The Role of Geographic Information System in Environmental Planning and Management in Oman

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Abstracts: The use of Geographic Information Systems (GIS) has grown to cover various disciplines. The ability to use big data and geoprocessing tools allowed many sectors to use spatial data analysis and modeling for more effective decision-making and increased productivity. The use of GIS has become even more vital in the field of environmental planning and management, where incorporating environmental information contributes significantly to sustainable development. In addition, the ability to use spatial modeling at small-scale local or large-scale regional levels will broaden the knowledge of the direct and indirect impacts of development projects on the environment. This paper assesses the role played by GIS in Oman for generating information to gain insight into the many environmental challenges faced by the country toward more sustainable development. It provides an overview of what has been achieved, the approaches taken, and the way forward.

Keywords: Environmental Planning, Sustainable Development, GIS, Oman.

1. INTRODUCTION

Geographic Information System (GIS) is defined as a system capable of capturing, storing, manipulating, analyzing, and presenting data spatially about a geographic location (Escobar et al. 2008). GIS helps in bridging spatial data and frameworks that specify landscape patterns and the processes used to create sustainable spatial configurations of land uses in these landscapes (Turner 1989). Due to the powerful geoprocessing tools in GIS, its application at various scales in urban and regional planning management, ranging from small to large scales, allows it to solve local and global environmental planning challenges (Yeh, 1991). The strength of GIS is the software's ability to integrate data from various sources to provide the needed information for effective decision-making in environmental planning.

During the 20th century, the global climate has been changing at an accelerated rate despite the many efforts across the world to reduce greenhouse gas emissions. One of the major challenges facing developing countries mainly, is the implementation of climate change adaptation strategies in planning and development practices. Climate change consequences on the environment and infrastructure and cities in developing countries have not yet been adequately mitigated. Hence, the use of GIS tools and techniques will allow planners and managers to make more informed and science-based decisions.

2. ENVIRONMENTAL PLANNING

Planning is considered a tool to link technical and scientific knowledge to produce different opportunities. Slocombe (1993) provided a useful definition of environmental planning that differentiates it from mainstream planning. "Mainstream urban and regional planning focuses on communities and their people, land use, economies, and infrastructure, through a process of goal setting, planning, and regulation. Environmental [planning] focuses on the biophysical environment of people and communities and on the effects of other planning and development activities. Environmental planning is more descriptive and science-based than mainstream planning". As environmental planning (EP) is based on making decisions in allocating functions and resources among various alternatives to secure their future, the need for spatial data and information becomes a must. Data and spatial information are considered the basic elements in making an informed decision (Harris and Elmes 1993). Since Ian

McHarg's book "Design with Nature" had been published in 1969, his legacy had influenced designers, landscape architects, and planners to reshape the natural and built environment (Fleming et al. 2019). McHarg believed that planners were mandated to understand the environment and people. Design with nature has resulted in various applications that encouraged multidiscipline integration and holistic design approaches (Steiner 2016). Due to the increased attention to human effects and their action on the environment, environmental planning was born out of necessity (Ortolano, 1984). According to Luccarelli (1997), the increased attention to human actions provided alternatives to manage human activities sustainably.

Furthermore, Ian Macharg's theory development helped establish the land-suitability analysis that produced the core of Geographic Information Systems (GIS). The land-suitability analysis appeared as an influential technique in solving complex environmental, social, and urban problems.

Scholars worldwide had implemented proactive planning to move toward resilient infrastructure, society, environment, and cities with the help of GIS and spatial data. For example, Biging et al. (2012) conducted a study to investigate the impacts of predicted sea-level rise (SLR) and extreme storm events on the transportation infrastructure in the San Francisco Bay region. Their study indicated that resiliency could help save money in the long run and reduce the disruption of daily life. This proves the significance of practicing proactive environmental planning to achieve sustainability and resiliency. Alruheili (2017) stated it is very important to integrate science in planning due to its ability to deepen the understanding of current and future issues within Oman or the international context.

3. HISTORY OF OMAN'S PLANNING APPROACHES

Before 1970, planning in Oman was random and lacked structure (Allen, 1987). In the early 1970s, development started in Oman, but at a slow rate due to the country's unstable conditions, such as limited financial resources, various political problems, and civil war (Tear & Forester, 1992). In the mid-'70s, the conditions stabilized, and Oman started to look for ways to accelerate development and diversify the economy by integrating and using natural resources. However, due to the lack of clear planning approaches and direction in Oman, the government faced many obstacles and challenges (Allen, 1987). With the oil industry expansion and subsequent increase in production, the country's financial resources improved significantly, and development in Oman started to accelerate. Hence, development-induced approaches and frameworks followed.

