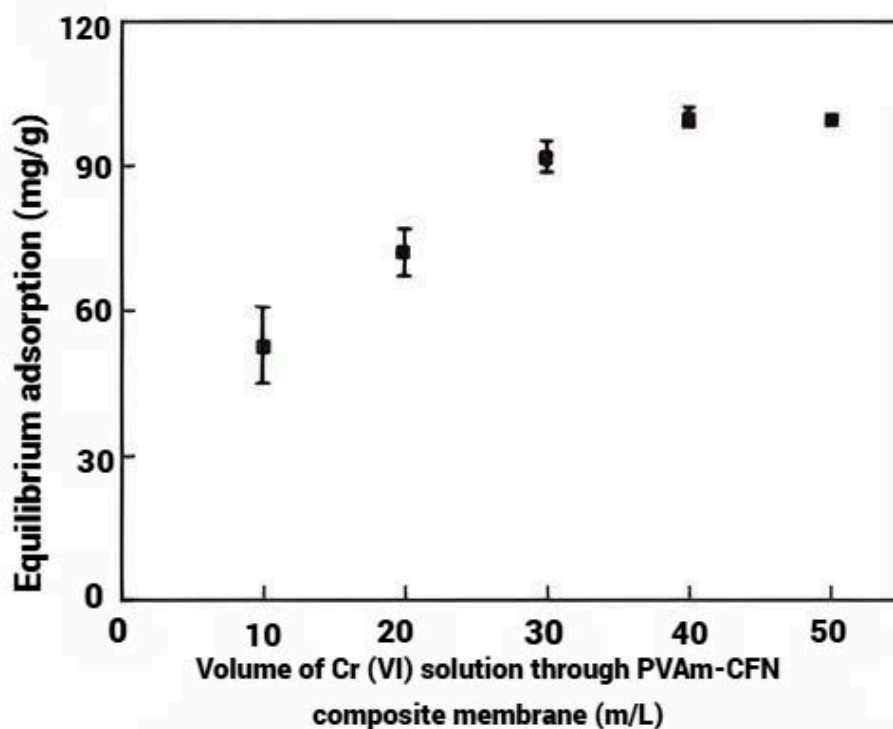
Figure 7: Active adsorption of chromium (VI) solution done with PVAm-CNF membrane [76].

9.5. Desalination

The procedure of producing fresh water by eliminating salts and minerals from seawater is called desalination [78]. In general, technologies of desalination can be separated into 2 separation procedures: desalination based on membrane and thermal desalination. Desalination based on membrane includes electrodialysis, nanofilteration, and reverse osmosis, whereas the thermal procedure includes multistage flash, multiple effect distillation, as well as vapour compression distillation, [79]. The application of membrane technology for desalination of water has remained steadily increasing, whereas the thermal procedure has remained largely unaffected [80]. In order to improve the membranes' performance, there has been a heightened interest in developing tiny composite membranes by combining matrix of polymer with hydrophilic tiny fillers. Several physicochemical characteristics of membranes have been discovered to be improved by the incorporation of hydrophilic nanoparticles [81]. The most often utilized nanomaterials in the creation of desalination membranes include graphene oxide, titanium oxide, silica, carbon nanotubes, alumina, clay, and carbon dots [60]. But the persistent problem with these nanomaterials is that they aggregate while making nanocomposite membranes, which still has to be fixed for better outcomes [82]. The use of cellulose nanocrystals as a nanofiller in membrane construction has grown significantly due to its inexpensive cost, hydrophilic nature, low density, and favourable mechanical characteristics. Furthermore, cellulose nanocrystals can be a desirable alternative to traditional inorganic fillers since they are non-hazardous, renewable, and simply changed to improve their surface qualities [83]. By adding cellulose nanocrystals to a polyamide layer, Bai et al. (2018) created a new thin-film composite tiny filtration membrane (CNC-TFC-Ms). When matched to control membranes (lacking CNC), the study found that the bivalent salts Na_2SO_4 and $MgSO_4$ had strong elimination performance, with elimination rates exceeding 98 percent and 97.5 percent, respectively [84]. Using the forward osmosis procedure, [85] have created and studied carbon tiny fiber/cellulosic membranes for desalination of water. Carboxylic and amine functionalized carbon tiny fibers were used to create membranes. For

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A Review on Innovative Nanocellulose Solutions for Wastewater Treatment and Reusability of Nanocellulose

seawater desalination, membranes made with functionalized carbon nanofibers have demonstrated enhanced H_2O flow (15 L/m²h) once employed in approach of forward osmosis. New multifunctional membranes with enhanced H_2O penetrability (25.4 L/m²h bar) and a higher rate of elimination for Na_2SO_4 (99%) have recently been described. These membranes are made by combining silver and CNCs into a layer of polyamide. Additionally, these membranes were discovered to have antibacterial and antifouling properties [86].

