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Patron-in-Chief Message

It is with immense admiration and admiration that I express my gratitude for the launch of the Aror University Research Journal (AURJ). As Patron-in-Chief, I believe this journal represents a significant milestone in our journey toward academic excellence, innovative research, and the preservation of our rich cultural heritage.

At Aror University, we are committed to fostering a vibrant culture of research and innovation that addresses contemporary global challenges while recognizing the unique traditions and values of our region. The AURJ is a vital platform for scholars, researchers, and practitioners from diverse fields, including art, design, heritage, and emerging technologies, to share groundbreaking ideas and transformative insights with a global audience.

In today's fast-paced world, interdisciplinary research and collaboration are essential for progress. The AURJ embodies this spirit by encouraging contributions that blend creativity with critical inquiry, ensuring that our research is not only advancing knowledge but also fostering significant social change.

I am particularly pleased to see this initiative align with our wider vision for Aror University, which emphasizes sustainability, inclusivity, and international collaboration. By publishing high-quality, peer-reviewed research, we aim to establish AURJ as a beacon of academic excellence and a catalyst for innovation across disciplines.

I express my gratitude to the editorial team, reviewers, and contributors for their dedication and dedication in making this journal a reality. I am confident that the AURJ will be a key component of scholarly engagement and will enhance Aror University's reputation as a center of academic distinction.

Let us continue to explore new frontiers of knowledge, inspire creativity, and contribute to the advancement of society.

Warm regards,

Prof. Dr. Zahid Hussain Khand
Vice Chancellor
Aror University of Art, Architecture, Design, and Heritage
Patron-in-Chief, AURJ

Editor-in-Chief Message

Dear Colleague,

It gives me great pleasure to introduce the very first issue of Aror University Research Journal (AURJ). AURJ is the inaugural peer-reviewed research publication of Aror University of Art, Architecture, Design and Heritage, located in the heart of the historic Indus Valley, one of the greatest and most ancient centers of culture and civilization in the world.

For more than five thousand years, the Indus Valley and the Sindh region have been both a center of civilizational development and a trading crossroads for diverse cultures, all of which have contributed to the magnificent heritage of the people of Sindh. As inheritors of this millenia-old heritage, our institutional mission at Aror University is focused on reviving traditional values and promoting the cultural and religious diversity of the Sindh region. Accordingly, AURJ has an especial, though not exclusive, interest in research related to art, architecture, archaeology, history, agriculture, and other fields of central relevance to the Indus region and its culture.

More broadly, AURJ aims to serve as a platform to bring together researchers from all disciplines in art, architecture, design, heritage, engineering, technology, and social and natural sciences. AURJ also aspires to be an interdisciplinary forum for sharing problems, solutions, novel ideas, case studies, and technologies in support of the goals of sustainable development.

We welcome submissions and queries for AURJ from academicians, researchers, and practitioners worldwide. At AURJ we are committed to scholarly professionalism. All submissions will be evaluated according to our double-blind peer review process, and all authors will receive prompt notification of editorial decisions.

We are humbly grateful for the opportunity to launch and participate in this new scholarly enterprise, and we welcome both your readership and your research!

Dr. Steven Bonta

Editor-in-Chief

Publisher, American Opinion Foundation, USA

Editorial Team

Reviewer Board

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Morphological Investigation of Qambar City in Sindh via Urban Information Technologies for a Sustainable Urban Future

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ABSTRACT

Morphological investigation of Qambar city in Sindh via use of urban information technologies is an uncharted domain. Especially in relation to sustainable urban future of secondary cities in Sindh, the significance of urban information technologies for urban morphological evaluation has been neither investigated nor elucidated. Consequently, the current research aims to fill this gap through identifying the most prominent urban information technologies used in morphological exploration of cities across the globe and the lessons learned for the local urban context of Sindh. Thus, this paper would reveal the interplay between urban informatics and city morphology for sustainable urban future of secondary cities via a case study of Qambar in Sindh to make an urban policy for apt use and application of urban information technologies. In this respect, the role and importance concerning urban information technologies as used in various urban systems across the globe are assessed. Moreover, a secondary city Qambar in Sindh is morphologically investigated and analyzed to address issues related to magnitudes and prospects of urban information technologies for the sustainable urban future of Sindh and for development of smart urban communities with urban planning & management.

