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GIS-Based Decision Support System and Analytical Hierrachical Process for Integrated Flood Management

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Abstract: Massive flood losses have prompted initiatives to reduce flooding all around the world. Flood risk assessment methods that are widely used nowadays include remote sensing and Geographic Information Systems (GIS). Both of these systems provide integrated models for analyzing flood risk. Web-based geographic information systems are superior to desktop GIS for doing real-time analyses of flood risk. The Wadi Aday Basin in Oman is going to be evaluated using a web-based geographic information system (GIS), which is the purpose of this project. Cities, location, census statistics, land use and land cover, road network, structures, flood risk management, wadi spread, geomorphology, and the boundaries of the study region are all things that will be discussed. Features such as zooming in and out, measuring features, managing layers, adjusting the level of transparency, and querying geographical data are all provided. A QGIS web-based GIS was designed for the Wadi Aday Basin in the Sultanate of Oman to evaluate and map the regions prone to flooding. The analytical hierarchical process (AHP) technique was applied where it provides a systematic approach for combining the impact of multiple thematic levels to obtain qualitative and quantitative information on successful mitigation of flood risks. The specifics of this information are explained in the article. In order to create a comprehensive Flood Risk Map, the relevant thematic data are brought together in a GIS setting. The AHP approach is used to calculate the flood hazard index, and this index not only takes into account the likelihood that each location will be flooded, but it also takes into account the overall influence that each of the themes has on the flood risk zonation.

Keywords: *Web-GIS; QGIS; DSS; AHP; Mitigation strategies*

1. Introduction

The flood development process is dynamic (Alexander, 1999) and spatially distributed (Waugh, 1995). Urban area flooding is common globally and is associated with significant rates of mortality and economic loss. That makes flood risk assessment, management, response, and preparedness crucial (Antofie, 2018). The use of this strategy is currently happening on both the international and the national level. The growing frequency of disasters caused by hazards demand for a more advanced and dynamic data sharing approach in order to improve the effectiveness of risk management. The development of an open data policy has become necessary since open data has become a prerequisite for the understanding, identification, and management of risk. This constraint was challenged in 2011 when the Global Facility for Disaster Reduction and Recovery (GFDRR) introduced the Open Data for Resilience Initiative (Open DRI), which stands against it because they faced difficulties in linking data information and decision support systems (DSS). Decision makers need the assistance of technology in order to make complex forms of decisions. Without some kind of spatial data infrastructure, decision makers are limited in their ability to make decisions.

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The application of Geographical Information Systems (GIS) technique is essential in all of the flood management stages (pre-flood, during flood and post-flood stages). It is a necessary tool for floodplain managers to identify flood prone areas of the districts and to inform the community how to mitigate with natural disasters (Panda, 2014).

A technique that is consistent and can be used to identify metropolitan areas that are particularly susceptible to the effects of intense and sudden rainfall is being developed. It is possible to further identify the areas that are particularly vulnerable to the effects of heavy rains by adapting hydrological models. However, in order for this to be achieved, the models need to have an appropriate adjustment made to them as well as highly accurate input data. Such specific data are typically difficult to obtain or are not available for less developed areas. It is also possible to accomplish this by conducting spatial analysis in a GIS environment, which is a more straightforward kind of modeling but yields results more rapidly; as a result, the amount of time spent on developing mitigating methods could be reduced significantly (Wicht & Osinska-Skotak, 2016).

On the other hand, a dependable plan for flood management consists of two components, the first of which is the formulation of an appropriate flood management strategy, and the second of which is the identification of flood-hazard zones. The primary strategy for determining whether or not a flood warning system is worth the investment. While the second one is to make an assessment of the places that are at risk of flooding. While attempting to estimate the spatial distribution of hazardous areas for the purpose of developing a strategy for flood control, some of the parameters that are taken into consideration are flow accumulation, slope, land use, rainfall intensity, geology, and elevation (Kourgialas & Karatzas, 2011).

