# Geospatial Information Systems on Cloud Computing Environment: A Systematic Review

**Mohammed Mahmoud Ibrahim Musa**

**Abstract:**

GeographicalInformation Systems (GIS) is a collection of tools to collect, store, analyze, manage and display data that linked to geographic locations. GIS plays a vital role in wide range of disciplines and domains. Cloud Computing has become popular technology in recent years, it can described as technology to provide IT resources, services and products on demands. Cloud Computing can be used to store large spatial data, perform complex spatial analysis and Geocomputation on cloud. This paper aims to provides a systematic review on Cloud GIS applications to introduce anorganized viewof the current state of the field of GIS applications based on cloud computing environment by looking for answers for two main question. How to design and develop a Cloud based platform for Geospatial Information and Geospatial Analysis, What are the GIS solutions, functions and services provided in Cloud Computing.The search for articles conducted in IEEE, Elsevier Science Direct, ACM Digital Library and Google Scholar. Retried articles are analyzed according to inclusion and exclusion criteria, finally articles selected for review.Forty-one articles were selected on GIS in cloud computingwith different applications, methodsand techniques. The selected articles are classified based on the articles topic, articles are classified to four classes, these classes are Cloud GIS approaches, Cloud GIS Architecture, Solutions and Cloud GIS functions.

**Keywords**:Cloud Computing, GIS, Geospatial Web Services, Cloud GIS Architecture, Cloud GIS Solutions.

# نظم المعلومات الجغرافية في بيئة الحوسبة السحابية
## (مراجعة منهجية )

محمد محمود إبراهيم موسى - باحث

**المستخلص:**

نظم المعلومات الجغرافية (GIS) هي مجموعة من الأدوات التي تستخدم لتجميع وتخزين وتحليل وإدارة وعرض البيانات المرتبطة بالموقع الجغرافي، وتلعب نظم المعلومات الجغرافية دور حيوي في معظم المجالات، تقدم هذه الورقة مراجعة منهجية شاملة عن تطبيقات نظم المعلومات الجغرافية في بيئة الحوسبة السحابية، حيث أصبحت الحوسبة السحابية تقنية شائعة في السنوات الأخيرة ويمكن وصفها بانها تقنية تعمل على توفير الموارد والخدمات والمنتجات المتعلقة بتكنلوجيا المعلومات حسب الطلب، ويمكن استخدام الحوسبة السحابية في تخزين البيانات الجغرافية الضخمة واجراء عمليات التحليل المكاني ومعالجة البيانات الجغرافية المعقدة، تهدف هذه المراجعة المنهجية الي تقديم عرض منظم للوضع الحالي لتطبيقات نظم المعلومات الجغرافية القائمة على الحوسبة السحابية من خلال الإجابة على سؤالين: ما هي حلول وخدمات ووظائف نظم المعلومات الجغرافية التي يتم تقديمها من خلال الحوسبة السحابية ،كيف يتم تصميم منصات نظم المعلومات الجغرافية قائمة على تقنيات الحوسبة السحابية، خلال هذه المراجعة المنهجية تم البحث عن الأوراق العلمية التي تجيب على هذه الأسئلة في المكتبات الرقمية التالية IEEE، ACM Digital Library، Elsevier Science Direct، Google Scholar، تم تحليل الأوراق العلمية وفقا لمعايير التضمين والاستبعاد التي تم تحديدها للإجابة على الأسئلة المذكورة، بعد تحليل هذه الأوراق تم اختيار احدى واربعون ورقة علمية عن تطبيقات نظم المعلومات الجغرافية في الحوسبة السحابية وطرق وتقنيات تصميم وتطوير تطبيقات نظم المعلومات الجغرافية باستخدام الحوسبة السحابية، حيث تم تصنيف الأوراق بناء على موضوع الورقة الي اربعه فئات، المنهجيات والتقنيات المستخدمة، معمارية تطبيقات نظم المعلومات الجغرافية القائمة على الحوسبة السحابية، حلول نظم المعلومات الجغرافية في بيئة الحوسبة السحابية ووظائف نظم المعلومات الجغرافية في بيئة الحوسبة السحابية.

**الكلمات المفتاحية:**الحوسبة السحابية، نظم المعلومات الجغرافية، خدمات نظم المعلومات الجغرافية على الويب، معمارية نظم المعلومات الجغرافية في بيئة الحوسبة السحابية، حلول نظم المعلومات الجغرافية في بيئة الحوسبة السحابية.

## 1. Introduction

Cloud computing technology increasingly become an important solution for organizations that looking to drive their business forward. The NIST defined Cloud computing a model for enabling ubiquitous, convenient, on-demand network access to a shared-pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) thatcan be rapidly provisioned and released with minimal management effort or service provider interaction (1). In Cloud Computing, computing resources are provided as on-demand services over the internet, these services delivered in three models, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS), Google Doc is an example of SaaS, Firebase Database is an example of PaaS while the Amazon EC2 is an example of IaaS. Organizations using cloud computing technology to consume cloud-computing services according to their needs. According to the NIST, there are four-deployment model for cloud computing private cloud, community cloud, public cloud and hybrid cloud. Recently, Geospatial Technology are increasingly providedon cloud computing, which provides dynamically scalable GIS technology, GIS Data and GIS functions as a web service. In this, approach no need to intensive investment in Hardware, software and Spatial Data in an enterprise GIS implementation (2). ESRI created ArcGIS Online as cloud GIS platform, ArcGIS Online is SaaS based platform, which, provides hundreds of analytical functions, and visualization capabilities delivered in easy to use applications with tens of thousands of ready to use datasets and maps that users can employ in their applications. Earth Observing System (EOS) created EOS platform, which is a cloud-based platform for image processing, analysis and visualization. Cloud GIS provides dynamically and scalable GIS technology, GIS Data and GIS functions as a web service. In this, approach no need to intensive investment in Hard-

ware, software and Spatial Data in an enterprise GIS implementation. This paper intended to conduct a systematic review forCloud based GIS solutions in order to understand Cloud GIS architectures and approaches. The review consists of three phases based on Kitchenham and Charters 2007 guidelines(3).

## 2. Methodology

A systematic review is a method of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Systematic reviews aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology. Guidelines for performing systematic literature review in software engineering report approach, which introduced by Kitchenham and Charter(3)was used to conduct a comprehensive search for this interdisciplinary topic. The guideline flow three phases to perform a systematic review. Phase one, is a planning phase, during this phase review objectives identified, need for review, research questions, keywords, review protocol, inclusion criteria and exclusioncriteria are specified. Phase two, is conducting review phase in this phase search for literature in digital libraries related to the research topic. Phase three reporting the review in this phase review results concluded and analyzed to respond to the research questions. Figure 1 shows the general systematic review methodology guideline and Figure 2 shows the exact review process that used in this study.

### 2.1. Phase One: Planning the Review

Increasing number of articles in GIS applications on Cloud Computing is ample evidence that applying Cloud Computing is an ideal solution for Geospatial Data management, and the absence of comprehensive review on GIS applications on cloud computing makes this review necessary for researches interested to work on Cloud GIS solutions. The review aims to conduct a comprehensive review for articles that respond to the following questions:

- RQ1: How to design and develop a Cloud based platform for Geospatial Information and Geospatial Analysis?
- RQ2: What are the GIS solutions, functions and services provided in Cloud Computing?

The main reason of this systematic review is to summarize the approaches and architectures for designing and developing Cloud GIS solutions and to find a good approach and architecture for Cloud GIS solutions. Four digital libraries used to search for articles that may respond to the research questions, IEE explorer, ACM digital library, Elsevier ScienceDirect and Google Scholar. Following keywords and terms (Cloud Computing, Geographic Information Systems and Cloud GIS)selected to search for articles in the title, abstract and keywords. All papers published in English between January 1, 2007 and January 1, 2021 are included in the review process.

