NAVIGATING WATER RESOURCES MANAGEMENT FOR SUSTAINABLE DEVELOPMENT VIA GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

Geographic Information Systems (GIS) are increasingly fundamental in water resource management, allowing for better organizing, surveillance, and equitable use of water resources. This comprehensive review investigates the significance of GIS in tackling major water concerns, focusing on poor nations where open-source GIS technologies, including QGIS, gvSIG, and MapWindow provide user-friendly water management options. These technologies allow for maps, visualize information, and execute well with minimal computational resources, finding them suited for the European Commission's Water Knowledge Management Platform (WKMP) and comparable efforts. Case examples such as the Grevenitis basin in Greece, show GIS implications in sustainable leadership, allowing for the investigation of hydrological variables, groundwater excellence, and surface water administration. GIS's incorporation with innovations such as remote sensing, artificial intelligence, and hydrological models improves its ability to manage water quality, flood hazards, agriculture, and famine. This paper emphasizes GIS's crucial function in attaining sustainable water resource administration by combining efficient methods and technological breakthroughs, as well as supporting the creation of flexible approaches to alleviate natural and anthropogenic effects on water systems.

Keywords: Geographic Information Systems, Water Resources Management, Sustainable Development, Water Quality Monitoring.

INTRODUCTION

Geographic Information Systems (GIS) possess actively created and designed for many years, including popular business applications, including ArcView and MapInfo. XML and Java were created to help with web development while also serving as a coding standard in the software industry. GIS is commonly utilized in poor nations for handling water resources [1]. The OGC has attracted practically all significant universities and companies in the industry, including IBM, Microsoft, Oracle, ERSRI, MIT, and Stanford University, besides others (Table 1). The OGC subsequently developed the Geography Markup Language (GML), Web Map Service (WMS), and Web Feature Service (WFS), which give standardised means of altering GIS data [2]. The XML and Java technologies are at the heart of OGC deployments. As a result, it has greatly simplified the creation of GIS applications. As a result, free and open source geospatial software has seen tremendous growth in recent years. Research has thrived during the last years beyond vendor-dependent software to open source software, whereby academics attract greater priority to optimize the worth of their information in order to assets may be used more effectively [3]. The expression "open source" refers to source software which can be readily accessed (often under the GNU license); the code can be altered, raised, and/or disseminated for non-profit uses, helping researchers, scholars, and various other consumers. A researcher correctly pointed out that creating countries' and their donor customer computer software purchasing practices should be examined to guarantee that possibilities to utilize low-cost and/or freely available goods are adequately investigated and both their advantages and disadvantages are thoroughly investigated [4]. Other advantages for adopting open source in developing countries include avoiding becoming enslaved to commercial applications and contributing to the establishment of a knowledge-based industry. This study investigates open source Geographic Information Systems and the possibilities for identifying and shortlisting the most appropriate, simple to use, reliable and effective software that might be utilized for assessment or creation of a system adaptable to water resource administration in poor nations [5]. Modeling and policy for decisions for water management in emerging economies face several kinds of challenges, including a lack of funding, expertise, insufficient training capacity, and reliance on specialists from other countries. The primary human-accessible sources of freshwater include glaciers in the mountains, snow, surface water systems (lakes, rivers, and reservoirs), water in the soil, and underground. The demands on water resources are increasing worldwide because of their highly unequal topographical and temporal dispersion [6].