Featured Application: The specific application or a potential application of this work will be in the form of an urban policy for use and application of urban information technologies in the Secondary Cities of Sindh Province of Pakistan for development of Smart Urban Communities with Urban Planning and Management.

1. Introduction

The end-result of human endeavors, since the modern Industrial era emerged via industrialization, urbanization, population growth, development of transportation, and food production activities, which[has??] affected the urban contexts across globe during post-industrial era [1]. As a repercussion, various urban information technologies came into existence and contributed to deal with the city complexity and urban chaos, and have generated sustainable and liveable built environments [2]. These urban information technologies include the World Wide Web, broadband mobile, locational sensing technologies, geographic information systems, radio frequency identification systems, ubiquitous sensor network and context aware computing [3]. The current demand for faster mobile broadband across globe is an outcome of widening obile networks [4]. Geographic information systems directly contributed towards enhancing the information of cities and fostered the growth of sustainable cities [5]. The ubiquitous computing and mobile augmented reality technologies, computing environments and convergence technologies contributed a lot towards creating current urban systems around globe [6]. The rising urban populations, varying lifestyles, and growing travel needs resulted in major tests for urban governments to deal with, congestion, accidents, comfort, efficiency, and pollution [7]. Looking at the future scenario, the urban road efficiency will be achieved by providing dedicated lanes for automated vehicles, to prevent potential conflicts between the autonomous and manually driven cars [8]. Similarly, electricity is quite critical to sustain economic growth, development, and quality of life [9]. Moreover, concerning quality of life, physical and socioeconomic conditions of dwellings [10] and resident's satisfaction regarding urban livability are also quite significant factors [11].

Likewise, centralized surveillance systems are quite vital to commonly installed in city squares, urban parks, and metropolitan railway stations [12]. Whereas in-house self-contained video surveillance systems are already installed and used in most institutions, banks, post offices, hospitals, schools, supermarkets, shops, offices and warehouses, homes, cars and even motorbikes and bicycles [13]. Globally, the magnitude and extent of emergency response systems have also grown enormously over past few years as human-made or natural disasters caused great economic and human loss throughout the world [14]. The rapid urbanization across the globe is expected to see about five billion people located in cities, with South Asia hosting a significant proportion of their population in megacities as well as small and intermediate cities or secondary cities [15]. Sindh, being located in South Asian context, is subject to population growth in its large metropolitan areas or megacities due to geo-political situations and needs to develop technologically advanced medium sized secondary cities to reduce the pressure from large cities to achieve a sustainable urban future. In this respect, it is quite significant to consider the existing energy crisis in the province of Sindh and the perception of citizens that consider solar energy as sustainable option [16]. Furthermore, since the last two decades, the natural disasters and other real estate and land management decisions also caused rapid urbanization in secondary cities of Sindh and there is a grave need to learn from the experiences across the globe. For instance, South[??] Korea brands its smart cities as 'ubiquitous cities' or 'ubiquitous eco-cities' and as 'compact and smart cities' of the future [17]. Chinese and Singaporean governments made a joint attempt to build a sustainable and futuristic smart city urban model via the Sino-Singapore Tianjin Eco-city project [18]. The Barcelona perspective on smart cities is also a comprehensive approach that places information and communication technology as a core element in the city's approach to become a smart city and to achieve sustainable urban future [19]. Amsterdam, Barcelona, Dubai, and Abu Dhabi in the UAE are other urban contexts where urban information technologies are installed as pathway to technology delivery and making smart cities for sustainable urban future [20]. The ubiquitous computing and mobile augmented reality technologies, such as mobile and built ubiquitous computing environments, are the essential elements to construct interactive urban spaces in futuristic cities [21]. Across the globe, construction companies and technology firms reap the financial benefit from installing urban information technologies [22]. The public sector in the developed world also took major risks through their technology support schemes and public investments that made people to adjust in new technologically facilitated futuristic urban life [23]. Looking at technological advancements in computer technology around the globe and lessons learned from the nature of computing indicates that processor speeds and processing power for computers double up every two years [24]. The digital revolution fulfilled the visions of many scientists and innovators, that computers augment human intelligence as tools for both creativity and collaboration [25]. The smart city as a city planning model is an emerging urban reality and continuously transforming paradigm [26]. The current urban research points out that entrepreneurship in smart cities is constantly growing, and well-known suppliers are moving into the market from the energy, transport, and building to government sectors, whereas start-ups are addressing a range of emerging opportunities [27]. Global intelligent urbanization initiatives help cities around the world to use broadband networks as utilities for integrated city management, better quality of life for citizens, and economic development [28]. Currently, smart urban environments and broadband networks disrupt the established innovation ecosystems by introducing significant changes in their building blocks, networks, and nodes [29]. Likewise, Uber is disrupting the transportation market by turning citizens into transport service providers [30]. Similarly, Airbnb is disrupting the hospitality and real estate markets by bringing in unutilized fixed capital investments in housing [31].

