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A REVIEW ON REMOTE SENSING AND GIS TECHNIQUES IN WATER RESOURCE DEVELOPMENT AND MANAGEMENT WITH SPECIAL REFERENCE TO GROUNDWATER

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Abstract

Water is one of the most important natural resource and physiological necessity to mankind. Fresh water is one of the basic necessities for sustenance of life. Use and development of water resource in a sustainable manner is very important in modern age due to regular increase in water crises. Remote sensing and GIS techniques are very powerful tools for analyzing and manipulating the data for the purpose of water resource development and management. GIS technology provides suitable alternatives for efficient management of large and complex databases. The greatest advantage of using Remote Sensing data for hydrological modeling and monitoring is its ability to generate information in spatial and temporal domain. Remote sensing and GIS techniques are found efficient to minimize the time, labor and money and are able to make quick decisions for Sustainable water resources management. Remotely sensed data are most useful where they are combined with numerical modeling, geographic information systems, and ground-based information. In short both these techniques play a great role in the field of hydrology for water resources development and management. The review paper highlights Remote Sensing and GIS techniques and presents a brief review on the application of these two emerging techniques for groundwater resource management and development.

Keywords: Water Resource, Development and Management, Remote Sensing and GIS.

Introduction

The human race through the ages has striven to locate and develop water resources. Most of the habitations and cities are developed close to the rivers. Over ninety percent of liquid fresh water available at given moment on the earth lies beneath the land surface. Groundwater, unlike surface water, is available in some quantity almost everywhere. Groundwater has long been regarded as the pure form of water compared to surface water, because of purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange. This is one of the reasons for the excessive consumption of groundwater[29]. Recently, due to increase of population, consumption of water also increases rapidly, so not only availability of water but also quality of water is a challenge for us. The fast growing population, rapid Urbanization and industrialization, coupled with spatial and temporal variation has effected water availability, water quality problems etc. [53].

The remote sensing and GIS technologies are being practiced for water resources development and management since the first Landsat satellite was launched in 23 July 1972 by NASA [55].

In succeeding years, several remote sensing satellites were launched for various purposes and of various resolutions, which provided a new dimension to the remote sensing technology. Now, most common remote sensing systems operate in one or several of the visible, infrared, or microwave portions of the EM spectrum. The series of satellites now known as LANDSAT launched by the US evolved in concept from the photographic observations of the early Mercury and Gemini orbital flights. Data from those manned earth orbital flights indicated the practice of observing from space orbits what is broadly referred to as “earth resources”. These observations and the thoughts they generated led to the NASA (National Aeronautic and Space Agency of the US) satellite program that developed the first satellite of the world called “Earth Resources Technology Satellite” (ERTS), which was launched in July 1972; it was later on renamed “Landsat-1” and the latest satellite in this series is Landsat-8 launched in 2013[55]. Thereafter, the satellites were also launched by other countries such as former USSR, Japan, European Space Agency (ESA), India, France and Canada as well as China and Brazil. With the advancement of technologies, the nature of remote sensing itself has changed during past few decades from a relatively qualitative art relying on inference for information to a quantitative science capable of measuring system states in some cases. Thus, extensive improvements in the field of remote sensing have been made and it is still developing as an exploratory science to meet the growing challenges of the world. This review paper deals with the works conducted on ground water field using of Remote Sensing and GIS techniques.

Historical background

Shrinivasan (1978) has made a detailed study to use remote sensing techniques for ground water studies in semi arid region of dharmpuri district, Tamilnadu.Visual interpretation was first used for delineate major geomorphological zonation, and structural feature of interest, which are manifested as lineaments in landsat imageries were picked up. Land sat black and white imageries of 1:50000 scale and false color composite of 1:1000000 scale were used [43].

According to Lerner et al. (1990), the choice of methods to investigate groundwater recharge is dependent on the objectives and the study area characteristics (including the flow mechanisms within the study area leading to the recharge), which determine the adequacy of the methods and the investigation time step [21]. Lerner et al. (1990) gave additional solutions to reduce uncertainties in estimation methods are suggested by Lerner et al. in previous work for permanent annual recharge estimations and comparison of estimates for aquifers with similar physical and climatic conditions. Indeed, groundwater recharge estimation according to the temporal variability of the components should never be done only once but in a continuing iterative process in order to update estimations and adjust management.