Remote sensing and GIS technologies are well-recognized tools for complex spatial relationship simulation during extreme flood situations (Eleni, 2011; Mioc et al., 2008; Huang et al., 2018). They permit multiple thematic layer integration for integrated model development and analysis (Sterlacchini, 2017). Unlike desktop GIS, Web-based GIS provides effective multi-platforms for instant and real-time flood risk assessment projects (Huang et al., 2018). More importantly, they are highly accessible to many users. Many stakeholders are involved during flood control and prevention operations. It allows decision-makers and emergency-response teams with little or no GIS knowledge to access and use geospatial information by offering them access to maps and data that can facilitate flood risk control and preparedness (Huang et al., 2018). Web- GIS support decision maker such as stakeholders and experts decision-making process for assessment and variety of different risk management strategies through an interactive participatory GIS approach (Zar et al., 2015).

A distributed GIS approach for flood risk assessment was utilized in Don valley of Toronto, Canada. The efficiency of Web-based GIS in simulating different what-if scenarios under different water level increase conditions been demonstrated with a visual model of the extent and the impact has been shown in the web using GeoServNet (GSN), a proprietary Web-GIS package (Rifaat, 2009).

Flood management must be approached in an integrated manner (Haidu & Nicoară, 2011). To mitigate with floods, flood hazard maps and risk maps created and discussed with the local people and authorities to derive suitable changes in the legibility with colour schema and the methodology adhered serves as a basis for local flood management.as the work been done for Troubky municipality in Czech Republic where they worked multi-criteria which using local inhabitants (Klemešová, 2014)

Hat Yai Municipality at the southern part of Thailand use GIS and satellite imagery in assessing the risk of floods and identifies efficient measures to reduce flood risk. The construction of structures or canals and other infrastructures is not the solution for mitigating flood, but proper land use planning using GIS, installation of flood forecasting mechanism through information and communication media and relocation of people are the vital measures that can be undertaken (Tanavud et al., 2004).

GIS technology can be utilized to construct a risk-based technique that can statistically estimate the risk of flooding based on hydrological models, land use, and socio-economic data. LATIS is a Geographic Information System (GIS) tool that was developed in 2007 by Flanders Hydraulics Research in collaboration with the Department of Geography at Ghent University. LATIS is one of the GIS tools that is used to help the government estimate the potential damage and number of casualties that could occur as a result of flooding. It also provides the possible actions that can be taken to undertake risk assessments in a timely and efficient manner. It was used by Flanders at the North part of Belgium flood calculation as presented in figure1. The calculation of damage and risk consists of three steps, which are I defining probability and extent of flooding, (ii) determining expected damage, and (iii) defining risk. It was used by Flanders at the North part of Belgium flood calculation (Deckers et al., 2015). Moreover, Salleh et al. (2021) highlights the importance of geospatial technologies for sustainable cities and communities. They use five papers to emphasize the importance of geospatial technology (remote sensing, GIS, photogrammetry, and geomatics and spatial statistics) on this field.

Susceptibility to map floods is vital to describe the high-risk flood zone areas and plan the easing methods. The application of a multi-criteria decision support system that uses a combination of RS/ GIS (Remote Sensing / Geographic Information System) and AHP (Analytical Hierarchy Process) along with the cloud computing APIs available on the GEE (Google Search Engine) platform helped in classifying five main flood causing parameters. The parameters are morphometric, hydrologic, land cover dynamics, permeability, and anthropogenic interference, with 21 sub-criteria to suspect flood regions in the Bihar region of northeast India. The AHP used PCM (Pair-wise Comparison Matrix) to develop the weightage technique. Relative importance and priority were associated with each criterion based on their contribution of suspecting flood. The combination of the GIS-AHP method helped provide helpful insight to map flood zones by using a high number of parameters in GEE (Swain & Singha, 2020). The figure shows graphic pictures of the procedures used to map flood vulnerability in Bihar, India.