Thus, it is quite vital that appropriate new techniques adopted on the well-established existing knowledge about use and application of urban informatics and urban information technologies that emerged and were practiced around the developed world shall be a necessary paradigm to ensure the sustainable urban future of Sindh. Especially it is significant for the developing urban contexts like secondary cities of Sindh where there are numerous morphologically unexplored small and medium size cities in the form of districts and sub-district headquarters. These unplanned urban contexts are surrounded by vast agricultural tracts and natural environments that are subject to rapid urbanization in last two decades with the creation of new housing settlements and commercial enterprises due to emerging internal migrations that created not only the demographic change but also densified the existing urban environments. Their impacts are quite discernible and evident within urban morphology of existing cities and affected the management and maintenance processes of built environments in secondary cities of Sindh. Consequently, the argument of this paper is to create an adequate contemporary understanding about the applications of emerging urban information technologies for morphological exploration in secondary cities of Sindh to generate an origin and foundation for ensuring sustainable urban future. Likewise, it is anticipated that the apt use and application of current urban information technologies for developing urban contexts like secondary cities of Sindh may lead to keep up with the developed world and be useful for academia and administration to take clever decisions for urban planning research and practice in future.

2. Materials and Methods

This investigation commenced through an in-depth literature review of urban information technologies and the existing situation of urbanization in secondary cities of Sindh that led to different fundamental research questions as knowledge gap to fulfill. Furthermore, in order to justify the theory building process and knowledge contributions, the case study of a secondary city in Sindh was selected to investigate its urban morphology with available urban information technologies. This morphological investigation conducted through urban information technologies led to different recommendations concerning the sustainable urban future of secondary cities in Sindh.

2.1. Research Questions

There are four essential research questions addressed and answered in this re-search:

1. What are urban informatics and its professional applications?

2. What urban information technologies are at present in practice for morphological inquiries?

3. Why are morphological investigations so significant for secondary cities of Sindh?

4.

How do morphological inquiries in secondary cities of Sindh confirm a sustainable urban future?

As result of answering these research questions there emerged various theoretical and conceptual themes of research to address for theory building and conceptual knowledge contribution.

2.2. Insight into the Themes of Research

The new knowledge generation cannot begin without identifying research gaps. Therefore, it is necessary to explain the themes as explored and integrated within this research. There are five major interwoven themes explored in this research (see Figure 1). Each of these themes has its own knowledge depth and complexity, ordered in hierarchy. The combined understanding of these themes would clarify a theoretical and conceptual framework through which the new knowledge contribution would be evident.