Rango (1994) reviewed the use of remote sensing in hydrology but did not list groundwater among its operational applications, possibly because "most approaches use surface indicators of the underlying groundwater reservoir and require considerable skill and knowledge on the part of the interpreter". This is true, but it does not prevent an operational use by many hydrogeologists in certain types of shallow groundwater systems [36].

Chaudhary et al. (1996) prepared HGM (Hydrogeomorphological) map which shows ground water prospect zones of Sohna block, Gurgaon, Haryana with using remote sensing and GIS techniques. Various thematic maps were prepared by visual interpretation of satellite data stereoscopic interpretation of panchromatic B/W aerial photographs and information extracted from digital image processing of satellite data. The maps were further supplemented with selected group checks. Maps were digitized and integrated in IDRISI Geographic Environment to prepare final map showing ground water prospective areas [10].

Shukla J.P. (1997) worked on ground water and studied structural and geomorphological controls on occurrence of ground water in Raisen District of M.P. and adjoining areas. His study was focused on management of water Resource using integrated Remote Sensing techniques. He suggested stop dams, check dams and recharge structures for water resource management [48].

Gert A Schultz (1997) developed a mathematical model, which connects the ground truth to data obtained from satellite (Meteosat) imagery. The parameters of the nonlinear mathematical model are calibrated based on short-term simultaneous satellite and ground truth data. Runoff time series it is possible to estimate the expected future performance of the intended water project. The model was applied to the Tano River basin (16 000 km2) in Ghana, West Africa [15].

Peters & Stuurman (1989) used thematic Mapper (TM) imagery for a detailed cover-type classification in an area in The Netherlands with unconsolidated rocks for which a systematic inventory of flow systems was made [32].

Bridget R Scanlon et al, (2002), outlined the importance of the spatial and temporal scales of the recharge estimation in guiding the choice of the methods and techniques of groundwater recharge. In addition, subsidiary factors like the methods, costs of remote sensing techniques and the required duration for deriving the parameters in the recharge estimation are also restrictive when selecting a method [8].

Schmugge et. al. (2002) worked on remote sensing in hydrology. In that study they use different satellite data for different purpose like land surface temperature from thermal infrared data, surface soil moisture from passive microwave data, snow cover using both visible and microwave data, water quality using visible and near-infrared data and estimating landscape surface roughness using lidar. Methods for estimating the hydrometeorlogical fluxes, evapotranspiration and snowmelt runoff, using these state variables are also described [40].

Basudeo Rai et al. (2005) Identified groundwater prospect zones in Jharia and Raniganj coalfields, Dhanbad district of Jharkhand state. In study, they used MSS sensor data of Landsat. By using visual Image interpretation elements like shape, size, tone, texture and pattern, the study area various hydrogeomorphological units like linear ridge (dyke), residual hills, pediplain, buried pediment, dissected buried pediment and lineament identified. Subsequently, the groundwater prospective zones were tested by using geoelectrical methods [4].

Puri et al. (2006) described aquifer characterization techniques, and also quoted the use of digital satellite images including multi-spectral data from Landsat thematic mapper and Radar images from the Space borne Imaging Radar to map the eastern Sahara groundwater basins. Besides the variety of methods aforementioned in the recharge estimation, none alone has enough accuracy to provide reliable recharge estimates. This is partly due to the hidden nature of groundwater resources, which implies that calculations be at best approximate based on consistent assumptions on the components governing the resource occurrence as aquifer and known to be temporally and spatially variable and therefore likely to induce inaccuracies in the evaluation [34].

Rokde et. al. (2007) worked on ground water potential modellling through Remote Sensing and GIS techniques. They did their study in Rajura Taluka, Chandrapur District of Maharashtra. With the use of satellite data they created geology, geomorphology, structural etc maps, found suitable recharge condition and delineated Ground water potential map [37].