The combination of RS (Remote Sensing) data and CSPs (City Strategic Plans) with GIS (Geographic Information System), 2D RRI (Rainfall-Runoff-Inundation) simulation model, and MCDA (multi-criteria decision-making analysis), which is AHP (Analytic Hierarchy Process), was used in Egypt, Hurghada, for more than 20 years from 1996 to 2019 to estimate flood regions. Along with being economical, the combination method was highly beneficial in overcoming the scarcity of data. It filled the gap between FRM (Flood Risk Management) and urban planning. It also helped develop comprehensive and high-quality maps of flood zones to assist the decision-making management systems. Based on the parameters, it produces both current and future social, physical, and economic susceptible maps. There are seven parameters: use of land, the height of the building, material used in construction, density of the population, total population, and land value (Abdrabo et al., 2020).

A plugin for QGIS known as the Geomorphic Flood Area tool, which is open source (GFA tool). It is designed to make the technique freely available to any and all users, with an interface that is simple and straightforward, so that it can be utilized by the community at large. Through a community-based development process, which will allow for a better understanding of the process and increase the production and utilization of pre-elaborated and more understandable data, anyone can contribute to the analysis, modification, and redistribution of the source code. This will improve the algorithms and produce new data. The QGIS tool for geographic information system analysis and mapping is free and open source. The identification of regions that are at risk of flooding and those that already have flooding is an important responsibility, but there are sometimes logistical obstacles that make it difficult to do the job. Where there is a lack of available data, such as in ungauged basins or when doing large-scale evaluations, geomorphic methods can be used to get information that is of help for flood danger exposure. An automated technique based on DEM that was able to detect flood-prone areas in numerous test sites located in Europe, the United States, and Africa with a high degree of accuracy and reliability utilizing GFA. These test sites were placed in different parts of the world. It does this by performing a linear binary classification based on the recently established Geomorphic Flood Index, which makes it possible to undertake flood mapping quickly and at a low cost (GFI). An approach that is simple to use for mapping flood risk across broad areas is provided by the GFA tool. A thorough flood map for Romania was created as a demonstrative use of the GFA tool, which is given here (Samela et al., 2018).

This study provides a Web-based Geographic Information System (GIS) based on QGIS that was developed for the Wadi Aday Basin in the Sultanate of Oman in order to analyze and map regions at danger of flooding. The Analytical Hierarchical Process (AHP), which provides a systematic approach for

integrating the impact of various thematic layers to derive qualitative and quantitative information on effective mitigation of flood risks, was utilized in this research. The specifics of the information derived from this research are described in the paper. In order to create a comprehensive Flood Risk Map, the relevant thematic data are brought together in a GIS setting. The AHP approach is used to calculate the flood hazard index, and this index not only takes into account the likelihood that each location will be flooded, but it also takes into account the overall influence that each of the themes has on the flood risk zonation.

2. Study area

The Sultanate of Oman is located in the south-eastern region of the Arabian Peninsula. It is bounded by the Arabian Sea in the southeast and the Sea of Oman in the northeast. The Sultanate of Oman has a coastal length of 3165 kilometers and an area of 309,500 km2. Yemen is located on the southwestern side of the Sultanate of Oman, while the United Arab Emirates are located to the northwest and Saudi Arabia to the west of the country. The research region is located within the Muscat Governorate and is referred to as "Wadi Aday." "with a total land area of 127 km^2 (127 square miles). The geographical extent of the study region is 23º 37'2" N , 58º 29' 4" E and 23º 19'3" N , 58º 19' 5" E longitude, with a mean sea level of 7 meters. It is one of the largest wadies that flows through Muscat, and its name is Wadi Aday. A portion of the 335-kilometer-square watershed is drained into the sea by it. The upper catchment is made up of a huge bowel with a gentle slope that is called the Al-Amerat bowel. It is flanked by a mountainous range that reaches an elevation of approximately 1500 meters above sea level.

The Wadi Aday itself is made up of a multitude of tributaries, all of which originate in the mountains and flow in a direction toward the northeast. the gradually approach this point at the beginning of the small gorge, which is located where the Wadi passes through the towering limestone obstacles. The mighty Wadi Aday emerges from its meandering course after 8 kilometers to reach the heights of Qurum. It then passes past the city center of Qurum on its way to the coast, where it terminates in the mangroves of the Qurum nature reserve.