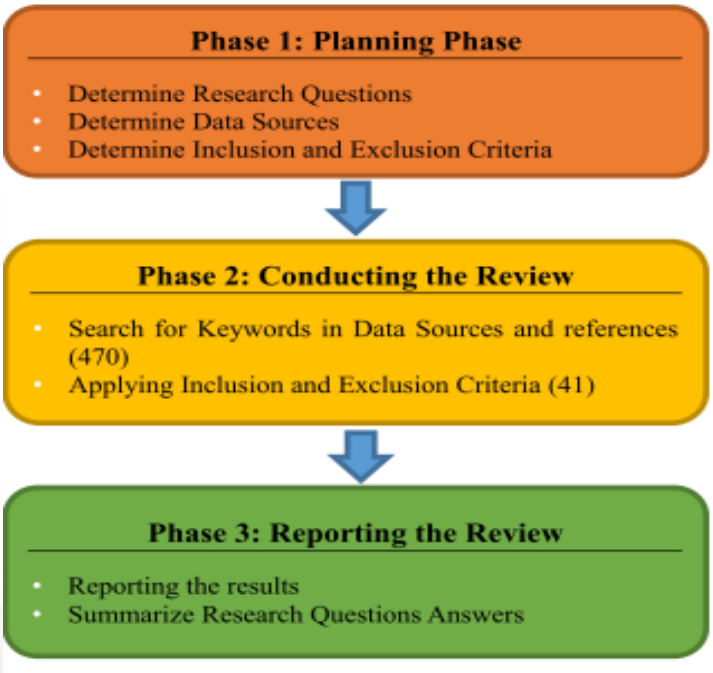


*Figure 1: General systematic review methodology guideline.*

2.1.1. Inclusion Criteria

Identified articles screened with a set of inclusion criteria, an eligible article should be available as full-text, discussing subjects relevant to Architectures and Approaches of Cloud platforms for GIS solutions and Cloud based GIS solutions for essential GIS functions and services such as GIS data storing, collection, processing, analysis and presentation.

2.1.2. **Exclusion Criteria**

The exclusion criteria of identified articles include, articles that discussing cloud GIS solutions form security and performance perspective, and articles that discussing Cloud GIS solutions from Remote Sensing and digital image processing perspective. Articles in form of books and report also excluded from the review.

## 2.2. Phase Two: Conducting the Review

Search for keywords and terms applied on specified data sources and digital libraries, Search conducted on title, abstract and keywords for articles that published between 2007 and 2021, the total number of articles retrieved from digital libraries are 197, 37, 125 and 90 articles from IEEE explore, Elsevier ScienceDirect, ACM digital library and Google Scholar respectively.

Retrieved articles analyzed according to inclusion and exclusion criteria. First, title and abstract reviewed according to the research questions to determine which articles cloud give answers for research questions. Then, full article reviewed according to the research questions specifically conclusion part. After removing duplicates and applying inclusion and exclusion, criteria thirty-seven papers selected.

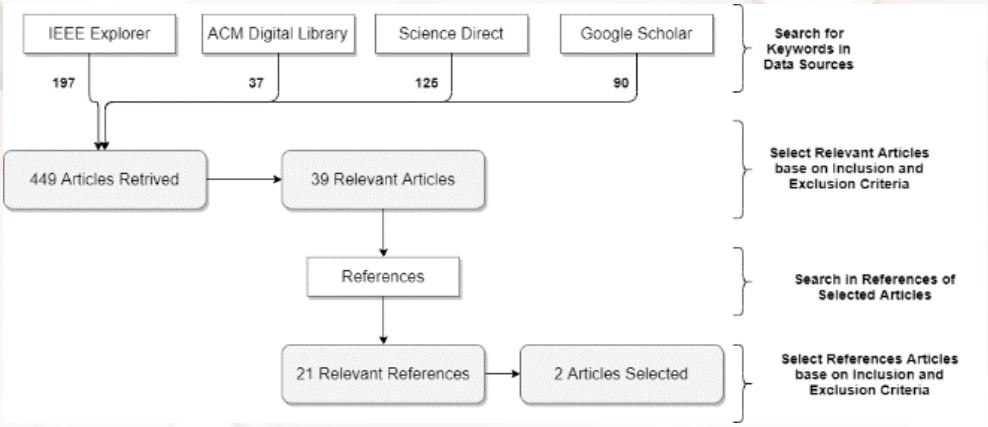


*Figure 2: Shows Review Process*

## 2.3. Reporting the Review

Thirty-nine articles selected for review; it is conference and journal articles published between 2010 and 2020. The major part of selected articles are conference articles, andmost articles came for IEEE Explorer.

Figure 3: Shows the distribution of selected articles through the digital library, out of 41 articles, 21articles (51 %) selected from IEEE Explorer. 5 articles (12 %) selected from Elsevier ScienceDirect. 4 articles (10 %) selected from ACM Digital Library. 7 Articles (22 %) selected from Google Scholar search, and there are 2 articles (5 %) select from the references of reviewed articles.

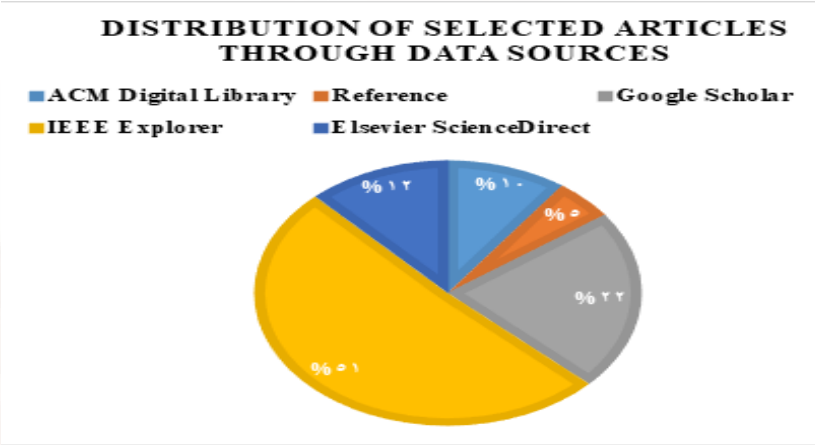


*Figure 3: Distribution of Articles through Data Sources*

Figure 4 shows types of publication for selected articles, 27 articles (66 %) from selected articles are conferences articles and 14 articles (34 %) are Journal Articles.

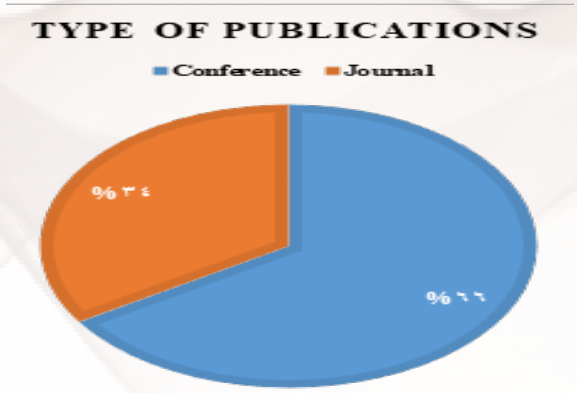


*Figure 4: Types of Publications*

Figure 5shows the distribution of articles across the countries, most of articles from china, 13 articles (32 %) published by Chinese institutes or researchers. four articles (10 %) published by USA institutes and the same percentage are published by Indian Institutes. Three articles (7 %) published by Egyptian institutes, two articles (5 %) are published by Germany Institutes, and same percentage are published by Zambian institutes, one articles (2 %) published by Italian institutes and same percentage published by Greece, Ireland, Japan, Jordan, Morocco, Spine, Taiwan, Thailand, Trinidad, Turkey, UK and Ukraine.