Madan et. al. (2007) highlights RS and GIS technologies and to presented a comprehensive review on their applications to groundwater hydrology. A detailed survey of literature revealed major areas of RS and GIS applications in groundwater hydrology: exploration and assessment of groundwater resources; selection of artificial recharge sites; GIS-based subsurface flow and pollution modeling; groundwater- pollution hazard assessment and protection planning; estimation of natural recharge distribution and hydrogeological data analysis and process monitoring [25].

Saumitra Mukherjee, (2008) worked on role of satellite sensors in groundwater exploration. In study it was found that IRS 1D - LISS data with 23.5-meter resolution when merged with the panchromatic data has produced very good results in delineation of interconnected lineaments over buried pediment plains as vegetation anomaly. Further the impact of urbanization on groundwater recharging in the terrain was studied by generating Normalized difference Vegetation Index (NDVI) map which was possible to generate by using the LISS-III sensor of IRS-1D satellite [47].

Chowdary et. al. (2008) carried out their work on integrated water resource development plan for sustainable management of Mayurakshi Watershed, India using RS and GIS [9]. This approach involves preparation of different thematic maps (resource maps) by using remote sensing data and/or by conventional sources. The critical analysis of thematic maps derived from satellite data interpretation and other collateral data leads to identification of problems and potentials of each of the thematic information in terms of its availability, sensitivity, severity and criticality of the resources for the optimum utilization of the resources. Combining these thematic layers under GIS environment using a set of logical conditions, integrated water resource development map for each watershed was generated and identified suitable areas for development of groundwater and location of recharge sites depending on the terrain. Boolean logic used for the selection of artificial recharge sites.

Shreenivas et. al. (2010) worked on detection of sub-surface water logging using Terra-1 MODIC data. The study was taken up to evaluate the potential of near-IR, short-wave IR (SWIR) and thermal-IR data from moderate Resolution Imaging Spectrometer (MODIC) aboard terra-1 acquired during day and night time post-monsoon data for detection of sub surface water logging [49].

Navneet Kumar (2010) studied Evaluation of Groundwater Quality in Shallow and Deep Aquifers in Dhampur tehsil of U.P with GIS modeling. The main aim of this study is to evaluate the groundwater quality for the purposes of drinking and irrigation with reference to recommended standards prescribed by WHO. This study had to main objectives to evaluate the concentration of some of the major constituents of groundwater such as pH, EC, TDS, Fluoride, Chloride, and Total Iron in shallow and deep aquifers [29].

Balakrishnan et. al. (2011) mapped groundwater quality using geographic information system (GIS) of Gulbarga City, Karnataka, India. In his study, they analyzed for physico-chemical parameters like TDS, TH, Cl and NO3, using standard techniques in the laboratory and compared with the standards. The ground water quality information maps of the entire study area have been prepared using GIS spatial interpolation technique for all the above parameters. Final map Shows potable zones, and non-potable zones, in terms of water quality [2].

Srivastava et. al. (2012) studied the mapping of ground water prospect using Remote Sensing, GIS and Geoelectrical resistivity techniques of Dhanbad district, Jharkhand, India. The ground water resources have been studied, by analyzing IRS LISS II multi band remote sensing data along with geological as well as geophysical resistivity sounding data carried out at places in GIS environment. Finally, ground water resource prospect map of the area has been prepared based on the integrated thematic maps, weighted analysis in Arc GIS environment [50].

Sarala C (2012), identified ground water prospect zones with the use of Remote Sensing and GIS techniques of Palleru subbasin, which covers three districts namely Warangal, Nalgonda and Khammam of Andhra Pradesh [39]. Her work involves creating a database both spatial and non-spatial with the help of Survey of India toposheets and Remote Sensing Imagery. Various thematic maps like drainage map, contour map, slope map, soil map, hydro-geomorphology map and lineament maps was prepared by using Survey of India topo sheets. After integrating all thematic maps using weighted overlay analysis tool, groundwater prospects map was generated.