X.   REUSABILITY OF NANOCELLULOSE

Adsorbent reusability is an important consideration for industrial wastewater treatment applications since it has a big impact on operating costs. Adsorbent regeneration is required due to economic considerations, particularly for costly adsorbents. There are two methods of regeneration: chemical and physical regeneration. Temperature is linked to physical regeneration, whereas chemical solvent is employed in chemical regeneration to remove adsorbate out of a solid adsorbent. As far as we are aware, no physical renewal has been done to renew changed NC adsorbents as it involves high temperatures which can break down the nanocellulose's structure. In order to regenerate the improved NC adsorbent, chemicals including alkaline and acid solution were utilized as seen in Table 3. For two to six adsorption-desorption cycles, regeneration with a strong base or acid produced a great regeneration effectiveness (greater than 50%) [75]. Nevertheless, in certain instances, such as the nickel and lead adsorption by succinic anhydride improved NCC, the active sites were damaged by the adsorbent renewal process using hydrochloric acid, which led to a poor regeneration efficiency. Continuous ion exchange amid multiple Na^+ and metallic adsorption led to good regeneration efficiency when $NaHCO_3$ and succinic improved NCC were regenerated utilizing saturated sodium chloride solution [87]. The results of using nitric acid to recover succinic anhydride-modified nanocellulose were not adequate. But after an extra 15 seconds of ultrasonic treatment, the regeneration effectiveness rises to 96% to 100%. It was noted that the entangled fibres might be separated by ultrasonic treatment, resulting in a reduction in adsorption efficiency. It was also examined how weak acids, including acetic, ascorbic acids, and formic, affected the recovery of nanofibers; the findings showed that weak acids were not appropriate for use in regeneration [88]. Even after four cycles, the regeneration of carbonated hydroxyapatite improved NC following Cd^{2+} adsorption utilizing nitric acid demonstrated a high regeneration effectiveness. However, when the number of rounds rises in the adsorption of Ni^{2+}, the adsorption capability decreases. Utilizing NaOH as the renewing agent, comparable results were achieved for the PO_4^{3-} and NO_3^- adsorption [70]. Although regeneration utilizing sodium hydroxide and the mixture of HCl/C_2H_6O gave high effectiveness, approximately 97 and 80 percent, respectively, it appears that the recovery of the adsorbent using NH_4OH/NH_4Cl and HCl did not yield good results for the adsorption of methylene [89].

Table 3: Renewal performances of modified NC adsorbent

Adsorbent	Sorbate	Regenerant	Concentration	Cycles	Efficiency	Ref.
Nonocellulose	Fluoride	NaOH	0.1 M	5	89%	[90].
Xanthated nano banana cellulose	Cd^{2+}	HCl	0.1 M	4	87.5%	[91]
Poly(itaconic acid)-poly(methacrylicacid)-graftednanocellulose/ nanobentonite	U^{6+}	HCl	0.1 M	6	89.60%	[92]
NFC	Cd^{2+} Pb^{2+} Ni^{2+}	HCl	0.5 M	4 4 4	74.38% 72.25% 63.35%	[75]

Magnetic iron tiny particles improved microfibrillated cellulose	As(V)	NaOH	1.0 M	4	69.16%	[93]
Succinic anhydride improved NCC	Pb^{2+}	HCl		3	48%	[87]
$NaHCO_3$ and succinic modified NCC	Pb^{2+}	NaCl		3	88%	[87]
Succinic anhydride modified NC	Zn^{2+}	HNO_3	1 M	2	14.15%	[88]

Using a new technique, Zhang et al. (2016) created an extremely effective aerogel based on cellulose with a great mechanical strength. With its flawless 3D structure and honeycomb-like linked pores, the produced aerogel demonstrated exceptional oil/H_2O selectivity. Additionally, the observed aerogels revealed steady super-oleophilic and super-hydrophobic characteristics, even approaching a significant mechanical scratch. Additionally, they revealed the 30-cycle reuse of cellulose aerogels [94]. The used adsorbent was obtained by filtering the reaction mixture following the first catalytic elimination of fluoride. After properly cleaning the adsorbent many times using distilled water, the nanocellulose fibre residue was let to dry. Up to five cycles, the recovered adsorbent was once again utilized straight away in a subsequent catalytic reaction run. It was discovered that the same adsorbent may be used for five repetitions of the reaction without causing a noticeable drop in performance in either scenario (Figure 8) [90].
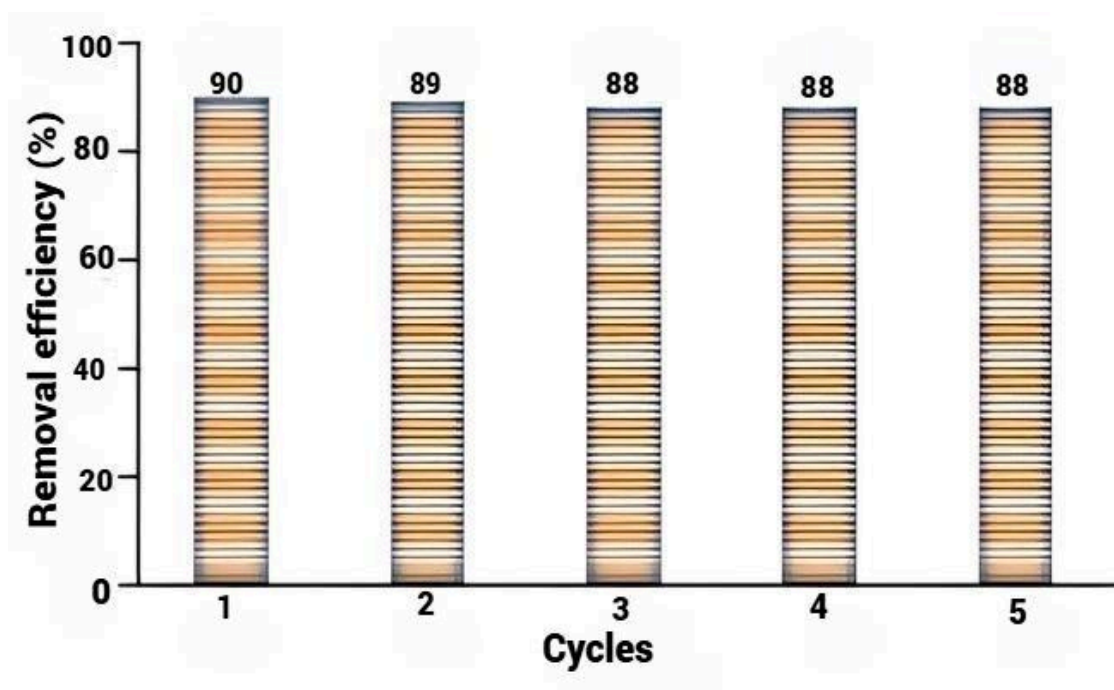
Figure 8: Reusability capacity of nanocellulose fibre after 5 cycles [90].