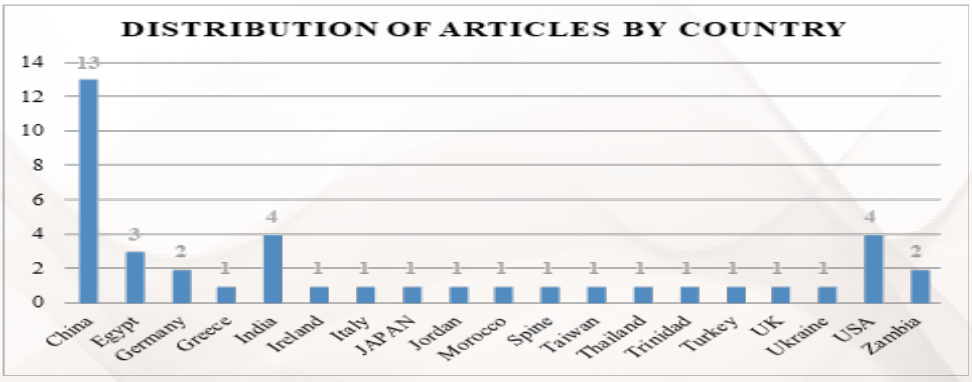


*Figure 5: Distribution of Articles By Country*

Figure 6 shows the distribution of articles through years, most of articles are published in 2010 and 2014. There are 7 articles (17 %) published in 2010 and the same percentage published in 2014. 5 articles (12 %) published in 2013 and the same percentage published in 2016. 4 articles (10 %) published in 2017 and the same percentage published in 2018. 3 articles (7 %) published in 2012. Two articles (5 %) published in 2011 and the same percentage published in 2015. One article (2 %) published in 2019 and the same percentage published in 2020.

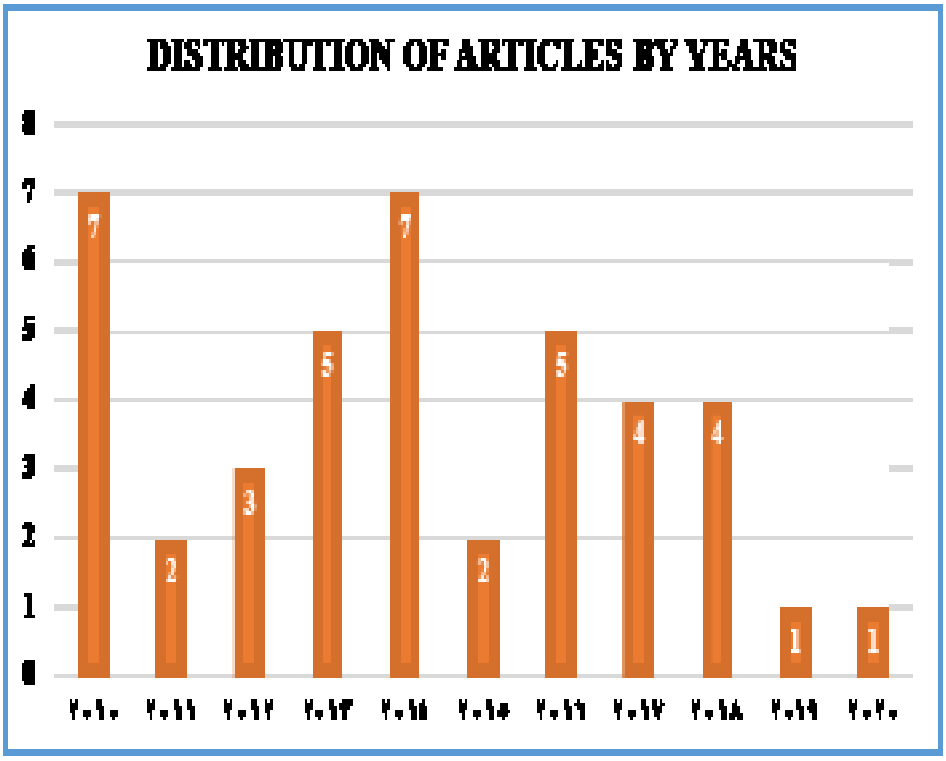


*Figure 6: Distribution of Articles by years*

*Table 1: Shows Selected articles and Publishers*

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| Computers & Electrical Engineering | 1 | Journal | (4) |
| Computers & Geosciences | 1 | Journal | (5) |
| Earth Science Informatics | 1 | Journal | (6) |
| Environmental Modelling & Software | 2 | Journal | (8) - (7) |
| FIG Congress 2014 Engaging the Challenges At Kuala Lumpur Malaysia | 1 | Conference | (9) |
| Future Generation Computer Systems | 2 | Journal | (11) - (10) |
| Geospatial thinking | 1 | Journal | (12) |
| International Computer Science and Engineering Conference | 1 | Conference | (13) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Conference - Cloud System and Big Data Engineering | 1 | Conference | (14) |
| International Conference on Advanced Information Networking and Applications | 1 | Conference | (15) |
| International Conference on Advances in Computing, Communications and Informatics | 1 | Conference | (16) |
| International Conference on Audio, Language and Image Processing | 1 | Conference | (17) |
| International Conference on Cloud Computing and Big Data Analysis | 1 | Conference | (18) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Conference on Computational Intelligence and Communication Networks | 1 | Conference | (19) |
| International Conference on Computer Modelling and Simulation | 1 | Conference | (20) |
| International Conference on Computer Science and Artificial Intelligence | 1 | Conference | (21) |
| International Conference on Computer, Information and Telecommunication Systems | 1 | Conference | (22) |
| International Conference on Computing for Geospatial Research and Application | 1 | Conference | (23) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Conference on Dependable Systems, Services and Technologies | 1 | Conference | (24) |
| International Conference on Educational and Information Technology | 1 | Conference | (25) |
| International Conference on Geoinformatics | 2 | Conference | (27) - (26) |
| International Conference on Geoscience and Remote Sensing | 1 | Conference | (28) |
| International Conference on Information Science and Engineering | 1 | Conference | (2) |
| International Conference on Information Society | 1 | Conference | (29) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Conference on Internet Technology and Applications | 1 | Conference | (30) |
| International Conference on Power System Technology | 1 | Conference | (31) |
| International Conference on Software Engineering and Service Science | 1 | Conference | (32) |
| International Journal of Advanced Computer Science and Applications | 1 | Journal | (33) |
| International Journal of Advanced Research in Computer and Communication Engineering | 1 | Journal | (34) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Journal of Advanced Trends in Computer Science and Engineering | 1 | Journal | (35) |
| International Journal of Computer Science and Mobile Applications | 1 | Journal | (36) |
| International Journal of Earth Sciences and Engineering | 1 | Journal | (37) |
| International Journal of Research in Computer Science | 1 | Journal | (38) |
| International Workshop on High Performance and Distributed Geographic Information Systems | 1 | Conference | (39) |

| Publisher | Frequency | Type | Articles |
|---|---|---|---|
| International Workshop on Mobile Geographic Information Systems | 1 | Conference | (40) |
| Mediterranean Symposium on Smart City Application | 1 | Conference | (41) |
| The International Conference in ICT (ICICT2019) Lusaka, Zambia | 1 | Conference | (42) |
| Third Pacific-Asia Conference on Circuits, Communications and System ((PACCS | 1 | Conference | (43) |

Selected articles are classified based on the articles topic, articles are classified to four classes, these classes are Cloud GIS approaches, Cloud GIS Architecture, Solutions and Cloud GIS functions, the cloud GIS function class are classified into four classes Store, Capture, Display and Analysis. Figure 7 illustrates the classification of articles in the study area.