Magesh et.al. (2012) delineated of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques [24]. MIF includes seven influencing factors, such as lithology, slope, land use, lineament, drainage, soil, and rainfall have been identified to delineate the groundwater potential zones. Interrelationship between these factors and their effects is weighted according to its strength. The representative weight of a factor of the potential zone is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones. Integration of these factors with their potential weights is computed through weighted overlay analysis in ArcGIS.

Lilly Florence and Dr. A. Paul Raj (2013) worked on Ground water quality assessment of Gangavalli Taluk, Salem District, Tamil Nadu, India. They used multivariate statistical techniques for this purpose. Ground water samples collected from open wells, bore wells and hand pumps for Pre-Monsoon and Post-Monsoon period were analyzed for their physico-chemical characteristics. Each parameter was compared with the standard permissible limit of the parameter as prescribed by World Health Organization (WHO). The multivariate statistical tools such as Correlation Coefficient Analysis (CCA), Factor Analysis (FA) and Cluster Analysis (CA) were also used for the interpretation of water quality data and its spatial variations [22].

Murali at el. (2013) carried out their work on assessment of groundwater vulnerability in Coimbatore South Taluk, Tamilnadu, India, using drastic approach [27]. The study was to develop an empirical model DRASTIC to identify the vulnerability index owing to groundwater contamination with increasing population, industrialization and agricultural activities. The most important factors for mapping , that control the groundwater potential are depth of water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity of the aquifer. Estimation of DRASTIC Index involves multiplying each parameter weight by its rating corresponding to its study area and summing the total. Based on DRASTIC index values, they observed that the vulnerability class in the study area falls between low vulnerability to high vulnerability. The results provided important information for the local authorities and decision making personals for effective management of ground water resource.

Waikar et. al. (2014) Identified of Groundwater Potential Zone using Remote Sensing and GIS Technique Parbhani district of Maharashtra. The information obtained the parameters that considered for identifying the groundwater potential zone such as geology, slope, drainage density, geomorphic units and lineament density were generated using the satellite data and survey of India (SOI) toposheets of scale 1:50000. It is then integrated with weighted overlay in ArcGIS. Suitable ranks are assigned for each category of these parameters [54].

Senthil Kumar et. al. (2014) assesst of groundwater potential zones using GIS Lekkur sub basin of Mangalur Block, Cuddalore district, Tamil Nadu, South India. All the thematic maps were such as geology, geomorphology, soil hydrological group, land use / land cover and drainage map were prepared and converted into grid (raster format) and superimposed by weighted overlay method (rank and weightage wise thematic maps). From the analysis the groundwater potential zones with excellent, very good, good, moderate and poor prospects [42].

Verma et. al. (2013) evaluate ground water quality of Lucknow, U.P. IRS- P6 LISS III used for creating land use and urban settlement map. The ground water samples were collected from the selected locations and were analyzed for different physico-chemical analysis and a water quality index was prepared. Water quality index (WQI) was then calculated on the basis of WHO standards to classify suitability for drinking water. The WQI map was interpolated using inverse distance weight (IDW) method on GIS for spatial variation and suitability of quality assessment [53].

Murry Y Benthungo (2013) used LISS III data to create various thematic maps and prepare ground water prospect maps. In additional Ground water recharge was estimated using lumped Water Balance approach (GEC, 1997) and a distributed physical, hydrological model (VIC).Using interpolation techniques such as IDW (Inverse Distance Weighting) and kriging were tested to obtain the spatial distribution of ground water quality parameters [28].

Balachandar et al. identified suitable site for artificial recharge. For this purpose created drainage, drainage density, lineament, lineament density, geomorphology, land use and land cover using Landsat data .Using digital image processing, the supervised, unsupervised Classification, band ratioing, filtering and NDVI Techniques for updating the all thematic maps [3].

Nag et. al. used IRS P6 Image o identify different hydrogeomorphological units, mapping of lineaments. Created DEM and by GIS overlay find suitable zones for groundwater potential. Prajit et. al. (2013) used LISS III and PAN of IRS 1D to identifie Ground Water Recharge by water harvesting Structures [31].

Srivastava et. al. (2012) mapped ground water prospect using remote sensing, GIS and Geoelectrical resistivity techniques of Dhanbad district Jharkhand. Analyzing IRS LISS II multi band remote sensing data along with geological as well as geophysical resistivity sounding data carried out at places in GIS environment [40].