Beyki et al. (2016) used an effective magnetic Fe3O4 cellulose core to remove Congo red dye. In a single process, they created the Fe3O4 cellulose core with magnet. To create a magnetic polymeric ionic liquid, this cellulose underwent more reactions with 1-methylimidazole and epichlorohydrin. Their findings demonstrated that the Congo red dye adsorption is considerably influenced by many parameters, including contact duration, ionic strength, and adsorbent dyes. According to a regeneration investigation, this proven nanohybrid was highly reusable as a magnetic sorbent for remediation of environmental applications [95].

XI. SUSTAINABILITY AND CHALLENGES

Worldwide environmental issues and the ongoing exhaustion of natural properties have led to a recent global adoption of green materials derived from natural sources as water pollution adsorbents. These minerals are tremendously valuable and help human communities thrive sustainably. Cellulose, the most prevalent polymer found in nature, is one of the environmentally friendly substances that is known to be suitable for removing contaminants from water structures. Cellulose is comparatively inexpensive to produce than other materials because of its great relative abundance and its versatility in transforming into derivatives such nanocellulose and composites [96]. However, many restrictions and difficulties still exist in spite of these exceptional qualities of cellulose. Cellulose is available in great quantities in nature and is recognized to be the substance that gives plant cell walls their hard structure. Its reliance on forest resources for production, however, was one of its drawbacks, since the loss of natural vegetation may lead to a natural disaster [97]. It also takes a lot of time, energy, and harmful chemicals to isolate cellulose components, which is bad for the environment and people [98]. For a number of reasons, materials based on nanocellulose are frequently employed as adsorbents in the wastewater treatment and water purification processes. These include:

i. Possess a greater adsorption capacity than commercially marketed commercial adsorbents (zeolites and activated carbons), or at least one that is equivalent.
ii. They are less expensive than activated carbon.
iii. They are easily regenerable without compromising their adsorption capabilities.
iv. They have a consistent adsorption capability and are readily accessible in large numbers.
v. Nanocellulose synthesis as an adsorbent is environmentally benign.

Chemicals are primarily used in the recovery or regeneration of nanocellulose and its improved forms. Excess regenerating chemicals must be appropriately handled after regeneration to prevent further environmental issues. Maintaining the adsorbent's structure and surface chemistry requires the right acid/base concentration. According to research on reusing nanocellulose crystal adsorbents, after many runs, up to 97% of the adsorption capacity may be maintained [70] This suggests that the adsorbents made of nanocellulose crystals can be reused.

Hypothetically, the accessibility of nanocellulose crystals and their improved forms in great quantities is not a major issue because any type of lignocellulosic material can be used as a precursor for the preparation of nanocellulose crystals, and raw materials for their production are widely available. But for commercial use, additional work has to be done to create a more environmentally friendly method of producing nanocellulose crystals without the use of dangerous altering chemicals. Moreover, adsorption research employing nanocellulose crystals in the near future have to concentrate on multicomponent systems and use actual wastewater as a solution model. The pilot plant scale should be used for adsorption tests if the laboratory scale proves effective [89]. Whereas the prospective of NC in wastewater treatment is substantial, numerous challenges must be addressed for effective scaling up. The cost of generating high-quality NC at scale remains an obstacle. Present production approaches can be costly and energy-intensive. Developing more cost-effective and maintainable production methods is critical [99]. The absence of well-known regulatory standards for NC in treatment of wastewater stances a challenge. Clear rules and safety valuations are essential to facilitate the implementation of these technologies in numerous sectors [100].

XII. CONCLUSION

This review highlights numerous possibilities for the utilization of nanocellulose in treatment of wastewater with distinct emphasis on materials based on nanocellulose as adsorbents or membranes. Products made from NC have demonstrated excellent efficacy in removing a wide range of pollutants,

comprising both inorganic and organic contaminants from wastewater. An affordable, sustainable, and renewable substance, nanocellulose has the prospective to displace other materials utilized in rehabilitation of wastewater and water. Nanocellulose shown remarkable adsorption capabilities for the elimination of salts, dyes, and heavy metals. Comparing cellulose-based materials to other adsorbing materials, they are a great option because of all these great qualities. The investigation of innovative nanocellulose solutions for wastewater treatment presents a favorable pathway towards addressing global water contamination challenges while encouraging sustainability. This research reviews the remarkable characteristics of nanocellulose, including its high surface area, adsorption abilities, and biocompatibility, that make it an active agent for eliminating pollutants from wastewater. By leveraging these aspects, nanocellulose not only improves the efficiency of traditional treatment approaches but also offers a sustainable alternative to conventional materials.