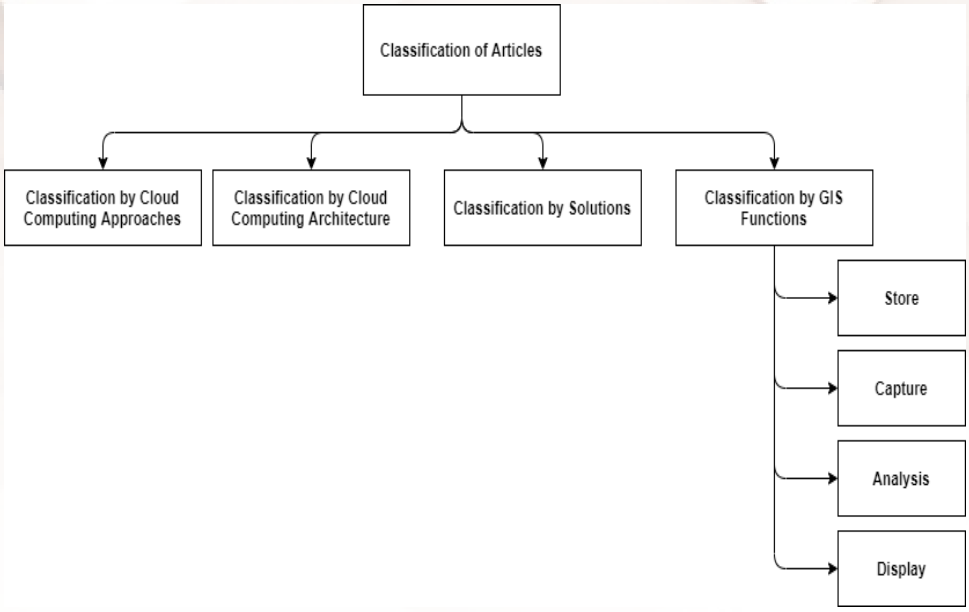


*Figure 7: Classification of Articles*

## 3. Results

### 3.1. Cloud GIS Approaches

**Cloud Computing Approach:**

Processing of Geospatial data require a massive processing capabilities, in the past, processing of Geospatial data was performed in a desktop computers and mainframes. cloud computing is considered a new approach for geospatial information in which geospatial storage and processing no longer performed in a single computer, but distributed across multiple machines provided by a third party provider as a services on demand. Cloud Computing term is overlapped with distributed computing and grid computing. the key features of cloud computing are scalability, Efficiency and resources on-demand, in addition to Services level agreement (SLA) which considered as a contract that guarantees the quality of services (4).The key technology in Cloud computing infrastructure is virtualization, which abstracts the physical computing resources to virtualized resources, hardware, software, networks, memory

and data can be virtualized. The architecture of cloud computing consists of four key components which are resources allocation users, SLA, Virtual Machines and Physical Machines, the architecture of cloud computing is based on service oriented architecture approach which introduce everything as a service (XaaS). The most common types of services in cloud computing are Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS), Cloud Computing services can be deployed as public, private or hybrid (partially public and partially private). Now a day various GIS organizations depend on cloud computing technologies to provide GIS solutions to different kind of users(5).

**Geospatial Web Services approach in Cloud Computing:**

The applications of GIS and data sources are diverse and the processing of Geospatial data is complex. Web Service technology invented to help us to face this challenges, which is an interface that accessible through networks and describes a set of data and operations using standardized XML messaging(17). A Web GIS Service approach used to provide GIS data and GIS functionality through networks. Web Service architecture consists of three components including Services Provider, Services Consumer and Broker (30). The web Services uses different protocols and standards including, Simple Object Access Protocol (SOAP ) is standardized way to enable Web services to communicates with the clients and enable various programs and platforms to communicate, Web Services Description Language (WSDL) is standard that describe the Web Services and the operations performed by the web services, Universal Description, Discovery and Integration (UDDI) is standardized way for publishing and finding the web services and Web Services Inspection Language (WSIL) is an alternative services discovery mechanism 6().The Open Geospatial Consortium (OGC) described web services standards for geospatial information including Web Map Service (WMS) to provide the maps

as images (png or jpg), Web Feature Service (WFS) for vector data, Web Coverage Service (WCS) for raster data, Sensor Collection Service (SCS) for sensors real time observations, Geography Markup Language (GML) XML standard for georeferenced data (7) Clients communicate with services through WSDL interface, the clients requests may be SELECT, UPDATE, DELETE and INSERT queries, web GIS service receive the request and extracts the query from the request, Web GIS services creates GML geospatial datasets and return the result to the user according to the service type(8).The OGC standards is interfaces for software developer to follow in creating their services and products, these standards not only for spatial database it is also cover map representation(9).

Cloud GIS is a service oriented platform for geospatial information, the main features of Cloud GIS including Extendable, Elasticity, On-demand service, Measurable, Transparency and Diversification of access. ArcGIS Server used to publish geospatial resources as services, these services are accessible through Desktop software, web browsers and mobile applications. The architecture of ArcGIS Cloud consists of three tiers ArcGIS Cloud Infrastructure for hardware integration which implemented through virtualization, ArcGIS Cloud platform is GIS software which is provided as services and accessible for users through networks and clients who can access the services of Cloud GIS through Web browser, Desktop applications or mobile applications (10). ArcGIS online is a Cloud GIS platform that enable users to store and publish and manage spatial data, tools and services, ArcGIS Online support various types of standards for Geosaptial data and services such as CSV, GPX, KML, WMS, etc(11). Generally, Figure 8 provides the main approaches of providing Geospatial Services on Cloud.