The lower channel of Wadi Aday passes through places that are highly obstructed by Qurum. Along the banks of the wadi, there is a dense concentration of residential and commercial structures, and in some areas these structures even perilously encroach towards the wadi bed itself. It is one of the main suburbs of the capital area, with more than 20,000 new plots already distributed, which would lead to an increase in population reaching to more than 90,000 people, and the number continued to increase day by day due to the enormous development of the area and the newly constructed highway, which connects the area to other cities. At the present time, the upper Al Amerat bowel is more inhabited. It is also one of the main parts of the capital area. (MRMEWR, 2009).

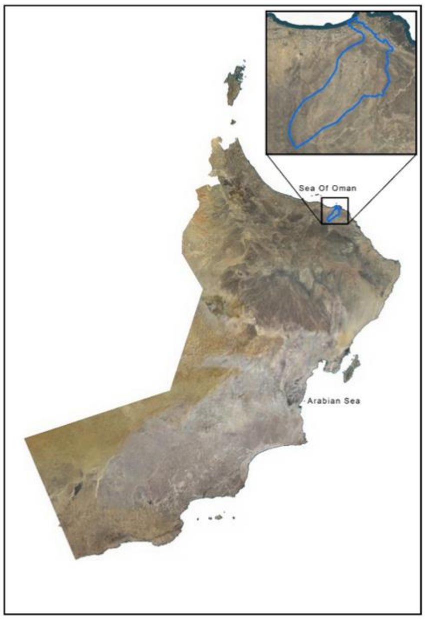

Fig. 1 Study Area of Wadi Aday Basin

3. Methodology

In order to create a WebGIS application, a cloud instance of the open-source GIS software QGIS was utilized. The application had five essential components: a geodatabase, an operational geodatabase, an operational geodatabase, and a web application. The web application was the foundation of the application. Upon the completion of the QGIS software installation, the WebGIS application was made operational by properly setting the proxy servers. On the desktop of a computer, the Python Plugin, the QGIS Cloud Plugin, and the OpenLayers Plugin were installed. The deployment of the Open Layer Plugin made it possible to exchange data between the Web Feature Service (WFS) and the Web Map Service (MMS).

In order to sign up for a QGIS Cloud account, the QGIS Cloud Plugin was required. On the desktop of the computer, a total of twelve QGIS themed leyers were reorganized. Cities, Location, Census Data, Land use/Land cover, Road network, Buildings, Flood risk management, Wadi spread, Geomorphology and Boundary of the research region, and Esri Shaded Relief were the twelve theme layers that were included. The theme layers were uploaded into the QGIS, and then the outcomes of the project were published with the help of a tool called Publish Map. Regardless of the user's prior GIS experience, web-based GIS apps have the potential to make spatial data and maps accessible and helpful to the user. A WebGIS application is comprised of five essential components, each of which may be accessed independently via the web or the internet. This is how they break down:.

A. A web application

The web application supplies the client with the software interface and the tools that correspond to it. These tools are used to visualize geographic information, interact with it, and do other tasks related to it. It is an application that may either be run on a mobile device or in a web browser.*A digital base map*

In a web-based GIS application, the base map provides the geographic context for each operation/process.

B. A digital base map

In a web-GIS application, the base map provides the geographic context for each operation/process.

C. Operational layers

Operational layers are the main thematic layers that users work with directly or derive as the result of an operation in a web-GIS application.

D. Operational tools

In many cases, a web-based GIS program will feature tools that are capable of doing activities beyond than mapping. The most crucial tools are those that allow for queries and measurements.

E. Geo database

Every single GIS application must have a robust geospatial data management framework in order to store the information that is referred to as geo database. Shape files, spreadsheets, and a variety of tabular datasets are all stored in here.

When designing a web-based application for GIS, the first step is often to set up a web server that is able to manage incoming requests and create responses that are relevant to those requests. A map server that is capable of providing our application with geospatial data is another important component that is housed on the server. Standardization efforts undertaken by the Open Geospatial Consortium (OGC) are typically relied upon by the functionalities of map servers. Georeferenced map pictures can be obtained through the Web Map Service (WMS), which is powered by spatial data (OGC, 2014).