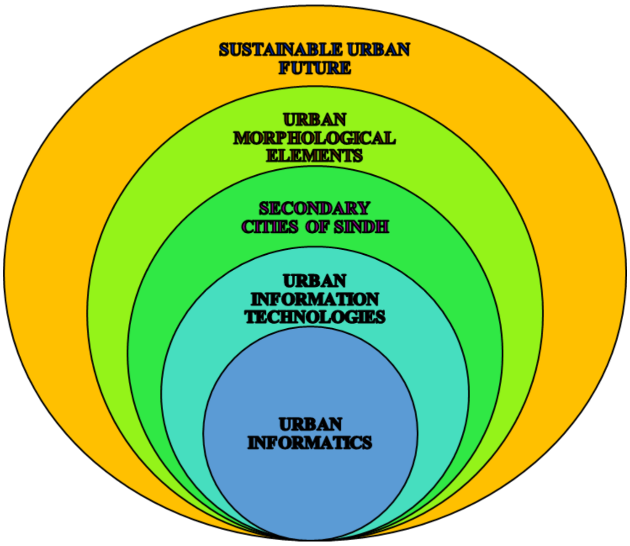

Figure 1. Themes of Research (Source: Generated by Author).

2.3. Process Used for Literature Selection & Analysis:

The process used for literature selection and analysis include Application of PRISMA 2020 Checklist. The PRISMA 2020 Checklist identifies total 11 items for the application in materials and methods section.

PRISMA 2020 Checklist	Application in Research
Eligibility Criteria	Specify inclusion and exclusion criteria for review and to group studies for syntheses.
Information Sources	Specify databases and sources searched or consulted to identify studies.
Search Strategy	Specify search strategy for databases and websites, with filters or limits.
Selection Process	Specify methods used to decide a study met inclusion criteria of review and if automation used in the process.
Data Collection Process	Specify methods used to collect data and if applicable, details of automation tools used in the process.
Data Items	Specify methods used to decide which results to collect. Describe assumptions about missing or unclear information.
Study Risk of Bias Assessment	Specify methods used to assess risk of bias in studies, and details of automation tools if used in the process.
Effect Measures	Specify effect measure(s) used in synthesis or presentation of results.
Synthesis Methods	Describe processes used to decide on studies eligible for synthesis, visual display of results, rationale, statistical heterogeneity, and software used.
Reporting Bias Assessment	Describe methods used to assess risk of bias due to missing results.
Certainty Assessment	Describe any methods used to assess certainty in the body of evidence.

All these above items were applied during the research process and discussed below:

2.3.1. Eligibility Criteria (Inclusion and Exclusion): Identification of most relevant published material since last 5 years on the identified themes of the research by including research papers and by excluding the books, reports, websites, blogs etc.

2.3.2. Information Sources: Research papers available with the Google Scholar database.

2.3.3. Search Strategy: The search strategy includes a filter i.e., Time Limit for published data from last five years, e.g. 2019 to 2024.

2.3.4. Selection Process: The method used to decide about a study that met inclusion criteria of papers relevant to themes of research with practical application and no automation used in the selection process.

2.3.5. Data Collection Process: The method used to collect data was individual and personal search from the Google Scholar database, selection of relevant article, downloading and conducting manual review and analysis of papers without any use of automation tools.

2.3.6. Data Items: The method used to decide which results to collect were those with practical applications in different geographical contexts around the globe. All those data items were avoided that described assumptions or having any missing or unclear information.

2.3.7. Study Risk of Bias Assessment: The methods used to assess risk of bias in the included studies, through critical appraisal tools by analysing and evaluating, random sequence generation, allocation concealment, blinding of participants and outcome assessment, incomplete outcome data, and selective reporting. The author was a single reviewer that assesses each study and worked independently, without the use of automation tools in the process.

2.3.8. Effect Measures: The effect measures are either ratio measures such as risk ratio & odds ratio or difference measures such as mean difference & risk difference. Since this study is not statistical but morphological and technological, therefore, the results extracted from the research papers were converted into a consistent, or usable, format for presentation of synthesis.

2.3.9. Synthesis Methods: The synthesis methods include decisions about eligible papers for synthesis, preparation of data for presentation and handling of missing data, and descriptive display results of individual studies, with a rationale for the choices of papers. No meta-analysis was performed to identify the presence and extent of statistical heterogeneity; instead, morphological maps were prepared through case study application. Thus presented a visual synthesis of technology application and its outcomes in the form of morphological maps.