On the contrary, people may be unaware of the locations and amounts of regional water supplies, notably isolated alpine glaciers and snow, as well as deeply, limited freshwater. The engineering of water resources focuses on controlling water transportation to meet the requirements of human societies and the surroundings (quality and quantity), analyzing and designing solutions that enable so. Water resources are critical to civilization because they sustain our standard of existence and the natural systems upon that we rely [7]. Geographical information system (GIS) software, used in computer-based information systems, helps with geometric knowledge archiving, role-playing, tampering extraction, examination, and reporting. This is a common definition that does not emphasize how GIS may be utilized for integrating data and make decisions within an organization. A broader viewpoint maintains that the goal of a GIS is to oversee the natural and biological settings, as well as offer a system for making intelligent decisions about the use of Earth's resources [8]. GIS connects systems that include data on attributes on objects and presents it as maps and characteristic icons. Studying at an outline can help you understand where objects are, how important they are, and just how they're connected. A GIS may additionally give a list of every network link, generate tabular summaries on the map's properties, and facilitate modeling of flow of rivers, travel times, or contaminant diffusion [9]. GIS is extremely versatile, particularly in regards to spatial analysis, simulation (imagining and computation), and management. Geographic information systems (GIS) have revolutionized water management technology by providing strong instruments for spatial evaluation, knowledge combination, and making choices [10]. In this article review, we wish to highlight the vital role of GIS in water management engineering. We explore the current status of water management engineering by analyzing gathering data, interpreting, modeling, and presentation for GIS purposes. We present case studies that demonstrate how GIS could possibly be utilized for tackling a variety of water management concerns, including analyzing water resources, controlling floods and droughts, measuring the health of water, and developing equipment. Our findings underscore the important role that GIS plays in improving making decisions and sustainable water resource administration [11]. As consequently, we advocate for broader

involvement and application of GIS in water-related procedures.

Table 1: Key Applications of GIS in Water Resources Management

Application	Description	Benefits	Example	References
Hydrological Modeling	Simulating water flow and distribution	Improved flood risk management, better water allocation	HEC-HMS, SWAT	[10]
Groundwater Management	Mapping and monitoring groundwater resources	Enhanced water quality, sustainable extraction	MODFLOW, GMS	[11]
Watershed Analysis	Analyzing and managing watersheds	Reduced pollution, improved ecosystem health	ArcHydro, SWAT	[15]
Decision Support Systems	Providing tools for informed decision-making	Efficient resource allocation, real-time monitoring	Web-GIS DSS, DSSAT	[9]

Techniques used for study

The first step was to acquire and research related bibliography, articles, essays, legislation, and facts about the study field. The field research was then conducted to evaluate and document the area's important geological, hydrogeological, and water resource administration data. The following step involves an analysis of demographic information, structural assistance and elimination networks, calculation of the rainfall-altitude connection and of the hydrological equilibrium calculation, the investigation of physical and hydrogeological information, the hydrodynamic variables of the reservoir, figuring out of everyday and yearly usage of water, the drive of water chemistry, and the comparative investigation between modern and future projections [12]. GIS ARC/INFO and AUTOCAD programs were employed to produce databases and thematic maps, whereas MS EXCEL was utilized for figures and sketches, and the HYDROPOINT application was utilized for processing data from water chemistry studies. The present research makes use of over 40 articles on GIS techniques (spatial evaluation, information preparation, map creation, and so on) in water resources management. They all have one thing in prevalent: they use a GIS environment combined with current approaches such as artificial intelligence and hydrological simulation to assess and handle various types of water supplies [13].

EU SWRM guideline and Water Knowledge Management Platform

The EU's standards referred to "Towards Sustainable Water Resources Management: A Strategic Approach" (hereinafter "the guidelines") had been an excellent summary of recent advances in the fields of Administration Water Resources Management (IWRM), providing a tactical strategy to arranging and overseeing water-related operations, including the establishment of national regulations, the administration of offerings, and the delivery of specialised assignments and programs [14]. The rules have been described as being designed for all individuals concerned in the creation of managing water and its usage, particularly governmental and commercial institutions. The principles are part of a larger framework of policies developed by the Member States of the European Union, partner countries, and additional cooperating organizations. The ECeAIDCO agreed to revise its recommendations by establishing a Water Knowledge Management Platform (WKMP), having the goal of fostering more collaboration and supporting relevant projects both inside the EU and in developing countries [15]. There are numerous Water Knowledge Management Platform established in the EU and around the world. Developments in technological innovation, as well as quick changes in IT provisions for the water sector, provide up new potential for enhancement and growth of the function of water expertise administration in the water industry. The upgrading of the EC guidelines is one of many processes that would offer an opportunity for more cooperation in Water knowledge management [16].