In this work, a Web-based GIS Application was developed for the management of flood risk in the Wadi Aday Basin in the Sultanate of Oman using the open-source QGIS cloud. As the base map, an ESRI Shaded Relief Map generated by WMS was used. The current Web-based Geographic Information System uses a latitude/longitude coordinate system that is based on EPSG: 4326 - WGS 84. This system is based on the center of mass of the Earth.

At the outset, Windows based QGIS desktop software was installed. Proxy server was configured to enable the WebGIS application. Python Plugins were fetched from the

Plugin Dialog. From the Python Plugins, QGIS Cloud was filtered and installed. QGIS Cloud has three server applications namely database server, application server and fail over server. Similarly, Open Layers Plugin was installed to enables data sharing from Web Map Service (WMS) and Web Feature Service (WFS).

Subsequently, QGIS Cloud account was established by signing from QGIS Cloud Plugin and creating permanent login credentials. The thematic levers were re-organized in the QGIS desktop. Totally twelve thematic layers were used for developing the WebGIS application in the present study. They are (Cities, Location, Road network, Wadi spread, Buildings, Census Data, Flood Risk categories, Land use/ Landcover, Geomorphology, Geology, Boundary of the area and Esri Shaded Relief). Redundancy in the attribute data was cleaned for each thematic layer and symbology was updated. All the thematic layers were later uploaded to the QGIS cloud and final project was created. The project was then published using Publish Map tools. QGIS cloud allows several customizing options to the author based on monthly subscription. It provides additional storage up to 1gb over the default storage of 50 mb. Further custom domain name and viewer customization like logo, CSS, etc. are allowed. Subscription also provides SSL support and permits daily data backups.

4. Results and Discussion

The Web-based GIS system enabled layer zoom operation, feature measurement, layer control, and information query on the spatial data. The application "Feature Info" tool displayed the spatial and non-spatial data of selected polygon on the map Figure 2). The layers and logo tools in the control panel permitted interactive switching on and off between different layers and a change of transparency level (Fig 2).

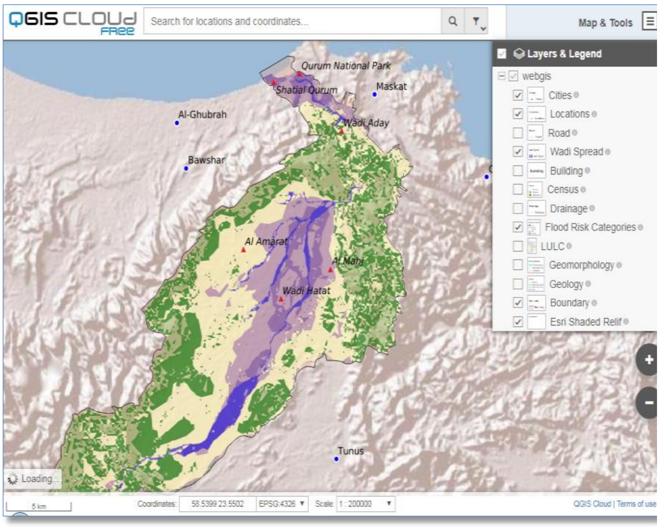

Fig. 2 QGIS cloud interface with Maps & Tools control panel

The application offers a set of overlay buttons on the screen that permits the user to display and zoom of different thematic layers for view. For instance, unlike other layers that could be fully displayed, the road and building layers could be zoomed and displayed at different zoom levels in the large-scale map. The functionality of the web-based GIS to display each thematic layer at different transparencies permitted blending and overlay of two thematic maps for spatial relationship analysis (Figure 3). Figure 4 shows building layer displayed at a specific zoom extent, whereas figure 5 shows land use and land cover map with transparency adjustment. Figure 6 shows the graphical representation of population theme in web-based GIS.