2.3.10. Reporting Bias Assessment: Concerning methods used to assess risk of bias due to missing results in a synthesis the strengths and limitations were assessed, compared different studies, and analysed its explanations and implications.

2.3.11. Certainty Assessment: The methods used to assess certainty or confidence an approach was planned, considered the importance of outcome, assessed study limitations, heterogeneity, indirectness, imprecision and publication biases.

Thus, by applying PRISMA 2020 Checklist literature review and analysis was conducted. In addition to that morphological case study of Qambar was conducted.

2.6. Data Collection and Analysis

In order to find out the answers to the above stated questions and explicate the themes of research, a comprehensive analysis was undertaken to elucidate about urban informatics and its professional applications in historical retrospect. The existing approaches of morphological investigations and use of different urban information technologies in them comprehended via identifying relevant practical examples from the profession. The conceptual understandings about secondary cities of Sindh established via application of locally available urban information systems and technologies to create a morphological map of Sindh and identified its primary, secondary, and tertiary cities. To establish the use of urban information technologies in secondary cities of Sindh, a detailed survey was carried out in Qambar, Sindh, with integrated UISs & GIS technologies to prepare morphological maps and create information concerning future planning and urban design.

3 Results and Discussion

In the following, answers to each research question are given with a detailed analysis and discussion.

3.1. Urban Informatics and Professional Applications

Urban informatics is the study of people designing, utilizing, and employing data, information, and communication technology in cities and urban built environments [32]. It is the juxtaposition of three knowledge domains, i.e., urban science, geomatics, and informatics, with an ultimate goal of creating more smart and sustainable cities [33]. The term "urban informatics" was coined in 1987; however, it became a domain of research and practice in 2006 due to the emergence of ubiquitous computing, big data analytics, and smart cities, and it has grown from academics to industry [34]. Whereas city governments also explored and applied urban informatics in city planning and management [35].

By definition, urban informatics is the design and practice of urban experiences in cities created by real-time, ubiquitous technology and augmentation that arbitrates the physical and digital layers of people networks and infrastructures [36]. Urban informatics research and practice involved three broad realms, i.e., people, places, and technology [37]. The people in urban informatics comprise city residents and communities from different socio-cultural backgrounds, non-profit organizations, and businesses [38].

The place in urban informatics includes diverse urban sites, localities, and environments such as neighbourhoods, public spaces, suburbs, regions, or peri-urban areas [39]. The technology in urban informatics involves ubiquitous urban computing and communication technology such as mobile phones, wearable devices, urban screens, media façades, sensors, and other internet of thing's (IOT) devices [40]. The use and applications of urban informatics is evident in various professional research domains. The social research domains include urban sociology, media studies, communication and cultural studies, and city planning. Spatial research domains entail urban studies, architecture, urban design, urban planning, and geography. The technology research domain spans over software engineering, and human–computer systems [41]. By taking into consideration the existing professional applications of urban informatics, it is quite important that the secondary cities of Sindh develop such indigenous localized systems of urban informatics to investigate the local urban context in a better way. With this changed paradigm, they can explicate the existing ground realities with an in-depth vigor and make the informed decisions for a sustainable urban future and making smart communities. After answering the first research question, it is significant to address the second research question about current urban information technologies used in morphological investigations across globe.