Open source GIS

Open source software has grown more prevalent and dependable compared to earlier (Table 2). Given the limited resources available to most poor countries, the use of open source software should be explored in the construction of the WKMP. In conjunction with the financial difficulty, interoperability represents a significant obstacle for potential relationships across companies. The Water Framework Directive is an important piece of EU water policy that defines basins of rivers as the fundamental component for managing water [17]. As a result, spatially dispersed variables including water amount and excellence, distribution and collection relationships, soil, vegetation, and crops, among others, must be collected, analyzed, and modeled for decision making. Geographic Information Systems (GIS) provide efficient tools for managing and modeling geographically distributed information. As an international standard for the creation of a new generation of GIS, the OpenGIS standard had been created over the past ten years by the OpenGIS collaboration under the W3C, particularly to solve the problem of interoperability. XML is currently accepted as the principal medium for presenting geographically dispersed geospatial and associated data [18].

Table 2: Open Source GIS and Data in Water Resources Management

Tool/Resource	Description	Benefits	Example	References
QGIS	Open-source GIS software	Free, flexible, extensive plugins	QGIS for watershed analysis	[17]
GRASS GIS	Open-source GIS with advanced processing	Free, robust, powerful	GRASS GIS for groundwater modeling	[18]
OpenStreetMap	Collaborative map data	Free, up-to-date, community-driven	OpenStreetMap for flood mapping	[21]
Copernicus	European Earth observation program	Free, high-resolution data	Copernicus for water quality monitoring	[24]

The art of GIS and water resources management

The modeling necessary to manage water resources encounters advanced due to rapidly growing computer capabilities. The implementation of GIS provides a precise and predictable technique for acquiring and assessing modeling variables related to water resources management. It may be defined as software that efficiently links graphical figures to characteristic data stored in a database, and the reverse. GIS can be utilized in a variety of applications, including water resource visualization, rainfall-runoff surveillance, prediction of floods, irrigation administration, and famine evaluation, regardless of a model connection [19]. The following chapters contain extensive assessments of these technologies based on available literature. Six subjects were chosen to debate according to various research papers released within this discipline.

Table 3: Integration of Remote Sensing (RS) and GIS in Water Resources Management

Technique	Description	Benefits	Example	References
Satellite Imagery	High-resolution images from satellites	Broad coverage, regular updates	Landsat, Sentinel	[43]
Data Fusion	Combining multiple data sources for enhanced accuracy	Improved data reliability, comprehensive analysis	ENVI, ERDAS Imagine	[44]
Real-Time Data Integration	Incorporating real-time data into GIS	Dynamic monitoring, rapid response	IoT sensors, real-time data platforms	[45]

GIS for water resources mapping

Water resource models are currently generated using a variety of methodologies, including GIS settings, remote sensing, and machine learning. Water sources are being studied and demonstrated to be actively moving or changing state and pressure throughout period. In this section, certain written articles have been chosen to illustrate this point. Surface water can vary significantly depending on the wet and dry times of the year, in addition to spatially. It is challenging to trace such diversity, particularly for short-lived occurrences. While precise mapping can lead to better handling of water assets and a better knowledge of interconnectedness and consequences of agricultural choices, modifications to surface water exert a significant influence on individuals and ecosystems [20]. In a 2019 study, an investigator tried to record surface water movements in numerous locations of the Upper Krishna River basin in Maharashtra, India. The present research used cloud-free Landsat information sets to evaluate the surface water patterns of the Sub-upper Krishna basin (SUKB) over a 17-year period from 1999 to 2016 utilizing the standardized differential in water index (NDWI) approach. To better understand the fluctuation of surface water across the study time frame, alteration identification and mapping are performed using GIS procedures. The results revealed the utility of the two methods: GIS of variation modifications investigation and the NDWI approach for charting surface water, particularly for recognizing variations as time passes [21].

Reliable surface water body maps are essential for tracking, handling, and preserving habitats and ecosystems, in addition to mitigating natural calamities. A research project offered a computerized surface water monitoring system for Germany that combined artificial intelligence algorithms alongside a GIS platform. The recommended model, ResNet+SNIC, achieved an excellent reliability rating of above 86% [22]. The research presented here provides comprehensive knowledge into approaches to evaluate GIS synergy with modern methodologies in massive operations surface water monitoring projects. Another investigator aimed to determine and monitor modifications to urban surface water reservoirs from 2000 to 2019 using several satellite imagery indices (Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI). They achieved this by combining Geographic Information Systems (GIS) via satellite imagery datasets. The investigation was conducted in Makassar, one of Indonesia's most populous cities. In the research location, urban surface waters have increased by around 129.8 ha during the nine prior years, corresponding to the results, that are shown on a map generated by a GIS system [23].