The reusability of nanocellulose is a critical factor that highlights its potential as a cost-effective solution. The capability to regenerate and recycle nanocellulose after its application in wastewater treatment reduces waste generation and decreases the overall environmental impact. This cyclical use aligns with the values of a circular economy, encouraging resource effectiveness and promising a shift towards more viable industrial practices. Particular adsorption of a class of contaminants is made possible by the occurrence of high-surface-density OH groups, which provide a wide range of surface modification options depending on their chemistry. Since electrostatic or van der Waals interactions with the contaminant molecules promote adsorption, the adsorbed molecules may be removed by washing treatment, allowing the adsorbent to be reused for several treatment cycles. The discoveries from this research specify that incorporating nanocellulose into wastewater treatment systems could considerably improve the removal rates of pollutant and facilitate compliance with stricter environmental regulations. Moreover, the development of tailored nanocellulose composites could improve performance, further increasing their applicability across various industrial sectors. The readily functionalizable surface of cellulose nanoparticles permits various surface alterations that might improve the effectiveness of contaminants' binding to the surface. Heavy metals, chemical compounds, oils, germs, viruses, and textile dyes are the most problematic contaminants found in water. When compared to other nanomaterials like carbon nanotubes, nanosized zeolites, and grapheme, the application of nanocellulose in the adsorption sector demonstrated encouraging promise.

In summary, the innovative utilization of nanocellulose not only speaks the crucial need for effective wastewater treatment solutions but furthermore paves the way for the improvement of eco-friendly technologies. Sustained investigation and collaboration in this field will be critical to expose the full potential of nanocellulose, ensuring its effective application and promoting maintainable practices that profit both society and the environment. Eventually, the transition towards solutions based on nanocellulose marks a substantial step forward in achieving a cleaner, more sustainable upcoming. Research initiatives are needed to improve understanding on recycling, membrane fouling, and regeneration. Further research is necessary to develop hybrid composites of the nanocellulose at nano-level to facilitate simultaneous interaction with various contaminants, but its inherent fibrous nature, amazing mechanical characteristics, biocompatibility, and reasonable cost guarantee it as a relevant constituent.

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ABSTRACT

Our earth about 71% percent is covered with water. Out of 71% of water, only 3.5% of water is fresh water and the remaining is saline water. Among the fresh water, only 1.2% of fresh water is under usage. Remaining fresh water is in the forms of glaciers & ice caps. Water is a natural resource. It exists in both the forms of surface water & ground water.

In our daily life water plays a vital role, as we are using it for drinking, domestic, agriculture, industry etc. Water quality is one of the most severe concerns around the globe. It is a major factor affecting the human health as well as ecological systems. The drinking water should be free from harmful chemicals and micro-organisms. The quality of drinking water and for various purposes is defined by different quality parameters.

In this study, to assess the quality of water in pulivendula urban, Kadapa district, Andhra Pradesh (AP), the water samples are collected, tested and analysed for different quality parameters viz pH, Electrical Conductivity (EC), Total Hardness (TH), Cl^-, Total Dissolved Solids (TDS), Alkalinity & Fluorides in our laboratory of department of chemistry, JNTUACE Pulivendula.

Keywords: PH, TDS, water quality index, alkalinity, DO, fluoride, turbidity etc.

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Then the results of each sample's quality parameters are analysed, and compared with standard values as per BIS (Bureau of Indian Standards) and Water Quality Index standards regarding drinking. Finally, these results and comparisons are reported.

Keywords: PH, TDS, water quality index, alkalinity, DO, fluoride, turbidity etc.

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I. INTRODUCTION

Water is an essential component of the environment and it sustains life on the earth. Even though water is one of the renewable resources, the growing human population is further increasing the demand of this renewable resources. Ground water exhaustion is faster than its percolation back into the ground. Ground water is preferred than surface water for drinking. Mostly, it is free from pollution when compared with surface water, there is no evaporation loss and it is the main source of water supply in the regions where there are no perennial rivers.

Water is essential for domestic purposes, including drinking, cooking, cleaning, bathing, sanitation, laundry, dishwashing and gardening. As well as, Water is crucial for irrigation purposes in agriculture, as it helps in crop growth, soil fertility maintenance, temperature regulation, pest and weed control and enhancing yield. Efficient water management and recycling in industries help conserve resources and reduce environmental impact. And also, water plays vital role in various industrial processes, including manufacturing of products, regulation of machinery's temperature, power generation in hydroelectric

plants and cooling systems of thermal and nuclear power stations, acts as a solvent, carrier, and medium in various industries.

The main objective of this study is "Assessment of quality of ground water by conducting tests by collected water samples of ground water from different locations of pulivendula urban, Kadapa (dist.,), A.P., as water quality possess a very important and key role in our daily life and also to compare the results with Water Quality Index standards."

1.1 Source of water

Rain is the source of ground water as well as surface water. Rain is the liquid water in the form of droplets that have condensed from atmospheric water vapour and then becomes heavy enough to fall down. It provides water for many types of ecosystems, as well as water for domestic, irrigation & industrial purposes.

In all these usages water quality is very important, the water with fair & poor quality will affect the human health and cause diseases such as typhoid, cholera and various seasonal diseases. And also, it leads to disturbance in ecosystems, and imbalance in climate.

1.2 Ground water

Ground water is the water present beneath the earth's surface in soil pores and rock formations. It is stored in underground layers called aquifers and is a major source of fresh water for drinking, irrigation, and industrial use.

Ground water is replenished through infiltration from rain water and surface water bodies like rivers and lakes. It can be extracted using wells and boreholes. Over-extraction can lead to depletion and environmental issues like land subsidence and reduced water availability.

Generally, ground water has very good quality because it undergoes natural filtration as it percolates through soil, sand and rock layers. These layers remove impurities, sediments, and harmful micro-organisms making ground water cleaner than surface water. And also, the lack of direct exposure to pollutants like industrial waste and sewage, helps to maintain its purity. Now a days due to rapid industrialization, water resources are getting lowered. In fact, industrial waste and municipal solid waste management has emerged as one of the leading causes of pollution of ground water.

However, quality of ground water can be affected by overuse, contamination from chemicals and improper waste disposal. Regular monitoring and sustainable usage are essential ways to preserve its high quality.