Oman implemented a 5-year strategic development framework to speed up development as most of the strategic development planning required to integrate economic factors (Allen, 1987). That led the country to embrace the sustainable development (SD) approach as the way forward in developing Oman's strategic planning (Alruheili, 2017). The SD theory was developed in 1987 by the World Commission on Environment and Development (WCED 1987) and became a trend among the international community and policymakers. It was adapting sustainable development elements, which indicated the need for consciousness and balance between the natural environment, economy, and society (WCED 1987; Santillo 2007). However, the term SD had been interpreted subjectively due to the lack of a clear approach and framework for balancing the three elements of SD. The lack of this clear framework led the countries to inherit subjectivity while applying SD principles in their planning. For instance, in Italy, the application of SD was through sustainable planning focused on the protection of natural resources by adopting the ultimate environmental threshold (UET) (Senes & Toccolini, 1998). As it appeared, Italy's focus was on one pillar of SD elements, i.e. natural resources (environment), and neglected the other two elements of SD.

As for Oman, according to Allen (1987), all of the developed strategic plans focused mainly on the incorporation and diversification of the economy. Therefore, Oman's strategic plans went under the impression of implementing the concept of sustainable development (Alruheili 2017). For example, Oman had developed Integrated Coastal Zone (ICZ) national survey to be used in forming sustainable economic development since the 80s (Salm and Dobbin, 1987). Moreover, a National Tourism Development Plan was formulated in 2005 to integrate tourism as an aspect of sustainable socioeconomic development. Additionally, Oman developed an environmental conservation national strategy that concentrated on preserving and conserving the environment and natural resources (Oman,

2002). As a result, Oman has 14 nature reserves across the various regions of Oman established to support nature and ecosystem conservation (Abdel Malek, 2015). This demonstrated the country's emphasis on integrating sustainable development with a focus on the environment or economy with no clear integration of SD principles in any developmental plan. The issue of the lack of linkage between SD principles to accomplish SD is also inherited. The case of Oman and Italy shows the subjective use of sustainable development principles and sustainable planning that created confusion for decision-makers about the SD application and framework (Alruheili, 2017).

Oman's 2020 vision strategy plan showed diversifying the economy was the core of the plan even though the 2020 vision branded itself as the plan that integrated SD principles. However, Oman's 2020 vision did not fully apply SD principles, especially in urban and environmental planning, for two reasons. First, the policymakers and planners focused on enchasing and diversifying the economy. Second, lack of mature spatial data infrastructure to perform science-based decisions on environmental and social planning. Due to that, a lack of resilient and sustainable cities, environment, and economy capable of withstanding unanticipated change are evident throughout Oman.

This situation is not unique to Oman, though. In other developing countries, the integration of spatial data and GIS in urban planning started in the 1990s due to limited data, lack of leadership, organizational structure, and planning practice (Yeh 1991). At that time, most urban planning practices were done based on limited data and information and in a fragmented manner (Taylor and Williams 2013). Since then, GIS has become increasingly accessible to planners and an essential tool for urban planning and decision-makers. More spatial data integration and science-based decision are practiced. Holmes and Clark (2008) stated that science integration into natural, physical, and social policy had been a catalyst in achieving informed policies and regulations.

Learning from the 2020 vision, the government of Oman and the policymakers saw the significance and the urgent need to integrate science in achieving the country's target goals by balancing between the three elements of SD. Therefore, the implementation of the science-based decisions in Oman's 2040 vision is more apparent and applied across the 2040 main strategy pillars. Each strategic plan for the urban, society, environment, and economy of each region in Oman must be based on integrating science and spatial analysis in building resilient cities and communities capable of serving future generations resilient in the face of the consequences of future change which is representing the core of environmental planning. This provided a clear contrast in approach with the Oman 2020 vision strategic plan development as it was more directed towards achieving sustainable economic development with less focus on the other SD elements.

The approach change in Oman's 2040 vision emerged in response to the urgent need to prepare sustainable cities capable of facing challenges, a need for a sustainable economy, and a need to protect the environment for future generations. The country and society need to be well prepared in technology adaptation and implementation to emulate the accelerating change of technology, spatial analysis, and EP application around the world. Assuring the parallel consideration of the three elements, environment, society, and economy, through implementing the environmental planning approach, is the only way forward for Oman towards a sustainable environment, economy, and society.