Sharma et. al. identified groundwater prospect zones using RS and GIS techniques in and around Gola block, Ramgargh district, Jharkhand, India [45]. Biswas et. al. used IRS-IC LISS III, Landsat TM digital and SRTM data for Delineation of Groundwater Potential Zones of Ganjam district, Orissa, India [6]. Jawad et. al. used Landsat ETM+ image for exploration of ground water [17].

Remote Sensing and GIS application for water resource management

“Remote sensing (RS) is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object area, or phenomenon under investigation”(Lillesand et. al. 2004)[23]. Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information" (Canada Centre for Remote Sensing Tutorial) [11].

The radiation emitted or reflected from various objects are of different amount. Same the emitted or reflected radiations are recorded by various sensors. Various sensors have different type of bands which records specific ranges of electromagnetic radiation (EMR). Every radiation or light is made of Electromagnetic energy and reflected according to the surface or object interacted with. Generally, smooth surface reflects more radiations that’s why the tones recorded by the sensors are light. In the case of surface water, the most of the radiations are transmitted through water so they provide generally dark tone.

For the management and development of water resources, remote sensing data provides a platform for doing initial and fast survey. Although, very few remotely sensed data can be directly applied in hydrology, such information is of great value since many hydrological relevant data can be derived from remote sensing information. However, the use of RS technology involves large amount of spatial data management and requires an efficient system to handle such data.

From the ground water point of view, occurrence and movement of groundwater is mainly controlled by many factors such as rock type, landform, geological structures, soil, land use, rainfall etc[46]. Remote sensing based groundwater prospect zone map serves as a base for further exploration using hydro geological and geophysical methods to locate well sites.

Remote Sensing data and GIS play a rapidly increasing role in the field of hydrology and water resources development (Seth et. al. 1999) [42]. Remotely sensed data are most useful where they are combined with numerical modeling, geographic information systems, and ground-based information (Matthew W. Becker, 2006) [54]. Selection of suitable sensors has definitely a cutting edge on natural resource exploration and management including groundwater (Saumitra Mukherjee, 2008). Parameters relevant for hydrogeology are spatially distributed and may show significant temporal variability. Earth Observation (EO) data, when used jointly with in situ data, can provide an essential contribution for the creation of inventories of surface water resources, the extraction of thematic maps relevant for hydrogeological studies and models (land cover, surface geology, lineaments, geomorphology) or for the retrieval of geophysical parameters; water quality, temperature, soil moisture etc. (Gert et. al., 2000)[15]. Concentration of drainage density and lineament density also helps the infiltration ability of the groundwater system.Remote sensing, GIS and MIF techniques are found efficient to minimize the time, labor and money and thereby enable quick decision-making for Sustainable water resources management (N.S. Magesh et.al, 2012)[24]. In the physical applications of imaging sensors, long wave radar can sometimes detect groundwater levels at depths of a few meters and other subsurface features, such as buried channels (McCauley et al., 1982)[26], but only if all conditions are suitable, i.e. coarse-grained deposits, dry vadose zone without vegetation and some a priori knowledge of the geology. Radar imagery has its general use in hydrogeology for the interpretation of geological structures (Koopmans, 1983; Drury, 1993)[20].

Geographic Information System (GIS)

"A GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (Redlands, CA: Environmental System Research Institute, 1990)[38]. Geographic Information System is Computer hardware and software based technology which is collecting, storing, analyzing and displaying spatial and non spatial data and generalization of data for users (By Author).

GIS is a relatively new branch of technology. Land Information System (LIS) is a similar system. In 1960 Canadian Geographic information System (CGIS) was developed. In 1973 the United State geological society started development of the geographical information retrieval and analysis system (GIRAS) to handle and analyze land use and land cover data. With the development in the application of topology for analyzing spatial data, GIS became a more useful tool[51]. In 1982, Environmental system Research Institute (ESRI) released the popular GIS software ArcInfo. With the advancement in the operating system, computer graphics, DBMS, computer-human interaction and graphical user interface design. GIS has now become versatile, sophisticated and user friendly software.