1.3 Description of the study area

The study area in the pulivendula, is located on the north-west region of the district of Y.S.R Kadapa district, A.P. 14 25' 19" North (Latitude) and 78 13' 32" East (Longitude) are passing through this particular study area and its open series map is D44G3. According to Kadapa Urban Development Authority, the area is 87.17 sq.km.

The study area, pulivendula is surrounded by Lingala, Thondur, Simhadripuram, Vemula, Veeranayunipalli mandals. Pulivendula was established as 3rd grade municipality in 2005.As per records the elevation of the area is 892 ft.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

80   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

1.4 Geological data

1.4.1 Rivers

The important rivers in the pulivendula region are papagni river, Chitrvathi river and Penna river. Many of the isolated blocks of rocky hills which are scattered throughout the district and occur frequently in western taluks of Pulivendula, Proddutur and Rayachoty.

1.4.2 Soils

Red and black soils are the two main soil types in the pulivendula region having poor good fertility. Red soils occupy 53% of the cultivated area and have low nutrient status. Black soils covered nearly 47% of the cultivated area and are generally associated with clay content. The black soils in Kadapa district is extend in two disconnected belts.

1.4.3 Minerals

Asbestos of chrysotile variety occurs at the contact of vempalle. Chrysotile asbestos is the most important commercial variety of asbestos for spinning into yarn and woven into fabrics. Barytes occurs in vempalli dolomite and associated basic igneous rocks as veins in Pulivendula, Kadapa, and Kamalapuram taluks.

1.5 Geographical Data

1.5.1 Forests

The forests of Kadapa district are mainly situated on the principal hill ranges, namely, Seshachalam, Nallamalai, Veligonda, palkonda, and Lankamalai. The forests of the district are of dry deciduous type. Red sanders or Pterocarpus are the famous and most important species which distinct the forest of the district as this is the only district of the country India in which the species occurs.

1.5.2 Rainfall

Pulivendula is part of the Rayalaseema plateau, a region with semi-arid climate, diverse terrain and with an average annual rainfall if 564 mm and 43 rainy days (day with rainfall 2.5 mm or more -on an average). Pulivendula receives scanty rainfall both from south-west and north-east monsoons.

1.5.3 Wind

Winds are generally light to moderate in spread with some strengthening during summer and early part of the southwest monsoon seasons. In the summer season and southwest monsoon season, winds are mostly from directions between south and west.

II. LITERATURE REVIEWS

2.1. Mahammad Rafi et al., (2018)

"Quality assessment of drinking water: YSR Kadapa district (A.P)" study investigates the quality of drinking water in YSR Kadapa dist., Andhra Pradesh, due to contamination from human, industrial and agricultural activities. Water samples are collected from various locations, including pulivendula, badvel, rajampet and Proddutur focusing on both surface and ground water sources. The samples were compared against Indian water quality standards to assess their safety for drinking. The study found that some water samples exceeded safe limits for turbidity, fluoride, dissolved oxygen, copper, iron, and

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

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aluminium. Overall, the research calls for immediate action to treat contaminated water sources to safeguard the health of the local population.

2.2. Amatasani Kalpana et al., (2023)

"Assessment of ground water quality in around RTPP, Muddanur, Kadapa District, Andhra Pradesh, India using multi analytical and stastical techniques" study evaluates groundwater quality around RTPP focusing on various hydro chemical parameters such as pH, electrical conductivity, and total dissolved solids. The findings suggest that while the ground water is suitable for domestic use, it is not safe for drinking due to high total dissolved solids and hardness levels.

2.3. Dr. Kondaiah et al., (2024)

"Assessment of Water quality parameters in around Proddutur city" study assess water quality parameters in around Proddutur city focusing on the impact of industrialization and agricultural practices on water sources. The findings highlight the need for regular monitoring and treatment of water sources to ensure safety for drinking and agriculture use Overall, the study emphasizes the importance of assessing water quality to mitigate the effects of pollution and safeguard public health.

III. METHODOLOGY

This study is particularly aimed to assess the quality of ground water in pulivendula urban. So, at first the Locations of Water samples were identified and marked in the map. About 15he sample stations are as follows locations of samples were identified and water samples were collected from the sample stations. The sample stations are as follows:

The results of these water quality parameters were noted down. The results were tabulated and compared with standard drinking values as per Water Quality Index (WQI).

3.1 Experimental procedures of parameters

These are the experimental procedures that we had followed are as follows:

a. Procedure for pH

Standard pH meter is used to determine the Ph of water samples. Firstly, it is calibrated with known pH and then pH of the water samples is measured directly.

Sample calculation: It is measured directly from the instrument pH meter.

b. Procedure for Dissolved Oxygen (DO)

The sample is taken full in 300ml BOD bottle and 1ml of manganese sulphate solution is added by dipping the end of the pipette just below the surface of water. The 1 ml of alkaline potassium iodide is added and is mixed thoroughly, and the precipitate so formed is allowed to settle down. Then 2ml of H_2SO_4 is added and the precipitate is made to dissolve by shaking 20ml of sample is taken into conical flask. Add 1to 2drops of starch indicator and titrate against until disappearance of blue colour which is the point.

Formula: Dissolved oxygen = k * 0.025 * 8 * 0.698 * 1000 x vol. Of hypo used / vol. of sample (20 ml)

c. Procedure for Total Dissolved Solids (TDS)

The dissolved solids consist of inorganic salts by carbonates, bi carbonates, chlorides, sulphates etc. Together with small amount of organic matter and dissolved gases. It is expressed in mg/lit or ppm. It can be determined by water analyser.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

82   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

d. Procedure for Chlorides

Take appropriate quantity of sample (20 ml) in a conical flask. If the sample is highly coloured, add 3 ml $Al(OH)_3$, suspension mix. Adjust the pH value of sample in the range of 7-10 with H_2SO_4 or NaOH solution. Add 1.0 ml (20 drops) K_2CrO_4 indicator solution to this sample (100 ml). Titrate the sample with standard $AgNO_3$ solution to a pinkish yellow end point in general, the colour changes from yellow to brick reddish. Record the volume of $AgNO_3$ used. Repeat the procedure at least three times in which two readings are same.