4. GIS AND ENVIRONMENTAL PLANNING IN OMAN

One of the major challenges Oman is facing is adapting to the impacts of climate change. The UNFCCC defines adaptation as "adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change" (UNFCCC, 2021). The environmental deterioration resulting from climate change impacts, such as extreme rainfall events, flash flooding, extreme temperatures, droughts, land degradation, sea-level rise, cyclones, and coastal erosion, poses significant threats to the general population in Oman. However, the integration of environmental planning with climate change-informed planning would not only build resilience to adapt to climate change but also enhance the communities' awareness to cope with climate change, promote environmental conservation, and secure sustainable development by adapting

all three elements, i.e., natural environment, economy, and society. In Oman, many researchers have used the power of GIS and spatial analysis to increase awareness about climate change and resolve various environmental and social problems. The following are examples of such studies in different fields.

4.1. Water Resources

Oman is characterized by an arid to hyper-arid climate with average annual rainfall varying from 77 mm/year in the interior region to about 182 mm/year in the southern mountains of Dhofar (Kwarteng, 2008). Surface water is minimal, while groundwater makes up 94% of the water used for domestic, industrial, and agricultural purposes. However, with an annual deficit of more than 326 Mm^3, the impact of the water deficit is evident in many regions in Oman. A study carried out by (Al-Awadhi and Mansour 2015) used spatial analysis techniques to assess the water quantity stress across Oman and showed higher values of water stress in the northeastern part of Oman due to high water abstraction for domestic and agricultural use. Other factors such as climate also played a major role in contributing to the variability in water stress in the different regions. Another study conducted by Al-Kalbani et al. (2014) used numerical analysis to assess the vulnerability of Al Jabal Al Akhdar's water resources in Oman and showed that 27% of the ecosystem health was under deterioration due to vulnerability in water resources. Gerner et al. (2012) suggested the use of fuzzy recharge areas combined with spatially distributed information on groundwater recharge as a tool to assess water balance in Northern Oman. Other studies (Abdalla et al. 2011; Al-Mashaikhi 2011) used GIS tools and spatial data to assess aquifer recharge and the rise in groundwater table after storm and cyclone events.

Moreover, a study carried out by Abdalla et al. (2011) used spatial data to study aquifer recharge and water table rise after a storm event. Another research conducted in Najd, Dhofar used spatial and GIS data in exploring groundwater recharge to aquifers due to cyclonic events (Al-Mashaikhi 2011).

In addition, a study done by Abulibdeh et al. (2021) used spatial and temporal data in GIS to map salt intrusion for groundwater in the Al-Batinah governorate, Oman. This study was able to recommend strategies to regulate and reduce the impact of this problem on the agricultural sector.

4.2. Drought

According to Al-Alawi (2014), 0.21 and 0.83 million hectares in Oman are highly and moderately vulnerable to droughts, respectively. El-Kenawy et al. (2020) assessed the spatial and temporal variability of drought in Oman and concluded that drought has accelerated in severity in the last two decades and can be attributed to the changes in sea surface temperatures due to climate change. However, while some regions in the east were showing drying trends, mountainous regions in the north and south were showing wetting trends. This study provides valuable information for planners and decision-makers to design drought mitigation strategies at local and national levels.

4.3. Land degradation

Al-Hashmi (2013) divided the causes of land degradation in Oman into physical and socioeconomic factors. Climate plays a crucial role in the physical factors resulting in water scarcity and droughts. Overgrazing and overpumping of groundwater also play a significant role. Al-Wardy et al. (2015) studied the spatial and temporal vegetation cover change in the southern mountains of Dhofar in the last three decades. They attributed land degradation in the area mainly to accelerating urban development due to tourism and extensive overgrazing. Al-Rawas et al. (2015) added that decreasing precipitation trends during the same period have also contributed to vegetation cover loss in some parts of the region. Al-Wardy et al. (2021) also indicated that the spread of invasive species in the region could also cause land degradation reducing the biomass of the native trees, and recommended specific control plans. Al-Aufi et al. (2021) studied the spatial and temporal vegetation cover change in the coastal plains of Al-Batinah since the 1980s and found that the agricultural area decreased near the coast in the north due to the salinization of groundwater caused by overpumping and seawater intrusion. However, vegetation cover maps showed a general shift towards the south and an increase in area cautioning decision-makers to better manage water resources and avoid further degradation of water quality and hence the land.