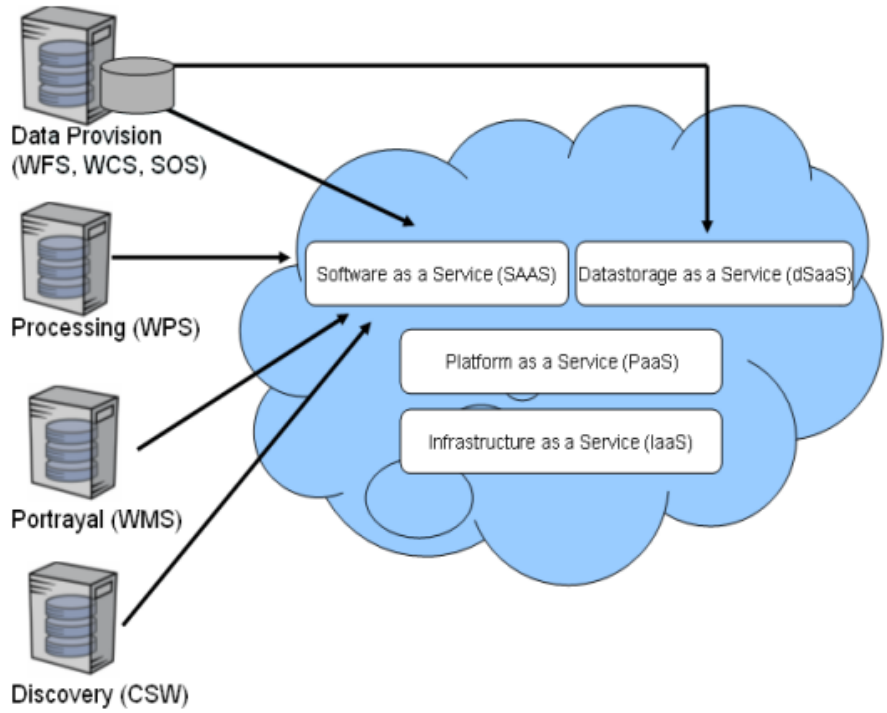


*Figure 8: Approach to Providing Web GIS Services on Cloud (26)*

**Integrating Spatial Data Infrastructure with Cloud Computing:**Spatial Data infrastructure (SDI) is legal, organizational and technical frameworks for geospatial resources. Geospatial data, metadata, Geospatial services and standards are considered the building blocks for SDI, Clearinghouses platform is used to search for distributed geospatial data uniformly, the SDI allows the participating society and organizations to reduce the cost of geospatial data production and data redundancy. SDI can be integrated with Cloud Computing through one of two options according to (12) the first option is adoption of Cloud computing principles and standards to SDI and the second option is migration of SDI services on top of Cloud Computing.Cloud Computing can be used to build reliable and scalable SDI, which is composed of people,

spatial data, metadata, standards, frameworks, clearinghouse, networks and policies. Huge amount of spatial data provided by SDI through web applications. Some SDI allow volunteer to create and share geospatial data, this systems called Volunteered Geographic Information (VGI), SDI should be scalable to include the large amount of geospatial data that are produced by VGI, numerous users should be able to access the SDI concurrently and a large number of computing resources required for Geospatial data storing and processing, all these issues can be solved by integrating Cloud Computing with SDI. ESRI deployed ArcGIS Server on Amazon EC2 as cost effective SDI platform to enable the organizations to publish geospatial data and geoprocessing tools to extract useful information and could be used in different applications (13).

**Integrating Geospatial workflow with Cloud Computing:**

Geospatial workflow is a set of geoprocessing tasks that executed in a certain logical order. Cloud based geospatial workflow implemented by using workflow management system, the execution starts by scheduling tasks to worker nodes by workflow management system. To execute task each worker node downloads required data for task execution from storage server, after execution completed, the worker node upload the result to the storage server to be available for other tasks in the workflow, the execution continue until all tasks complete (14).

**Software Engineering approaches for Developing Cloud GIS Applications:**

The nature of Cloud GIS architecture is fully distributed and integrates software from client, server, development, test and management sides. the common software engineering approaches in cloud computing are spiral and concurrent pattern, instead of purchasing software license, Organizations renting license from cloud providers in software development life cycle which, reduce the cost of software, the cloud computing make the process of software

development, management and maintenance more flexible(15).

### 3.2. Cloud GIS Architecture

Cloud GIS architecture can be divided into two components including Cloud GIS interface and Cloud GIS server. Cloud GIS Interface provides flexible and effective web interface for users. Cloud GIS server hosts computing resources, the Cloud GIS server consists of five layers which are communication layer, repository layer, utilities layer, logic layer and configuration layer(16).

The Architecture of Cloud GIS for flood monitoring cyber infrastructure proposed by (17), it is consists of four components, which are the Global Flood Inventory (GFI), web server, cloud services, and user interface. Preprocessed GFI will stored in cyber infrastructure, the user interface is designed by HTML and JavaScript to enable the users to interact with Cloud GIS cyber infrastructure, the web server is receiving users requests and sending responses to the users, the cloud services handles queries, analysis and visualization of data(18).

The General Architecture of Cloud based oil spill detection using Open Source components proposed by (19)as shown in Figure 9. The general architecture consists of three key components, which are Spatial Database, Web Server and Spatial framework. PostGIS used as Spatial Database, Tomcat used as Web Server and Geoserver and HADOOP used as spatial framework for Spatial Data processing and Geocomputation (20).

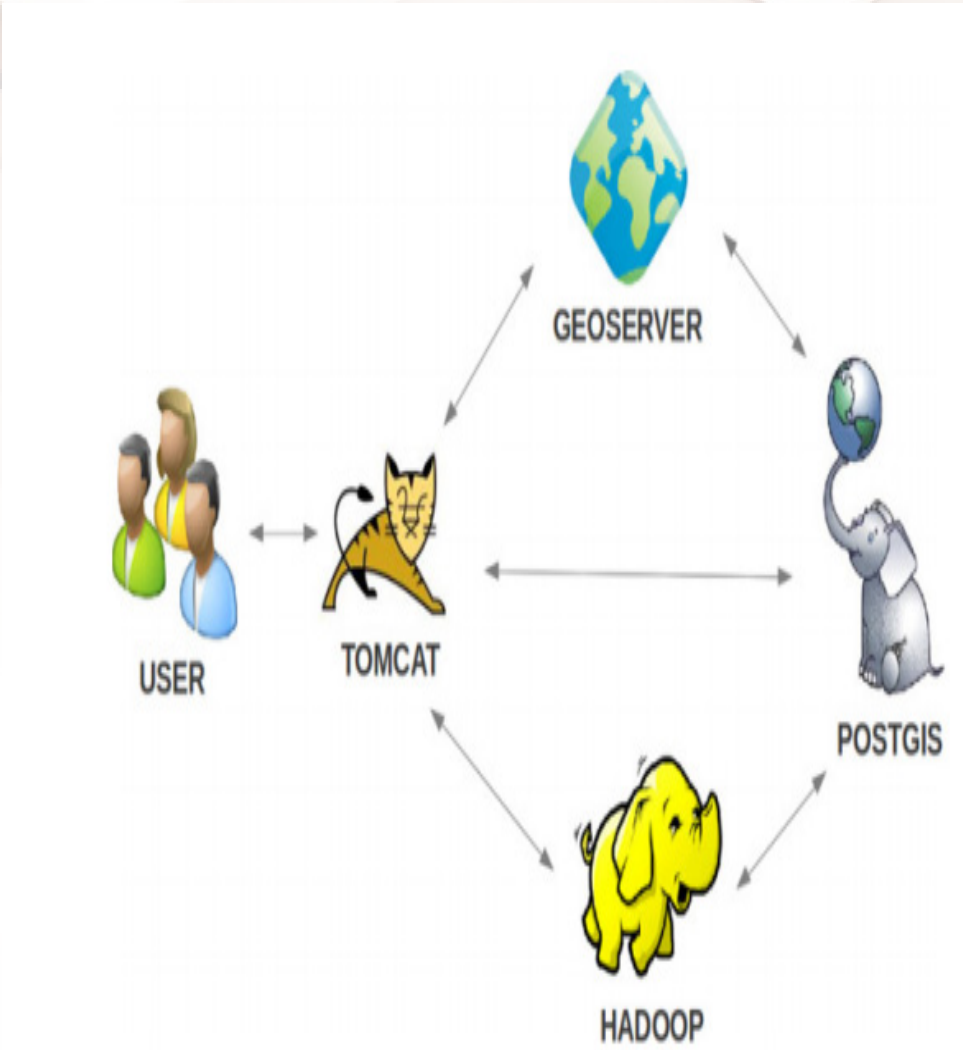


*Figure 9: General Architecture for Cloud Based oil spill detection using Open Source Components (10)*

Hybrid Cloud GIS Infrastructure divided into seven segments (21) by(22)including client segment or user interface which allows users to interact with Cloud GIS platform. Hybrid management segment (portal) to connect users with contents based on their

privileges. Application segment which provide Cloud GIS services and applications to the end users. GIS segment this segment provides geospatial services such as map services, geoprocessing services, spatial analysis and hosts geospatial resources. Data management segment handles the movement of spatial data between GIS segment and storage segment. Storage segment to store various types of data in database management system, in hybrid cloud environment the private data stored in private cloud while the public data stored in public cloud. Infrastructure segment to control data centers and uses virtualization to create virtual machines. these segments are distributed in two environments (2E) public cloud and private cloud (23).