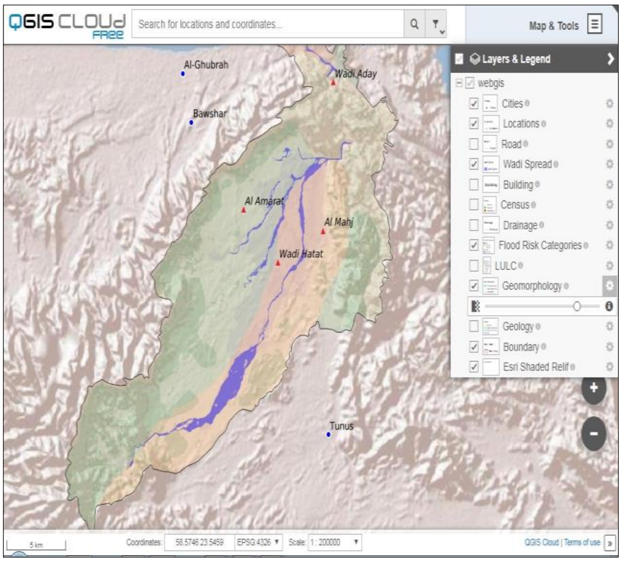

Fig. 3 Transparency blending of Geomorphology with Flood Risk Category Map

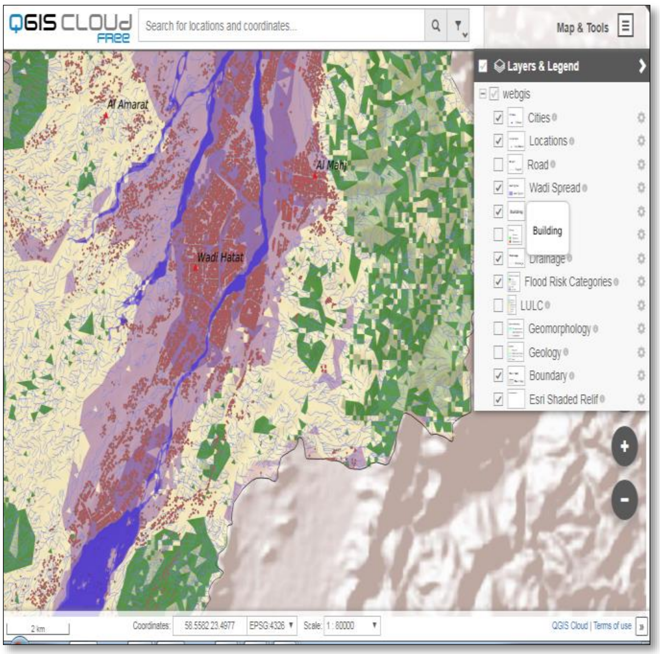

Fig. 4. Building layer displayed at a specific zoom extent.