4.4. Urban Development

Oman's coastline extends for more than 3000 km along the Sea of Oman and the Arabian Sea on the Indian Ocean. Therefore, it's no surprise that the coastal zones are densely populated in many parts and experience more considerable population growth and faster urbanization. According to the 2010 census, more than 80% of the Omani population lives on coastal plains. The increase of cyclonic activity in the Arabian Sea in recent years, evidenced by the cyclones Gonu in 2007, Phet in 2010, Keila in 2011, Mekuno in 2018, Hikaa in 2019, and Shaheen in 2021, and the increase in extreme rainfall events (Gunawardhana and Al-Rawas 2016; Al-Manji et al. 2021) makes major cities on the coast prone to flash flooding, storm surges, sea-level rise, and coastal inundation. Al Ruheili and Boluwade (2021) showed that, in the Al-Batinah region, coastal erosion occurred at an average rate of -40 m/year between 2018 and 2019. This coastal erosion was attributed to the consequence of Kyarr's cyclone in 2019. Al-Awadhi et al. (2019) combined urban growth maps with flood risk maps and showed the flood risk to urban infrastructure has increased ten times in the capital city of Muscat between the years 1960 and 2010. Al Ruheili (2020) used GIS and hydrodynamic modeling to quantify and visualize the flash wadi flooding damage due to Cyclone Mekuno in 2018 in the city of Salalah in Dhofar. Herher et al. (2020) showed that more than 800 km of coastline is highly vulnerable to sea-level rise, while Al-Awadhi et al. (2016) showed that more than 900 km of land could be inundated with the worst-case sea-level rise scenario of 5m. Hereher (2020) also assessed the coastal infrastructure vulnerability due to tsunami in Oman using GIS and spatial data. The research provided vulnerability maps that could inform the planners about tsunami-threatened areas to avoid infrastructure damage and casualties. The study asserts the benefits of GIS as a geospatial analysis tool for risk assessment.

Another study done to investigate the socioeconomic impacts as a consequence of climate change and hazards, along the coastal countries of the Persian Gulf (PG) and the Sea of Oman over 30 years (1988–2017) was able to predict the vulnerability of these areas under various climate change scenarios in association with sea level rise (SLR) for 2030, 2040, and 2050 (Mafi-Gholami et al. 2020). Mansour et al. (2020) used GIS and spatial data to analyze land use and land cover change and simulated urban expansion in Oman and its impact on agricultural land. This study has the potential in helping the national planning strategy in the country to plan proactively for future urban expansion to avoid unintended consequences.

Furthermore, Al Ruheili and Radke (2018) used GIS and hydrodynamic modeling to visualize and quantify the storm surge of the 2002 (ARB01) cyclonic event in Dhofar, Oman in association with SLR. GIS and hydrodynamic modeling were used to quantify and visualize the flash wadi flooding damage due to Mekuno in 2018 in Dhofar (Al Ruheili 2020). Azaz (2010) used GIS and spatial data to evaluate the cyclonic impact of Gonu and showed that GIS was a useful tool in managing natural disasters and provided maps that could be used as a database in reconstructing and calculating the damage. Al Manji et al. (2021) tracked cyclones' landfall spatially in Oman to categorize the vulnerable and high-risk areas. The research showed the seasonality and patterns of the landfall that help in creating knowledge about the hotspot area which contributed to the improvement of disaster planning and management in Oman.

Furthermore, Herher et al. (2019) used GIS to locate and select suitable locations for landfills in the Muscat area, Oman for better urban health planning. (Gastli and Charabi 2010) used GIS to show the potential and optimal location for harvesting solar energy in the Duqum area in planning the new developmental area toward green energy.

The main of this paper is to guide the decision-makers in implementing the EP approach to get minimal environmental impacts and to apply balanced SD principles. The 2040 vision accommodates more involvement, participation, and comminution between the decision makers and the researchers and science. There is a clear observation in the country pushing for the integration of GIS, spatial data, and science in creating decisions across different aspects of the country's developmental plans.

5. DISCUSSION

As the world is changing every day and climate change taking place, there is an urgent need to balance between human needs, the environment, and the ecological capacity. Utilizing geospatial technology and tools will assist in achieving a sustainable future (Steiner 2016).

The concept of environmental planning in Oman is fuzzy as the country adopted sustainable development principles as a way to move toward sustainability, but due to the lack of a clear SD framework Oman fell short, and EP was not applied appropriately.