Architecture of Geospatial Services in Cloud Computing is a client server architecture customized to achieve the openness and interoperability between various components. The Architecture consists of three layers, client, application and Data as shown in Figure 10. The client layer is the end user software that enable the users to visualize the geospatial data and perform geospatial operations as well as discover and share the geospatial data through cataloging services. The application layer consists of the core geospatial services, application services uses OGC standards and contains Catalog Server to store metadata information, Data Server to provide the geospatial data to the clients using the common OGC standards including WMS, WFS and WCS, Processing Server to provide a set of geoprocessing services through WPS standard. The data layer to hold and store the geospatial data (24).

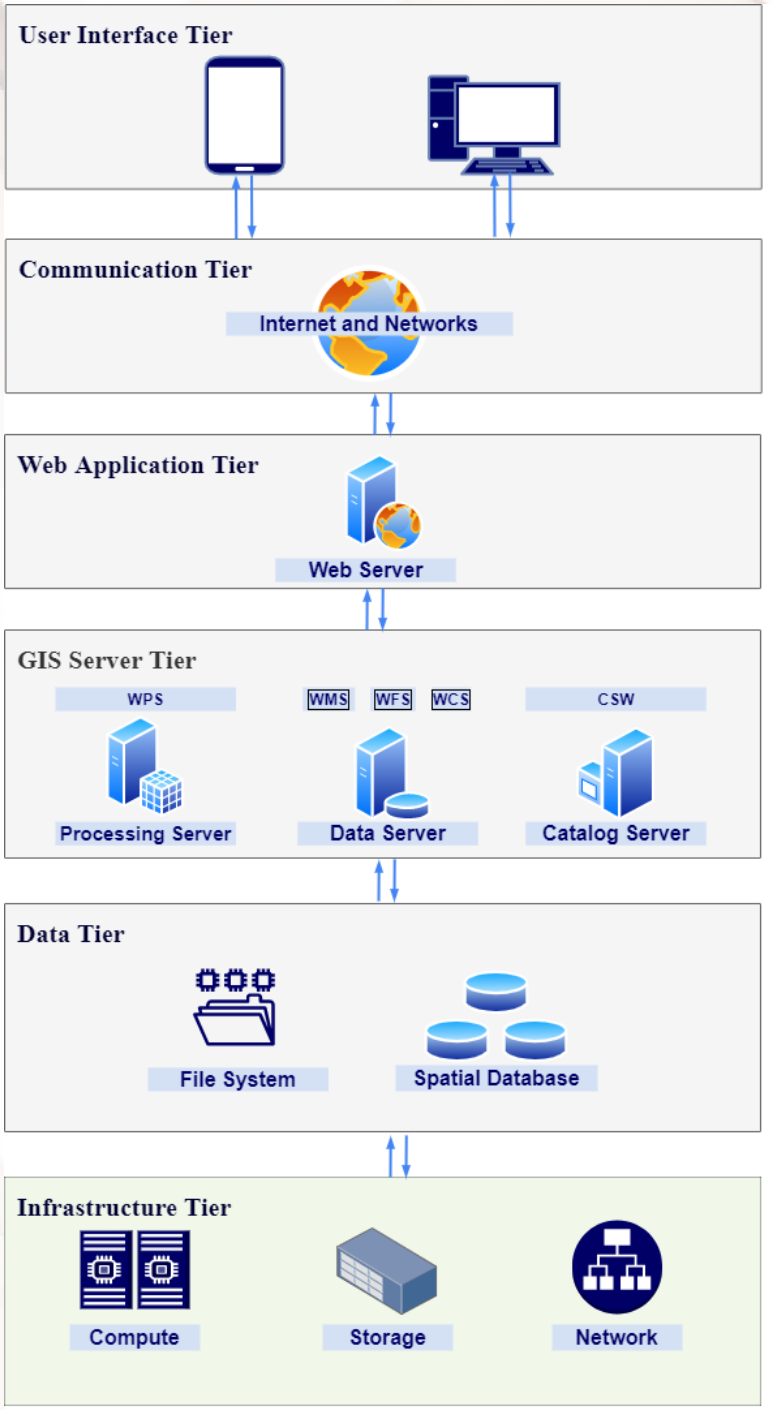
User Interface Tier
Communication Tier
Internet and Networks
Web Application Tier
Web Server
GIS Server Tier
WPS
WMS
WFS
WCS
CSW
Processing Server
Data Server
Catalog Server
Data Tier
File System
Spatial Database
Infrastructure Tier
Compute
Storage
Network

*Figure 10: Architecture of Geospatial Services in the Cloud*

According to (25), The Architecture of Cloud GIS is divided into five layers including Client layer to enable the users to manipulate and manage the geospatial data, Application layer which enable the users to organize their geospatial data to form Information System for making decision. GIS Platform layer contains GIS utilities such as mapping, geocoding, routing and navigation, Storage layer to handle geospatial data storing in Database system and Infrastructure layer to build the computing infrastructure using virtual machines and physical machines.

Tripathi, Agrawal, and Gupta divided the architecture of Cloud SDI into three layers including client layer to provide a mean for accessing, processing, retrieving and visualizing the geospatial data through client's applications. The middleware layer handles various types of geospatial services such as data services, catalog services and geoprocessing services, as well as users authentication and privileges and cloud services infrastructure for cloud resources management and control. Cloud based SDI is based Service Oriented Architecture which allows the service creation, discovery, orchestration and monitoring to be performed at the endof cloud provider (26).

Aly and Labib divided the Cloud GIS architecture to six layers, Client Layer, Cloud GIS Application layer, Data Management layer, Storage layer, Platform layer and Infrastructure layer(27).

The architecture of Mobile Cloud GIS follows the client server architecture which composed of the following modules user interface, business logic, GIS functions, data storage and access, these modules are developed as independent modules, this architecture is a multi-tier architecture which composed of client tier, communication tier, application tier, GIS server tier and Data tier. in this architecture client tier refers to the mobile application that enable the users to interact with geospatial data and geospatial analysis

tools (28).

The structure Cloud GIS platform divided by (29) to the followe ing layers The Data layer for Grid geospatial data extraction and analysis using ArcGIS server. Data Access layer for data screening and analysis. Cloud services platform layer for system integration, And Presentation layer for clients (Desktop, Web or Mobile) to access the Cloud GIS services by using Rich Internet Application (RIA).

The Cloud GIS architecture for meteorological hazards in power system consists of four layers including, Implementation layer which refers to cloud GIS infrastructure such as hardware, operating systems, networks, storage and other infrastructure resources that delivered as a services on demand. Architecture layer refers to the mechanisms for managing the geospatial data, meteorological and power grid data, Service layer provides meteorological hazards evaluation and power system assessment tools as services to the end users applications, Application layer provides user interface to meteorological hazards assessment (30).

The architecture of Cloud GIS for real time macroeconomic impact decision support system composed of Enterprise Geodatabase, which contains all data required for macroeconomic impact decision support system, Administrator who manage the web GIS application for macroeconomic impact decision support system. Cloud platform to provide computing resources as services on demand for example Amazon AWS and Microsoft Azure, GIS server enable the users to share their Geospatial data and tools as Geospatial Web Services, GIS Web Services which is standard or protocol to share Geospatial resources across applications using Web standards such as REST API and SOAP. Autonomous Software to extract and collect information from distributed web data, macroeconomic loss assessment on the county level and edit and update the geodatabase(31).