Chemical reaction is

$AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$

$2AgCl + k_2CrO_4 \longrightarrow AgCl + NaNO_3$
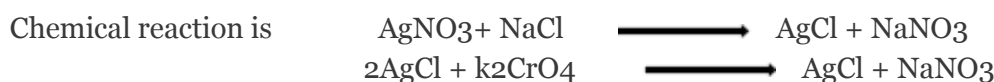
Calculations: Chlorides concentration, Cl-in mg/lit = $((A-B) \times 35.46 \times 0.0156 \times 1000)$/volume of sample taken; where A= ml of titrant used for sample, B= ml of titrant used for blank, N= normality of $AgNO_3$ & V= volume of sample.

e. Procedure for Fluorides

Take 5ml water sample into the beaker and fluoride reagent to the sample. Thus, formed solution is taken into the quvites and the quvite is placed into the slot provided in the Spectro quant Pharos 300 and it gives the fluoride content in the water sample.

f. Procedure for Electric Conductivity

By using conductivity meter, the electric conductivity of the water samples is determined. After the calibration of conductivity meter conductivity of samples is measured directly. Calibration is carried out by using standard solution (0.7456 g of anhydrous KCl in 1 litre of deionized water = 1408 micro siemens/cm).

g. Procedure for alkalinity

Pipette out 20 ml of the water sample in a conical flask. Add 2-3 drops of phenolphthalein indicator. Titrate the sample against standard acid solution ($N/50$ H_2SO_4) until pink color disappears. Note the volume of titrant used P ml. Now add 2-3 drops of methyl orange solution to the sample of water. Titrate the sample with $N/50$ H_2SO_4, solution in the change of color from yellow to red. Again note the volume of titrant used including two previous one. This corresponds to 'm' ml. Repeat the procedure for at least concurrent readings.

h. Procedure for hardness

Take appropriate volume of sample in a conical flask (20 ml). Add 1 to 2 ml of buffer solution and 2 to 3 drops of Eriochrome black T indicator to it. Titrate it with standard EDTA solution till the end point i.e.; the color changes from wine red to blue.

Record the burrete readings and calculate the total hardness. Repeat the procedure from step 1 to 4 till the conformation. Take another appropriate volume of sample.

Calculations: Total hardness as mg/lit $CaCO_3$ = V; {V = B * 1000}

V= volume of sample used for titration.;{V = A * 1000}

Where; A=ml of EDTA used for total hardness.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

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B=ml of EDTA used for permanent hardness

3.2 Locations of samples

Table-1: Locations of water sample stations

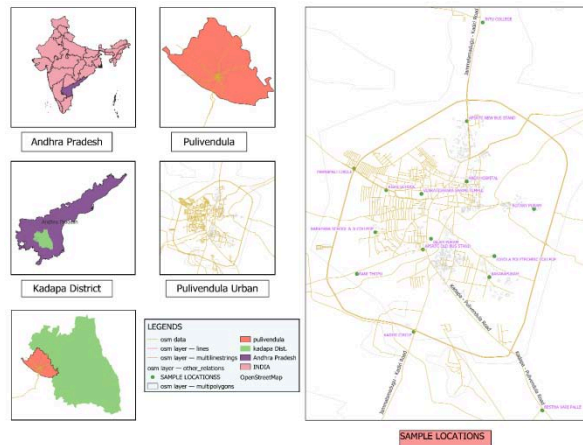| s.no.	Sample Locations
1.	Location-1: JNTU college of Engineering
2.	Location-2: New RTC Bus stand
3.	Location-3: Area hospital
4.	Location-4: Islam puram
5.	Location-5: Parnapalle circle
6.	Location-6: Rishi school
7.	Location-7: Narayana school & Jr. college
8.	Location-8: Rani thopu
9.	Location-9: Old RTC Bus stand
10.	Location-10: Kadiri circle
11.	Location-11: Loyola polytechnic college
12.	Location-12: Bestha vari palle
13.	Location-13: Venkateshwara swami temple
14.	Location-14: Rotary puram
15.	Location-15: Bakara puram

Fig.1: Locations of water sample station

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

84   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

IV. FINDINGS AND RESULTS

After completion of conducting tests we had noted the results of experiments as follows:

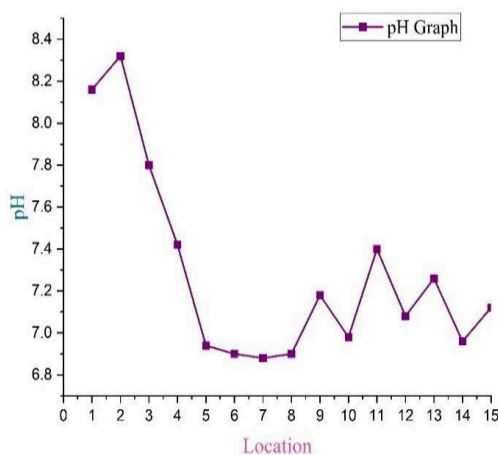| S.No.	location	pH	Alkalinity	EC	hardness	chlorides	TDS	DO	Fluorides
1.	JNTU college of Engineering	8.16	736	2.2	1540	1320	1120	3.2	1.8
2.	New RTC Bus stand	8.32	778	4.2	2845	2520	2270	3.6	1.6
3.	Area Hospital	7.80	754	2.6	1820	1560	1405	4.0	1.8
4.	Islam Puram	7.42	712	2.2	1540	1320	1190	4.2	2.0
5.	Parnapalle circle	6.94	496	1.1	770	660	595	2.4	1.2
6.	Rishi School	6.90	538	1.3	910	780	700	2.6	1.3
7.	Narayana school & Jr. college	6.88	556	1.4	985	840	760	3.0	1.1
8.	Rani Thopu	6.90	592	1.9	1330	1140	1030	4.0	1.0
9.	Old RTC Bus stand	7.18	706	2.1	1470	1260	1135	5.0	1.6
10.	Kadiri Circle	6.98	646	2.0	1400	1200	1080	4.4	1.8
11.	Loyola polytechnic college	7.40	700	2.0	1465	1210	1085	4.8	1.48
12.	Bestha vari Palle	7.08	620	1.8	1280	1080	975	3.8	1.5
13.	Venkateshwara Swami Temple	7.26	724	1.7	1190	1025	920	5.6	1.58
14.	Rotary Puram	6.96	598	1.8	1260	1095	975	4.4	1.62
15.	Bakara Puram	7.12	682	2.1	1480	1260	1135	4.6	1.42

V. ANALYSIS

5.1 Analysis as per BIS

i. pH

As per BIS standards, the drinking water's pH should range in between 6.5-8.5. pH has no units. Here in this study, pH of all samples lie within the limits. It indicates that, it is safe to drink the water.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

ii. Alkalinity

As per BIS standards, Alkalinity always should be less than 500 ppm for drinking water. Here, for all samples collected, the alkalinity value is more than the limit except the Parnapalle location. In Parnapalle location alkalinity is 496 ppm. Usually, alkalinity is measured in mg/l or ppm.
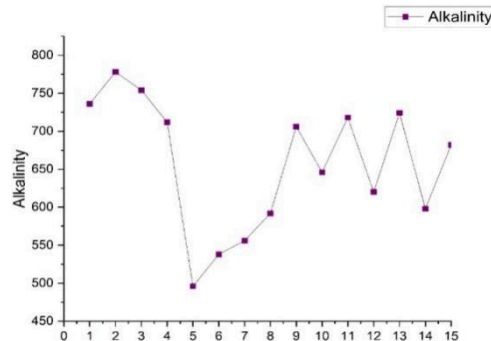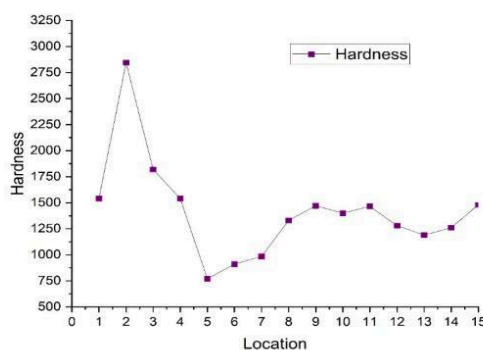

iii. Electric Conductivity (EC)

Electric conductivity is expressed in the terms of micro siemens. Drinking water's electric conductivity standard range is 300μs. Here, all samples are out of the range.
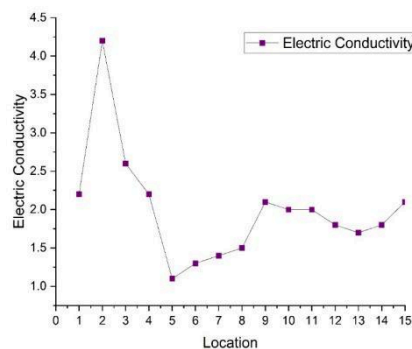

iv. Total Hardness

Total hardness refers to concentration of calcium and magnesium salts in water. It is usually expressed in milligram per litre (mg/l) as calcium carbonate. As per BIS standards, total hardness should be less than 200 mg/l. Here, all sample's total hardness is out of the range.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

86   Volume 25 | Issue 11 | Compilation 1.0   ©2025 Great Britain Journals Press

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v. Chlorides

The range of chlorides for safe drinking water is 250-1000mg/l. here, maximum chloride content is 2520 mg/l and the minimum chloride content is 660 mg/l at New RTC Bus stand and Parnapalle circle respectively. Chlorides content in water can be expressed in terms of mg/l.
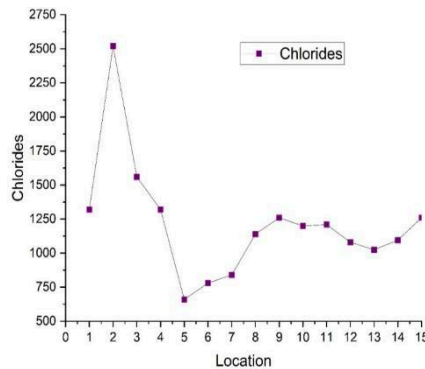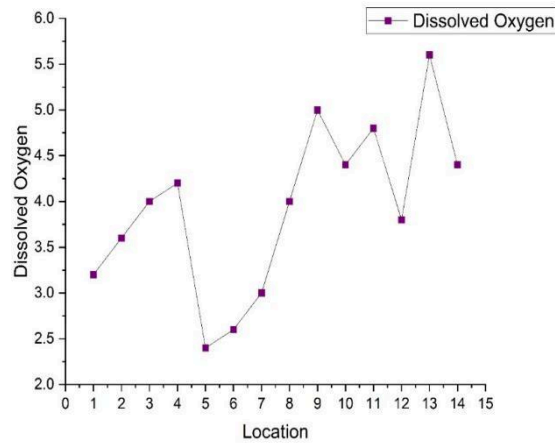