To accomplish sustainable development (SD) a balance between the environment, the economy, and society is a must as these elements are not disconnected. The debate on SD usually prioritizes either the environment or the economy, and not working in parallel. According to Neumayer (2003), most decision-makers prioritize the economy in their policies, and the environment and society were treated as separate elements that will take advantage of a strong economy.

In addition, a sustainable design framework helped in creating a venue to enable the interaction between humans and the environment to create an informed urban design (Yang and Li 2016). Therefore, the merger between SD and environmental planning through the use of spatial data and information becomes a major element for resilient planning to achieve sustainability and resiliency.

Since the sustainable development principles of Oman's strategic development planning were mainly focused on diversification of the economy and sustainable socio-economic development, this led the country to underestimate the need to incorporate science, spatial data, and environmental planning within the national development strategy planning. Due to that, Oman's Vision 2020 strategy has inherited the goals of focusing on sustainable socioeconomic development with less focus on the other elements of SD (Alruheili 2017).

"Economic Vision Oman 2020" focused on generating a diversifying economy by strengthening other sources of income, especially agriculture and tourism. Moreover, Oman National Spatial Strategy (ONSS) was established to promote a long-term strategy that attempts to achieve sustainability in socioeconomic contexts to enhance the quality of life and encourage the use of spatial data and GIS (AlGharibi, 2014). But due to the lack of infrastructure and the scarcity of spatial data in the other sectors, the optimal functioning of ONSS was affected drastically.

The subjectivity in the interpretation and implementation of SD created a misunderstanding about achieving a sustainable environment, society, and economy. This misunderstanding was reflected in the planning process as decision-makers were under the impression they were implementing environmental planning. However, as Oman's 2020 strategic plan fell short, decision-makers were alarmed a complete shift in approach was applied in Oman's 2040 strategic plan development and procedure with more focus on applying EP and sustainable development principles.

A country will achieve resiliency when it can respond, recover, and adapt fast to major situations and circumstances. Resilience is defined as the ability to predict; resist, absorb, and adapt to abrupt change; and to be able in recovering in a short period (Hansen & Neale, 2014). As the world advances rapidly, the integration of GIS, spatial data, progression in technology, and environmental planning is considered the path toward a resilient country. That being said, SD necessitates ensuring long-term viability for social, economic, and environmental factors that involve consideration of future change. Therefore, proactive planning, and environmental planning, are requirements to achieve resiliency. As mentioned earlier, most of Oman's residential, infrastructural, and economic developments are within the wadi watershed and along the coastal area. If proactive environmental planning, spatial data, and GIS were used in the planning process lots of unwanted consequences could be avoided. Consequently, resiliency and environmental planning add positively toward a sustainable future.

A paradigm shift in Oman's planning is necessary as the current methods and practices are unable to accomplish the country's goals and vision. According to Ndubisi (2002), a paradigm shift take place when the

dominant paradigms were unable to convey stable solutions to scientific problems. As we are living in an uncertain future, a combination of spatial data, GIS, science, and the practice of EP with the current regional planning and strategic planning will help the country achieve resilient and sustainable development. As suggested by Lee (2001) the integration of science within the planning system help in generating unforeseen outcomes that could help the decision makers to identify the non-anticipated change within the system.

Finally, adapting environmental planning with GIS will help Oman move forward in applying proactive planning that ensures the resiliency of the country, the people, the urban area, the economy, and the environment.

CONCLUSIONS

The concept of environmental planning in Oman lacks the linkage between academics, planners, and decision-makers. Many researchers studied the impact of climate change, urban vulnerabilities, and other aspects on the environment, and society, but these researches were done independently with no linkage and communication to the decision-makers.

Recently, Oman has been emphasizing and encouraging the use of spatial data and GIS in the analysis and planning, and adapting sustainable development principles to move toward sustainability and resiliency. Oman 2020 Visions fell short due to the lack of a clear SD framework and inadequate use of spatial data and analysis in planning. Now, the possibility of achieving SD balance through environmental planning framework is promising, due to the huge amount of spatial data and information that exists. The integration and use of this big spatial and non-spatial data are very compatible with GIS and its powerful tools.

The current Oman Vision 2040 is the first strategic developmental plan developed based on the environmental planning concept with the integration of SD principles, spatial analysis, and GIS. A paradigm shift in Oman's planning is happening as the current methods and practices are showing a shift in the planning practices and approaches.

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