### 3.3. Cloud GIS Solutions

Cyber flood infrastructure is a cloud based platform that enable authorities and public to collects, organizes, visualizes, and manages flood data from various global flood databases in real-time, the cyber flood infrastructure provide visualization, statistical analysis and graphics capabilities which aims to update the existing flood inventory. the platform is based on crowdsourcing data collection methodology which enable the public to report new flood events by using their smartphones and engage the citizen scientists to be cultured about the hydrological modeling and satellite remote sensing(32).

Cloud based integrated framework for marine spills detection using GIS, Remote sensing and Cloud Computing technologies. The framework isolate the dark areas in Synthetic aperture radar (SAR) images using segmentation algorithms and fuzzy clustering (33).

Cloud based embedded GIS application has been developed to provide GIS functionalities in embedded devices (Mobile)such GPS positioning and mapping. The mobile application in this system is developed by using Java Micro Edition (J2ME). The system's server is a virtual server based on Cloud Computing technology, the processing and analysis of data are executed in the server part, Geospatial data are hosted and updated in centralized server, while the embedded terminals can obtain geographic information updates from the server without maintenance (34).

GIS framework for Geological information based on Cloud Computing constructed for data organization, sharing and services, a 3D map for China a Geological Survey Information carried out, Users can use 2D and 3D data discovery mechanism. The GIS framework of geological information service platform based on cloud computing is used to publish the three-dimensional spatial information of integrated organization and management by form

of service, the data directory service consists of two main functional modules: search module and update module (35).

Global Earth Observation System of Systems (GEOSS) clearinghouse deployed on Amazon Elastic Cloud Computing (EC2) platform to utilize cloud-computing technology in Geoscience applications. GEOSS clearinghouse is a web-based platform for metadata cataloging to manage metadata of Global Earth Observations geospatial resources. GEOSS clearinghouse based on GeoNetwork Web Based catalog application to manage Geospatial resources. (36).

A Framework for Marine Navigation Alerts has been developed based on Cloud computing technology to identify the of marine incidents, visualize the heatmap, generate alerts through the Cloud based Marine Navigation framework (37).

Integrated Enterprise GIS for Transportation Planning and Modeling has been developed on Cloud Computing to integrate Geospatial Data with Cloud enabled viewing and editing applications. This integration enable Durham Chapel Hill Carrboro Metropolitan Planning Organization (DCHC MPO) to efficiently house the data related to transportation planning process, distribute it among the partners and collaboratively edit, manage and maintain that data in the cloud computing environment (38).

Vehicular traffic management system developed on GIS Cloud Computing to enable the users to access, collect and analyze geospatial data related to vehicle (longitude, latitude, speed, date and time) through their smartphones or tablets while they are working in the field. The Geospatial data captured by GPS equipment sent to the server to store the data in database system and process it real-time through Traccar application (39).

Cloud based Decision Support System (DSS) for soil fertility management developed to provide recommendations for fertilization, Soil Test Crop Response (STCR) equations used for targeted

yield approach for different crops. the system enable the farmers to select the crop, variety, soil type and season and then the system calculate the precise recommendations for fertilization(40).

Real time macroeconomic impact decision support system developed based on Web GIS and Cloud Computing platform integrated with real time situational awareness software outage statue and economic loss in power and electric utilities, the system enables the emergency managers to assess hazard driven regional economic loss(41).

Cloud based decision support system for the Solutions of Domestic Wastewater Treatment Modelling in Wexford, Ireland developed to assists the local authorities to make better decision about domestic wastewater treatment in low permeability zones. Determination of low permeability area depends on four criteria including the distance from existing sewerage network, density of existing septic tank, the T value (how long it takes effluent to percolate through the subsoil); and the bedrock's depth (42).

### 3.4. Cloud GIS Functions

#### 3.4.1. Data Collection

Mobile GIS application for Property has been developed based on Cloud Computing to help the local authorities to solve some problems related to identification of property and capturing, the trial map was created by integrating OpenStreetMap and embedded GPS devices on Mobile. The location information, attribute information and images are captured in real time from the ground by residents through their mobile phone(43).

Mobile Health (mHealth) Application for public health information collection using GIS and private cloud computing developed as a mobile application for health information management. GPS service that available on common mobile devices has been employedfor the geospatial data collection. The Mobile Health application provides several GIS functions such as geospatial data

store, modify, update, search, manage, analyze, and report findings (44).

GIS application for managing the assets of power utility has been developed based on Distributed cloud computing to provide effective information and disseminate it at low costs, assisting in assets planning, operations, maintenance and expansion. The essential part in this application is geospatial data collection, which done by using embedded GPS device on Android Mobile (45).

Cloud based framework for health shocks data analysis and visualization has been developed based on large health informatics datasets, The framework has been developed on Amazon web services (AWS) integrated with GIS to facilitate the process of geospatial data collection, storage, visualization and indexing through the smartphones of the stakeholders. The prediction model has been developed based on datasets collected from 1000 households in rural area in Pakistan, with focus on the following factors including health, economic, environment, social and accessibility to healthcare facilities. The collected data has been used to generate the prediction model of health shock based on fuzzy summarization technique, which provide causal factors of health shocks for stakeholders in interpretable way(46).

Cloud GIS application for AL-Kamaliah region has been created based on GIS Cloud Computing platform, which is easy to use platform for non-GIS professionals. The GIS Cloud Platform consists of GIS portal, Map Viewer, Map Editor and Mobile Data Collection (47).

Participatory GIS system for property damage certification due to Tsunami was developed based on Web GIS and Cloud Computing technologies to build a system that enable users from Japan to participate building damage survey due to Tsunami (48).

Mobile GIS for Patrol system has been developed based on Cloud computing technology to enable the field staff to collect critical data in an effective way and to increase the productivity and

security, The system consists of Mobile Application, Application server, repository and GIS Server(49). Figure 11 shows general enabling cloud based data collection using mobile devices.

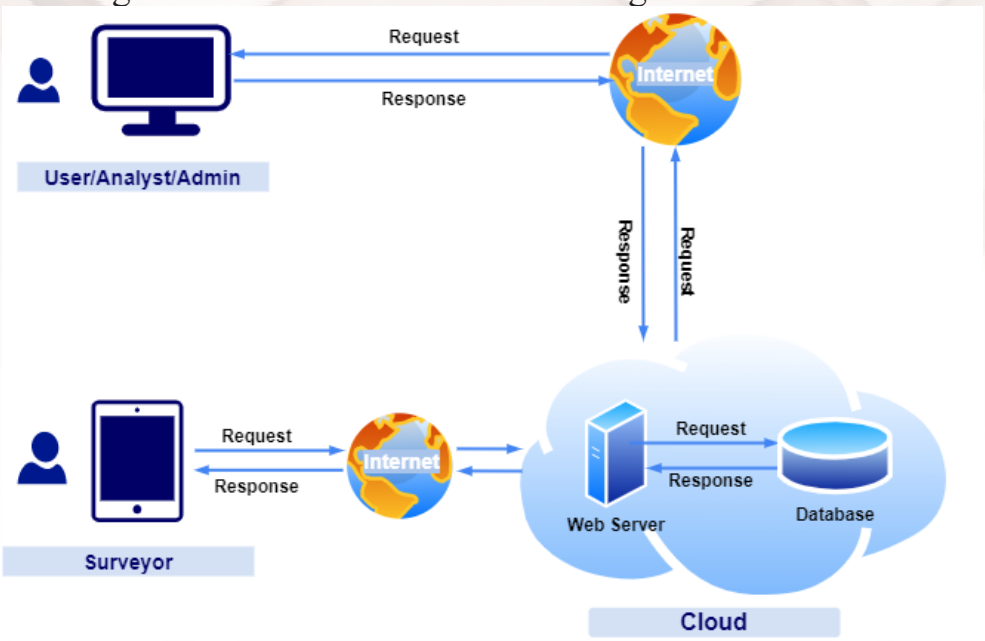


*Figure 11: Cloud Based Data Collection using Mobile Devices*

### 3.4.2. **Data Storage**

Various types of storage devices are assembled to build the cloud storage, which is a complex system consists of a several parts such as storage equipment which is a core components, servers, network devices, applications, interfaces and client programs. These storage devices work together by using software with functionality of grid, distributed files and clustering (50).