3.2. Urban Information Systems and Technologies in Morphological Investigations

Urban information systems (UISs) are the effective means for governments to meet long-term strategic planning and management challenges [42]. Across the globe at present the morphological investigations are mostly conducted with the help and support of urban information systems because UISs provide an enhanced knowledge about mutuality among environmental, social, and economic health and the impacts of decisions made by neighboring jurisdictions, government agencies, and private businesses [43]. Numerous urban information systems and technologies affect the mechanisms of urban contexts and the actors, processes and resources involved in it [44]. Consequently, it is quite important for city planners to gain a comprehensive under-standing about the decision support systems (DSS) and planning support systems (PSS) and use them in the practice of urban morphological exploration [45]. Especially for the developing contexts of global south and the secondary cities of Sindh, this is an essential ingredient for creation of a sustainable urban future. The DSS are the computerized information systems that support decision-making activities [46]. Whereas PSS are the interactive computer-based systems designed to help decision-makers in processing data and create models to identify and solve complex, large-scale urban environment problems and make appropriate decisions [47]. In case of secondary cities in Sindh the DSS and PSS can be allied and cast off for solving urban and rural land management issues and for creating solutions to rapid urbanization in the central and suburban areas. Many innovative technologies rapidly developed in the last decade, and awareness about them dramatically increased with demand for better reliable decision-making processes [48]. For instance, the most used urban information systems are of GIS spatial and descriptive data that use analytic methods and software to organize, to automate, and to deliver urban information through geographic presentation [49]. The use and application of GIS technology in urban morphological exploration is quite common in the developed world, whereas in the local urban context of Sindh this is also practiced by various formal sector organizations and institutions. In generic terms, GIS is a smart map tool that allows the users to create interactive queries and analyse the spatial information [50]. Its other such useful applications are Interactive Internet Map Server (IIMS), an online mapping utility that enables users who are not familiar with GIS [51]. Similarly, there is ESRI's Arc extensible markup language or Arc-XML, which is a language used for sending requests and receiving responses through internet map server's spatial server [52]. In this respect, there is also Web-Based Public Participatory GIS, which is an online application of GIS used for increasing public access to information and active participation in the decision-making process [53].

In secondary cities of Sindh, there is a grave need to augment the use and application of this tool for future morphological explorations and in this respect, localized user-friendly system development is quite indispensable so that the local citizens may participate in all the future decision making about their city. There exists Web-GIS technology that is used to display and analyse spatial data on the Internet, which offers people a new means to access spatial information without owning expensive GIS software [54]. As there are inadequate professional architects, urban designers, and planners working in districts, sub-districts and secondary cities of Sindh, therefore, all professionals need to enhance the use of this technology for their professional endeavors. In addition, other UISs and technologies for smart cities that used big data, artificial intelligence, and the internet of things for sustainable urban future [55]. For instance, communication infrastructure is growing and improving internet of things by execution of 5G, which will appear within the urban context of Sindh [56]. Another structural factor integrated within the genetics of UISs, and technologies is to make model of sustainability via applications of smart lighting, using renewable energies, waste management, and a transport network of self-driving vehicles which is directing the automotive industry across the globe [57]. Thus, inclusion is the paradigm for smart cities technologies and quite useful to be developed for sustainable urban future of secondary cities in Sindh. After answering the second research question, it is quite vital to move forward towards answering the third research question concerning secondary cities of Sindh and their morphological investigations.

3.3. Secondary Cities of Sindh and Morphological Investigations

The phrase secondary cities was coined in the early 1980s with the purpose of devolution and decentralization of the governments in Europe to promote the policies for economic development of small and intermediate cities and their surrounding rural areas [58]. The derivation of this planning originated in European countries, to enhance and integrate their economic development system by facilitating their rural population and to increase the local trade and commerce activities in their countries, within their systems of cities [59]. In case of Sindh, there occurs no such policy of devolution and decentralization for economic development of small and medium size cities and their urbanizing rural areas. There is neither devolution nor decentralization of physical, economic, and social development system that facilitates the urbanization process in secondary cities. Therefore, it is necessary that secondary cities in Sindh be morphologically investigated because they need recognition for their nature of physical, social, and economic development and planning for sustainable urban future. The definition of secondary cities varies in each urban, regional, national, international context. Based on political, economic, and historical implications, administrative area, and size of population in the system of cities within a country [60]. Usually, each country defines its secondary cities as part of city hierarchy after primary cities in their context; however, there is a variation in the definition of secondary city and there is no one universal definition [61]. However, in Sindh there is no official definition or hierarchy established by decision makers for designation of the primary, secondary, or tertiary cities. Consequently, based on their population statistics, historical significance and as part of urban hierarchy for administration, economic development, and urban management there emerges a distinction and designation of secondary cities in