GIS for rainfall-runoff measurements

Rainfall, runoff, as well as soil saturation levels all have a significant impact on the physical makeup of a floodplain. The rainfall-runoff mechanism describes the way water throughout a storm moves from rainfall to runoff. Rainfall-runoff mechanisms expose a watershed's hydrological qualities, thus hydrologists should research. Numerous investigations have shown a rise in interest in the application of GIS and RS combination for estimating runoff from rainfall across wetlands. It is typical in hydrology to employ GIS applications to generate outputs for dispersed rainfall-runoff model simulations [24]. Furthermore, GIS assists experts in tracking and researching the occurrence of flooding and droughts, and also identifying locations that are particularly prone to catastrophic rainfall-runoff situations. There are numerous techniques to calculate rainwater, however the Soil Conservation Curve Number method is widely used and regularly delivers correct findings in comparison with various alternatives. This method employs a hydrologic characteristic to indicate the possibility for rainwater runoff in a draining basin. It is dependent on the kind of soil, moisture content, and land use/coverage details, hence GIS can be useful for spatially dispersion of these variables [25]. A further investigation found that the SCS CN procedure, along with GIS and Remote Sensing (RS) strategies, may be used to predict daily, monthly, and annual flow for ungagged basins in the Bojiang lake watershed in China. A GIS framework was used to construct a characteristic surface, generate a weighted curve number, and overlaying numerous theme planes. When the correlation coefficient (r) was used, the association findings revealed a mean runoff of 17.78 mm, or approximately 7.18% of the annual rainfall for the period 2001-2016. A study employed the GIS-based SCS-CN flow simulation framework to determine runoff from rainfall in Ethiopia's Awash river basin [26]. The SCS-CN runoff simulation framework took three components: the Global Curve Number (GCN250), High Soil Water Retention (S), and Rainfall. In the studied area, runoff ranged from 83.95 mm/year to 1,416.75 mm/year. The freshly created Global Curve Number (GCN250) data, intended to be used as input for the SCS-CN runoff simulation model, was tested using the Pearson correlation coefficient. This enabled the verification of the expected runoff generated by SCS-CN using GCN250 being an estimation parameter versus reality runoff recorded using station gauges in the study location [27].

GIS for Flood forecasting

Building actual time flood forecasting techniques for public early alert has been increasingly popular in the past several years due to the catastrophic consequences of the many floods that are categorised as flooding of rivers, mud flooding, dam flooding, and flash floods that affect people worldwide. The primary contributory factor of river flooding is heavy, sustained rain that is more than the land can absorb. A flood is caused by above-normal flow rates of streams, usually inundates areas that were normally not completely submerged by the water [28]. It is mainly restricted to sudden shifts with elevated flowing stream concentrations. Floods with varying recurrent lengths can now be represented geographically due to the combination of flood modelling and Geographic Information Systems (GIS). Alternatively, the effectiveness of GIS analysis is greatly impacted by the precision of the information being provided and the integration of GIS methodology with machine learning and statistical methods [29].

In the year 2020, researcher carried out an investigation that used a review methodology to show the primary elements affecting Malaysia's flood frequency using GIS. The effectiveness of Geographic Information Systems (GIS) is the focus of the present investigation. The results indicates that the risk of flooding has risen as a result of the most recent flooding that have affected Malaysia. This research investigation adds to a reservoir of information on the incorporation of GIS application with parameters impacted by floods [30]. Human-induced ecological alterations are the cause of the variance in the likelihood of flooding from year to year. This information is essential to the development of GIS spatial modelling as a flood control technique in Malaysia. Current investigations on flood danger mapping using GIS are included in this review record, which also highlights any shortcomings that might offer a unique perspective for further flood risk minimisation research [31]. Additionally, a study conducted an investigation on floods in the similar nation, Majalaya, with the goal of creating a GIS application model for estimating flood areas and the interruption of roadways caused by flooding. By combining several processes, such as thematic data and an SPSS software module, utilising GIS software, the flood analysis model uses an advanced judgement-based rules tree to create a decision tree technique which could possibly be utilised for flood management [32].