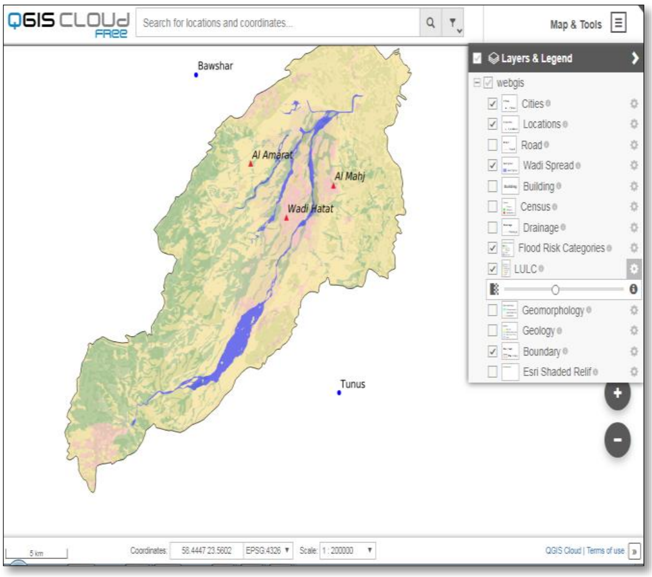

Fig. 5. Land use / land cover map with transparency adjustment

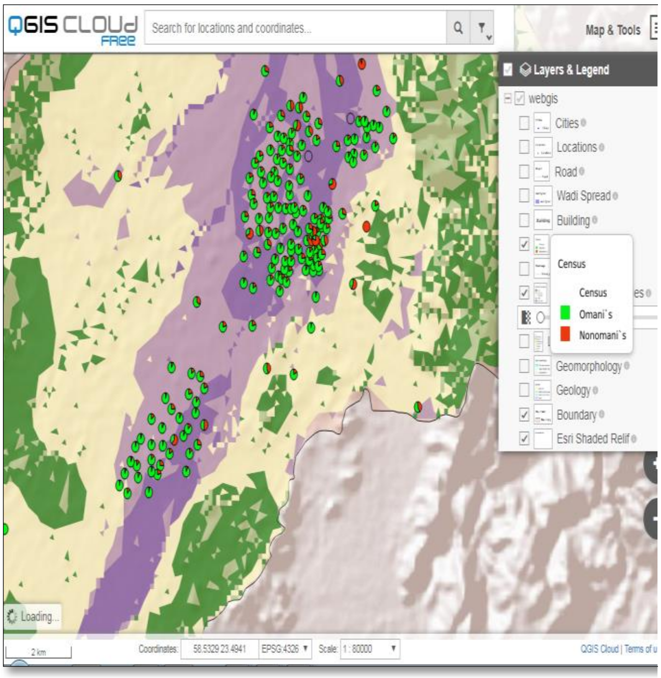

Fig. 6. Graphical representation of population theme in WebGIS

Furthermore, a measurement tool was available under the control panel for the position, angle, length, and area measurements on the Web-based GIS maps. It has census datasets displayed as Graphical maps. Also, the Web-GIS application has the Status Bar tool for coordinates and coordinate systems, map display, and view the maps at different scale units. The data generated by the Web-GIS is stored in the cloud in PostgreSQL databases. The databases were password-protected and securely accessed via a Secure Shell (SSH) connection. Finally, data sharing is enabled via the Open Geospatial Consortium (OGC) and allows map display via MMS and downloading via WFS. Also, with the aid of WFS-Transactions (WFS-T), direct data editing over the web service is possible.

The Web-based GIS developed in this research study has features that make it useful for assessing flood risk in the selected location. Interactive features for switching between the thematic layers make it possible to view desired different sections for proper assessment of different features of the study area. When combined with the zoom function, the differential transparency adjustment for the theme layers enables an overlay of the spatial and non-spatial data/map that is generated by the application for comparative analysis of the desired aspects of the study area. For example, the application could display the building layer and the road layer with varying degrees of transparency adjustment so that an overlay of the two different types of maps could be created. This would allow for an examination of the spatial relationships that exist between the road infrastructure and the building distribution in the area being studied.

The available measurement tool allows measurement of the longitude and latitude, time in minutes and seconds, and length/distance between desired data points or features on the map. The graphical map feature of the Web-GIS application has a pie chart tool for displaying the percentage population distribution concerning the spatial settings. For instance, it could determine and provide the percentage distributions of the Omanis and Non-Omanis with the spatial relationship in the study area. Ultimately, data sharing and downloading with the enabled web-based data editing feature of the application permits improvement of data quality and maximizes the usefulness of the data for review for present and future use.

5. Conclusion

The objective to develop a web-based GIS application for Decision Support System (DSS) in flood assessment and management was achieved. The QGIS cloud server tools make it possible to create, edit, visualize, analyze, and publish spatial data. Besides, it is an open-source application that enables data sharing and editing, making it accessible to users. Also, the objective to create the most commonly used twelve thematic layers in the Web-GIS were realized. Because of this, the application will encourage research connections and collaborations, as well as the distribution of findings and evidence among the researchers, the stakeholders, and the decision-makers. The dissemination of the data will contribute to the investigation, assessment, and management of the impact of flooding. All in all, it will assist in the implementation of flood risk mitigation measures and preparedness.

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