Sindh. In this respect, a criterion developed to identify secondary cities in Sindh for their morphological investigations. This criterion is based on the population characteristics, built environment, and socio-economic conditions of cities in Sindh within the new economic geography. According to the new economic geography and global scale and order of cities, the secondary cities are defined as the regional administrative centers with governments at the province, division, district and sub district level as main driver of economy, governance system, high level of business, land & real estate management [62]. Concerning the primary, secondary, and tertiary cities of Sindh, there are a total of six divisions, 30 districts and 138 sub-districts and subdivisions. Principally, there are six primary cities as divisional headquarters, 30 secondary cities as district headquarters and 138 tertiary cities as sub districts and subdivisions within Sindh.

However, as per population characteristics, built environment and socio-economic conditions of cities within new economic geography, only 3 cities qualify as primary cities due to being national, provincial, and regional economic hubs, 30 cities qualify as secondary cities, and 138 tertiary cities due to their administrative and political status as district headquarters and as sub-districts and subdivisions of Sindh. Regarding morphological identification of secondary cities in Sindh, the first aspect was to detect the existing primary, secondary and tertiary cities in Sindh and make its digital map. In this respect, UISs & GIS technology used to identify the primary, secondary, and tertiary cities of Sindh (see Figure 2) with variables of divisions, districts, sub districts, and their built environments. Secondly, for detailed morphological investigations, a secondary city of Qambar was analysed in detail with UISs & GIS for explicating about sustainable urban future of secondary cities in Sindh.

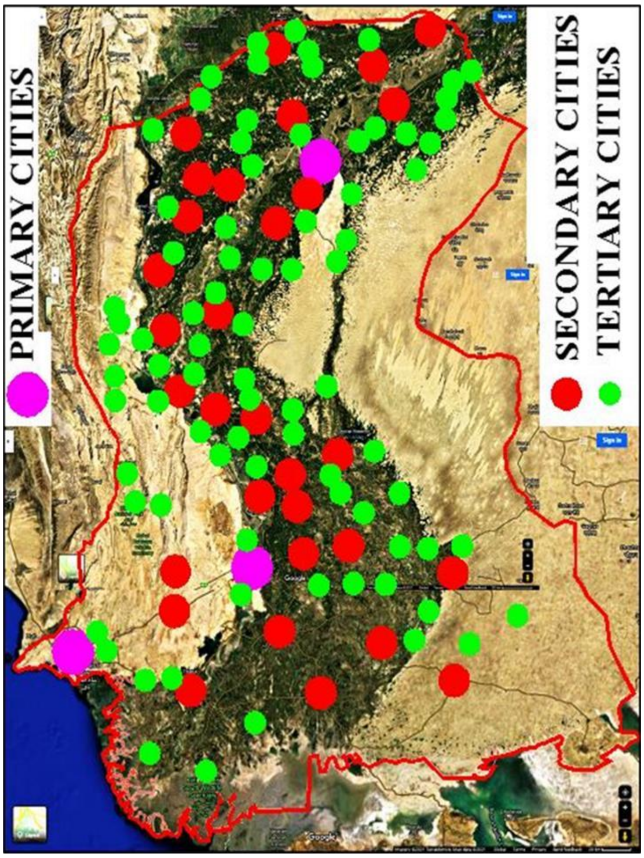

Figure 2. Digital Map of Primary, Secondary and Tertiary Cities in Sindh.

3.4. Morphological Investigation of Qambar, Sindh for Sustainable Urban Future

Before going into a detailed discussion about morphological investigation of Qambar city, it is important to identify and compare the earlier attempts of Strategic Development Planning of Secondary Cities in Sindh by Directorate of Urban Regional Policy & Strategic Planning, Planning & Development Department, and Government of Sindh. Moreover, why the case study of Qambar is important and why these findings are significant.