GEOLOGICAL DATA

The Mesohellenic Trough, situated in the geographical region between the Sub-Pelagonian Zone and the Zone of Pindos, is a portion of the research site. The region's geological structures include: the molassic sediments of the Lower Miocene Tsotili and Pentalofos formations (sandstones, conglomerates, marls, and marl sandstones) with an overall depth that measures roughly 6.2 km. Having an overall depth of around 200 meters, the Plio-Pleistocene sediments were made up of loose conglomerates, clays, sands, and loose sandstone that discordantly covered the molassic deposits [33]. The riverbeds are covered with Holocene alluvial sediments that are only a few meters deep. Throughout research zone's entire surface, 62% is covered by Molassic sediments, 29.2% by Plio-Pleistocene sediments, and 8.8% is made up of alluvial deposits. Despite not being folded down, the molassic sediments exhibit eastward inclinations due to tectonic processes that have occurred throughout the Miocene. There are not many NE-SW flaws in molassic sediments [34].

WATER CONSUMPTION DATA

In 2007 and 2015, the average yearly consumption of water were 2.9x106 m3 and 6.0x106 m3, respectively. The overall quantity of drinking water required each year was 2.11x106 m3 in 2007 and is predicted to rise to 2.33x106 m3 in 2015. Among the yearly requirements for drinking water are:

− The citizens' requirements for drinking water,
− The water requirements of the home,
− The requirements for irrigation in small gardens,
− The water requirements for household animals,
− The water requirements for small businesses and
− It has been estimated that as much as 15% of the total drinking water requirements are caused by leaks in the water supplying system. The city of Grevena seems to be suffering from the greatest water requirements (76%). Currently, the Grevenitis basin's external springs (Aetia, Smiksi, Filippaioi, and Orliakas) provide 81.2% of the 2.86x106 m3 of water supply annually, while the basin's internal springs provide 2.5% and wells provide 16.3% [35].

Throughout winter, the overall amount of drinking water required is 3.32x103 m3 d-1, and in summer time, it is 8.27x103 m3 d-1. Given that the area is related to agriculture, the significant amount of water required for garden irrigation (48%) through the hottest months is justified. The primary cause of the high everyday water use (300 lit per person) is it. All the residential areas have the capability to meet the water requirements over the course of the winter. While Grevena, Doksaras, Kalamitsi, Amigdalies, Mikro, and Megalo Seirini gets the water they require from wells, 11 villages can hardly meet their requirements throughout the summer [36]. To meet all of their requirement for water throughout the summer, these 11 villages—Elatos, Kastro, Kirakali, Rodia, Sidendro, Kalirahi, Megaro, Oropedio, Anavrita, Mavranaioi, and Mavronoros—need to expand the availability of water. Water scarcity during the summer months totals 240 m3 d-1, or 10 m3 h-1. According to Kirakali, Grevena, Megalo, and Mikro Seirini, the standard yearly water consumption for irrigation of 0.75 Km2 for crop cultivations (corn, clover, vegetables, and fruit-bearing trees) is 508,500 m3 y-1 [37].

GIS for water quality

Whereas chemical analysis studies can determine the condition of subsurface water, sensor technology gives Water Quality (WQ) information related to thousands of water-based surface locations with a high degree of temporal and spatial accuracy. By analysing variations in the condition of water and detecting diseases and dangerous algal blooms, GIS can assist remote sensing and chemical analysis tests to assess environmental issues and possible health hazards. The subsequent research were utilised to elucidate the capabilities of GIS in this domain. Research established a link between the shift in land use and its impact on the surface water purity of the northern Algerian Mitidja river basin [38]. Applying GIS and statistical evaluation gathered from three consecutive years of data, the correlation among land use change and the surface water quality index was examined. Land usage and surface water quality are represented by the information provided. The study's conclusions show the river basin's regional heterogeneity in terms of both chemistry and in the form of physical characteristics. The quality of the water upstream was better than that of downstream. There was a significant spatial correlation between the surface water quality indicators and three distinct land usage categories—vegetation cover, cropland, and urbanised residential property [39]. The study that evaluated and analysed the WQ in the Thamirabarani River in southern India, they produced 12 spatially interpolated maps to help visualise the variance in chemical structure along the whole length of the river. Using information gathered from twelve WQ criteria for the years 2020 and 2021, the water quality associated with this river was examined and divided into 4 groups. The following groups (Zone 1 = water alkalinity, Zones 2 and 3 = water impacted by waste from industry, and Zone 4 = water impacted by see water intrusion) indicate the variation distribution for the whole WQ and were categorised using Principal Component Analysis (PCA) [40].