GIS hydrological modeling analyzed by Jenson S. K. and J. O. Domingue 1988[19], while Eli Robert N, 2000, gives a detailed analysis of the current state of the art and proposes a new algorithm based on relaxation processes[14]. The interesting of all such work is that the basic information needed to begin with is the terrain surface represented by a digital elevation model (DEM).

Various GIS components are people, data, hardware, Software and methods. People are a most important component in a GIS, they must develop the procedures and define the task of the GIS. They can often overcome shortcomings in others components of the GIS, but the best software and computers in the world cannot compensate for the incompetency of the people. The availability and accuracy of data can affect the results of any query or analysis. Hardware capabilities affect processing speed, ease of use, and the type of output available. Software includes not only actual GIS software but also various databases, drawing, statistical, imaging, or other software. Analysis requires well-defined, consistent methods to produce accurate, reproducible results. Capturing of data (Digital format, Hardcopy, GPS, Vector and Raster formats), Querying data (Identifying specific features based on conditions), Analyzing data (Proximity, Overlay, Network), Displaying data (Maps, Graphs and Reports), Output (Paper Maps, Images, Documents) are the function of GIS. Terrain modeling, hydrological modeling for quantity and quality, hydrodynamic modeling for flow simulation, study of spatiotemporal variation and providing management strategy in map form are techniques for acquiring topographic information of inaccessible area[13].

The hydrologic modeling functions in ArcGIS Spatial Analyst provide methods for describing the physical components of a surface. The hydrologic tools allow to identifying sinks, determining flow direction, calculating flow accumulation, delineating watersheds and creating stream networks. Using an elevation raster or digital elevation model (DEM) as input, it is possible to automatically delineate a drainage system and quantify the characteristics of the system.

Using the DEM as input into the flow direction tool, the direction in which water would flow out of each cell could be determined. With the Sink function, any sinks in the original DEM are identified. To ensure proper drainage mapping, these depressions can be filled using the Fill tool. Using the Watershed tool, the watersheds are delineated for specified locations. To create a stream network, use the flow accumulation tool to calculate the number of upslope cells flowing to a location. The output of the flow direction tool from above is used as input. A threshold can be specified on the raster derived from the flow accumulation tool; the initial stage is defining the stream network system. This task can be accomplished with the con tool or using map algebra. Apply the stream order tool to represent the order of each of the segments in a network. The available methods for ordering are the Shreve and Strahler techniques. Using the flow length tool, the length of the flow path, either upslope or down slope, from each cell within a given watershed can be determined. This is useful for calculating the travel time of water through a watershed (ESRI)[13].

Conclusion and Recommendations

Remote sensing and GIS methods permit rapid and cost effective natural resource survey and management. Moreover, remotely sensed data serve as vital tool in groundwater prospecting and management. The remote sensing data helps in fairly accurate hydrogeomorphological analysis and identification and delineation of land features. Remote sensing is not applicable directly for the ground water purpose. Groundwater occurrence being subsurface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features like geological and geomorphic features and their hydrologic characters of lithology, hydrogeomorphology and lineament is been taken up. Satellite remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units, lineament features, following the integration with the help of Geographical Information System to demarcate the groundwater potential zones. Furthermore, monitoring of water quality can be achieved with the aid of remote sensing techniques at least to a certain extent.

The detailed reviews presented in this paper indicated that the current applications of RS and GIS techniques in groundwater hydrology are limited to three areas: (i) exploration and assessment of groundwater resources and potential zones (ii) selection of artificial recharge sites, (iii) GIS-based subsurface flow and pollution modeling. RS and GIS based applied groundwater research is also required in conjunction with field investigations to effectively exploit the expanding potential of RS and GIS technologies, which will perfect and standardize current applications as well as evolve new approaches and applications in the future.the remote sensing technology has great potential to revolutionize groundwater monitoring and management in the future by providing unique and new data to supplement the conventional field data. Therefore, an integrated approach, including studies using remote sensing and GIS techniques, for proper management and development of groundwater potential in the study area.

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