A model for Spatial and Temporal data storage suitable for Cloud Computing was proposed to describe the geospatial data from different aspects and dimensions including space, time and attribute dimensions and the temporal and topological relationships. The proposed model is based on NoSQL Spatial and temporal data to solve the massive spatial and temporal GIS data storing, to achieve high performance and high availability and efficient management,

query and process of Spatial and Temporal Data (51).

### 3.4.3. **Spatial Analysis**

Turkey Spatial Datasets has been gathered on a Cloud based geodatabase to build a Cloud based platform for Geospatial queries and analysis. All datasets has been uploaded to ArcGIS online platform, ArcGIS online cloud platform provide a Web interface with ready to use tools such as Basemap, Add data tool, data sharing tool, measure tool and the most common GIS analysis tools like Overlay, Hotspot, Intersect, Buffer and some networks analysis functionalities (52).

Cloud based decision making tool for agriculture production management has been developed based on ArcGIS online platform to increase the efficiency of decision making in agriculture production management, which enable agronomist and enterprise manager apply image indices to determine the current situation of crops (53).

Cloud based GIS model for emergency management has been developed to overcome the problems related to large scale geospatial data and to find a solutions for big geospatial data in emergency management(54).

Cloud based model for earthquakes prediction has been developed to give early warning about potential earthquakes damages for quick response to the disaster, this application enable the government to minimize losses of people life and their property, Cloud Computing, GIS technology and Historical earthquakes data have been used to estimate the potential future earthquakes(55).

Cloud computing and spatial analysis has been combined to enhance the efficiency of geoprocessing, spatial analysis and decision support tools. By applying cloud computing with high computing capabilities data processing, buffer analysis, overlay analysis, statistical analysis, networks analysis and terrain analysis will be enhanced, and also the knowledge acquisition and extraction for

decision making will be more efficient (56).

### 3.4.4. **Data Display**

Cloud based decision support system for soil fertility management has been developed to manage geospatial data related to agriculture such as crop type, soil type, season, seed varieties and etc. The system includes maps that shows the distributions of soil nutrients and recommendations for soil fertilization based on STCR equations to achieve the targeted yield for for different crops (57).

Cloud based decision support system for crime mapping has been developed as a cost effective decision support system to help the police department to analyze and mapping the crime. Crime news are gathered daily from RSS feeds in Google docs spreadsheet by using ImportFeed function, Crime news are extracted in suitable format with the desired attributed like location, crime type, crime details and news link, by using visualize as a map option in Google fusion tables the crimes data are displayed as maps(58).

Cloud based model for crime mapping has been developed to automate the process of crime mapping, the proposed system contains spatial data visualization tool to visualize the crime data on google maps (59).

## 4. **Recent trends and Open Issus**

Currently Internet of Thinks (IoT) is promising research area, IoT is a network of objects (things) that are embedded with sensors and other technologies to exchange data with others devices and system over the Internet (60). Traditionally, Geospatial technology includes mapping, spatial databases, spatial analysis and image processing. One of the most important requirement in IOT is the ability to link sensors location with the other sensor parameters.Sensors are spatially distributed devices that are connected together to form sensors network, which is accessible through computer to monitor situation at different places, such as

temperature, pressure, noise or pollutions, sensor networks that are accessible through the web are called Sensor Web. Sensor data can be archived, discovered and accessed through standard protocols and APIs.OGC has introduced standard for sensor networks data called Sensor Web Enablement (SWE), to exploit all types of sensor systems and Web connected sensors such as air pollution monitors, flood gauges, stress gauges on bridges, Webcams, mobile heart monitors, airborne imaging devices and other sensors, SWE provides opportunities to add real tine sensors data, Cloud GIS and IoT is open issues and it is very important in disaster management, transportation management, environmental monitoring, public safety, science, facilities management and other domains of activity.IoT devices generate huge amount of data in various format, this may take time to be transferred to the cloud platform for processing or analysis, it might loss it is value. IoT data requires fast processing and analysis to take action in real time, a new computing model invented to minimize latency and Conserve network bandwidth this computing model called Fog Computing, which extends the concept of cloud computing to be closer to the IoT devices that produce the data, these computing devices are called fog nodes, any device with computing, network connectivity and storage can be a fog node and can be deployed anywhere in a vehicle, on a factory floor and etc.(61). Examples include embedded servers, switches, routers, Integration of Fog Computing and GIS considered a promising research area.

## 5. Conclusion

In this paper, a systematic review conducted to summarize the application of GIS in Cloud Computing Environment from Approach, Architecture, Solutions and Functions perspectives. Cloud computing is new IT approach in which computing resources are provided as a services over the internet, in cloud computing resources are scalable and provided on demand. Cloud

Computing adopts services oriented architecture and facilitates everythingas a services. Now a day Cloud Computing introduced as a new framework to enhance the traditional GIS through Web Services approach, a web service is an interface that describe a set of operations accessible through networks using standardized XML messaging. Open Geospatial Consortium (OGC) described web services specifications and standards for Geospatial data and applications, these standards include Web Map Services (WMS), Web Coverage Services (WCS), Web Feature Services (WFS), Web Processing Services (WPS), Sensor Web Enablement (SWE) and Geographical Markup language (GML) to encode the georeferenced data for transfer. The main characteristics of GIS applications in Cloud Computing are Extendable, Elasticity, On-demand service, Measurable, Transparency and Diversification of access.

The Architecture of Cloud GIS is a multi-tier architecture like Web GIS Architecture, which can be broadly divided into three tiers, Client Tier, GIS Server Tier and GIS database tier. This architecture may vary from platform to platform. The client layer is flexible and robust interface to the users, in this layers users could interacts with Cloud GIS data and tools through Web Browser, Mobile Applications or Desktop GIS Software. The GIS Server tier used to manage GIS resources such asgeospatial databases, GIS Server include Catalog server to keep records of metadata. Data server provide geospatial data to the clients as services, categorized in standardformats. The GIS Database tier to handle GIS data storage and management. The architecture of Cloud GIS may be different when we look the Architecture from Infrastructure as a Services (IaaS) perspective in this case, infrastructure tier added to the architecture.

Different Cloud GIS solutions developed in different domains such as Marine, Natural Resources, Hazard and Disaster Management, Navigation and Transportation, Health and economics for

decision making. These solutions uses different GIS functions, these functions including Data Collection, Data Storing, Spatial Analysis and Query and Data Visualization.

Recently IoT become a promising research area and it is important to link IoT sensors location with the other sensor parameters. Mostly, sensors are spatially distributed and connected together to form sensors network, which is accessible through computer to monitor situation at different places, such as temperature, pressure, noise or pollutions, sensor networks can be accessible through Web Services on Cloud computing environment.

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