vi. Total Dissolved Solids

According to BIS standards the maximum limit for drinking water is 500 mg/l. It measured in terms of mg/l. TDS content of all samples are not within the limits. All are out of the limits.
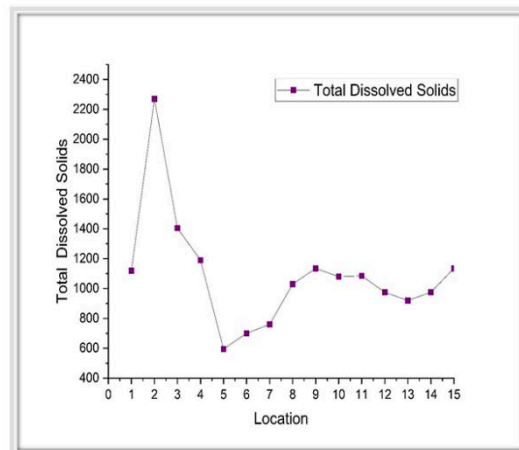
vii. Dissolved Oxygen (DO)

As per BIS standards, the DO content should not more than 5 mg/l. But the water with 6-8 mg/l can be treated as well oxygenated water and fresh water. Here, the DO content is within limit for all sample stations except the location – Venkateshwara swami temple. It's DO content is 5.6 mg/l. Dissolved oxygen is expressed in the terms of mg/l.

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

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viii. Fluorides

Fluorides is one of the parameters used to assess the overall quality of water. The standard value of fluoride is 1.5 mg/l. Some locations exceeded the limit and some locations are within the range.
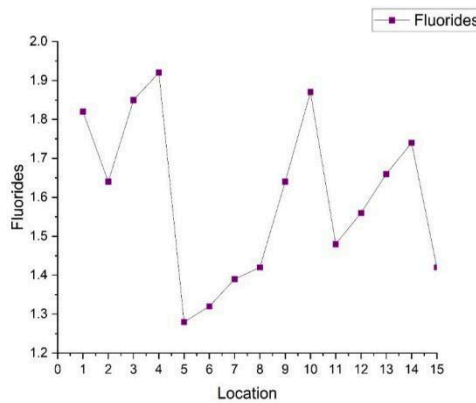
5.2 Water Quality Index (WQI):

The Water Quality Index (WQI) is a numerical tool that combines multiple water quality parameters into a single number to show how suitable water is for drinking. It helps easily access and communicate the overall quality of water based on standards like those from BIS.
Mainly there are five methods. They are:

National Sanitation Foundation Water Quality Index (NSF-WQI)

Oregon Water Quality Index (OWQI)

Weighted Arithmetic Water Quality Index (WAWQI)

Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI)

Bhargava Water Quality Index (BWQI)

We had used Weighted Arithmetic Water Quality Index (WAWQI) – Key Points

1. Selection of Parameters

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

88   Volume 25 | Issue 11 | Compilation 1.0

2. Assigning Weights (Wn)

   Weight (Wn) = K / Sn

   Where: K = proportionality constant

   Sn = standard permissible value of parameter

3. Calculating Quality Rating (Qn)

   $Qn = [(Vn - Vo) / (Sn - Vo)] \times 100$

   Where: Vn = observed value

Vo = ideal value (usually 0 for most parameters)

 Sn = standard permissible value

4. Computing Sub-Indices

   $SI = Qn \times Wn$

5. Aggregating the WQI

   $WQI = \Sigma(SI) / \Sigma(Wn)$

VI.   CONCLUSION

The Water Quality Index (WQI) scale is used to indicate the overall quality of water. It ranges from very poor to excellent based on a single score. It simplifies complex water test results into an easy-to-understand number. Thus, WQI helps quickly assess if water is safe for drinking.

WQI	Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
100	Unfit for drinking

Water quality of sample stations according to WQI is as follows:

S.No.	Location	WQI	Quality
1.	JNTU college of Engineering	130.47	Unfit for consumption
2.	New RTC Bus stand	185.24	Unfit for consumption
3.	Area Hospital	119.19	Unfit for consumption
4.	Islam Puram	87.34	Very poor
5.	Parnapalle circle	37.56	Good
6.	Rishi School	45.18	Good
7.	Narayana school & Jr. college	49	Good
8.	Rani Thopu	59.78	Poor
9.	Old RTC Bus stand	71.05	Poor

Qualitative Assessment of Ground Water using the Water Quality Index of Pulivendula Urban, Y.S.R. Kadapa Dist., A.P. India

10.	Kadiri Circle	58.39	Poor
11.	Loyola polytechnic college	82.09	Very Poor
12.	Bestha vari Palle	57.04	Poor
13.	Venkateshwara Swami Temple	67.02	Poor
14.	Rotary Puram	54.32	Poor
15.	Bakara Puram	67.21	Poor

Quality of water samples are as follows:

Quality of water is good enough at all locations except JNTU college, New RTC bus stand and Area hospital other than these 3 locations water is suitable for drinking. For irrigation purposes all water sample's quality is suitable.

As per BIS standards

➢ Ph of all samples are within limits.
➢ Alkalinity of all samples are not within the limits exceeded the limit it causes digestion issues
➢ Electric conductivity, Hardness, Chlorides content TDS are not within the limits.
➢ Dissolved oxygen content is more than the limit 5 mg/l at Venkateshwara swami temple. Except this samples DO; all are within limits.
➢ Except Parnapalle circle, Rishi school, Narayana school & Junior college, Rani thopu and Bakarapuram are out of the limits. Fluoride content of these 5 locations are within the limits.

ACKNOWLEDGMENTS

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