The main advantage of using GIS in the water industry would be that it allows hydrologists to connect geographical data, like water basins, with visual data, like rainfall and levels of water height. These two types of data can then be used together to perform analyses which can be beneficial, such as building structures like reservoirs and dams. It also aids in the investigation of underground water conditions, over pumping of groundwater, intrusion by seawater, water for agriculture, drought evaluation, and the purity of water [41]. A GIS interface was created to collect, store, query, examine, manage, and visualise spatial information. Both of them such as the geographic location and the attributes of physical characteristics are included in spatial information. GIS comprises not only geospatial data but also other elements such as individuals, corporations, software, and hardware. People, corporations, governmental organisations, educational organisations, as well as academics use GIS at various levels [42].

Conclusion

Selecting appropriate freely available GIS software applications for prospective WKMP participants in countries that are developing is the aim of this research. Within a number of requirements, focus has been placed on comparatively simple installation and faster processing. The setting up and validation runs were conducted on a Pentium III PC. Additionally, its capacity to produce huge visuals has been selected as a crucial metric.Within the current circumstances, QGIS operated remarkably well. Furthermore, its features are sufficient for the majority of ordinary uses in the handling of water-related assets. Connecting to GRASS could improve its functionality. One can conclude that QGIS is unquestionably the best option for the WKMP after carefully weighing the arguments raised above. Considering current computing circumstances, Open JUMP operates adequately, however it is not quite as effective as QGIS. It does, however, have a wealth of water-based features, and the number of plug-ins kept growing. Additionally, open JUMP is suggested for the WKMP. MapWindow GIS and gvSIG simultaneously provided satisfactory results in terms of functionality and efficiency at a respectable level. Since the scores for gvSIG and MapWindow GIS were nearly identical, WKMP is advised to use each of them. Additionally, if the uDig and GeoServer packages can enhance their map processing capabilities, they have a chance to be among the easiest to utilise open source GIS products. Since several GIS software packages continue to be in the early stages of advancement, it is anticipated that several intriguing programs may be made available soon. GIS is used to develop and manage hydraulic and hydrologic models which simulates the behaviour that water exhibits in a watershed. This helps experts predict issues related to water quality, irrigation upper management, floods, and droughts. The quantity of runoff that results from an occurrence of rainfall can be measured with the use of rainwater-runoff models. Rainfall-runoff modelling can give benefits greatly from the use of GIS since runoff is heavily influenced by watershed features. Details describing hydrological events is dispersed when hydrological models and spatial data are integrated. By collecting hydrological data in a GIS framework, numerous studies have effectively combined GIS alongside hydrological models.

Due to the fact that it can identify particularly susceptible regions and predict probable hotspots for vulnerability, flood susceptibility mapping is crucial for hindering disasters like floods. This helps disaster mitigation and evacuation authorities organise and react in areas with exceptionally high vulnerability. Digital maps of regions that are most probable to be submerged with an emergency flood are created using GIS. This information is used by strategists and disaster specialists to identify regions with elevated risk and plan mitigation measures. Water infrastructure, such as reservoirs that store water pipes, and filtration plants, is mapped using GIS in water supply planning. Such data can be used by planners to identify areas that may experience a lack of water and to schedule the building of additional infrastructures to accommodate expected expansion. Additionally, engineers can use GIS to create visual representations of underground water assets used for groundwater modelling, thereby helping them better comprehend how groundwater flows through aquifers and anticipate how circulating would affect water quantity and purity. GIS is a superior method for visualising the quality of water data, such as the outside temperature, oxygen saturation, and mineral levels, when engineers are attempting to regulate the state of the water. It helps engineers identify areas that are susceptible to the contamination and create strategies to reduce water quality problems. Considering various forms of data, such as soil conditions, field types, and weather information, GIS was utilised to develop irrigation management techniques that determined the perfect quantity of irrigation water for every single crop in order to maximise irrigation water usage and minimise wastewater.

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