The Government of Sindh has established the Directorate of Urban Policy and Strategic Planning (UP&SP) in the Planning and Development Department, with the mandate to plan for sustainable urban development in the province to realize the objectives of the economic growth, and planned infrastructure development. In the year 2012, the UP&SP has initiated a project of Strategic Development Planning or Master Planning of Secondary Cities in Sindh with the financial support of Asian Development Bank and prepared the Strategic Development Plans of at least 17 secondary cities of Sindh. The primary issue with this exercise was the absence of morphological retrospect of the urban development process and built fabric in all the prepared master plans and strategic development plans [63]. Moreover, the city of Qambar was not the part of this planning exercise, and therefore, it was quite important to develop a case example of morphological investigation in Sindh to become a catalyst in the future planning and development process. The findings of this case study are also significant because they identify the historicity of each urban element that makes the current morphology of city with a retrospect of its urban design and planning.

Urban morphology is generally defined as the study of urban form or of various factors that govern and influence the urban arrangement [64]. It is an enquiry of physical or built fabric, people and processes, which are shaping its built environment [65]. As an object of study, urban morphology is explicated as an approach to conceptualize the complexity of physical form in a city [66]. It addresses the physical complexities at various scales, from individual buildings, plots, street blocks, and the street patterns that make the structure of towns and helps to understand the ways in which towns have grown and developed over time [67]. Thus, morphological investigation of Qambar involved UISs & GIS to identify urban spatial structure and its relevance with various morphological components and spatial elements for sustainable urban future. The elements of urban form such as streets, plots and building patterns interwoven within its land use patterns. In this respect, the first morphological element identified was the existing streets and roads network or primary, secondary, and tertiary roads of paved and unpaved nature in Qambar (see Fig. 3).

The other analysed morphological element was the railway line as the northern edge of city (see Figure 4). This railway line historically was built by the British government to link the city with Larkana city in the east and Shahdadkot city in the northwest side to facilitate trade and commerce of Qambar.

Although currently it is not functional as such, the tracks have the potential to be redeveloped with development of China Pakistan Economic Corridor in near future which will make Qambar as major trade and commerce hub in the region.

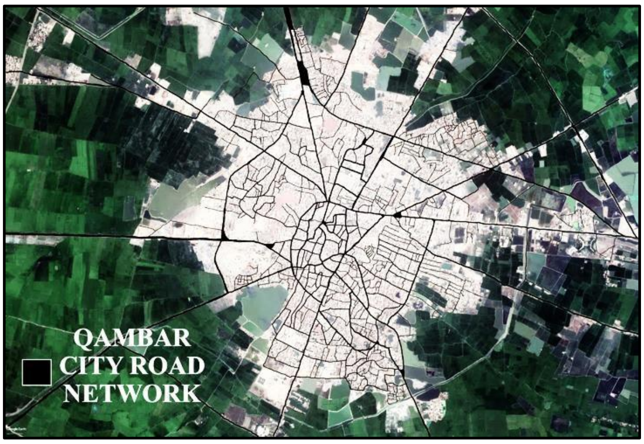

Figure 3. Morphological Map of Primary, Secondary and Tertiary Streets in Qambar, Sindh.

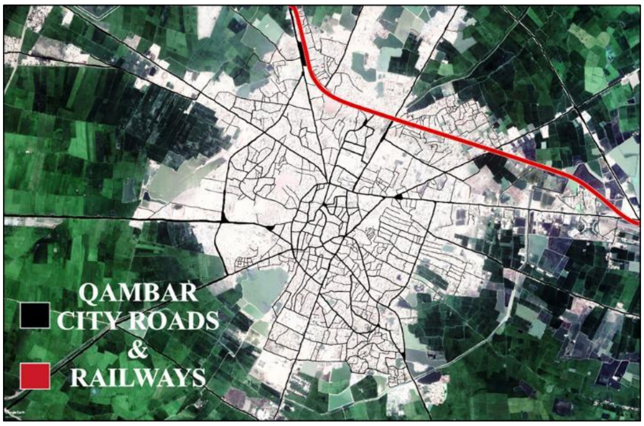

Figure 4. Morphological Map of Railway Network developed by British in Qambar, Sindh.

The next analysed morphological element was the historical British era spatial structure of Qambar city and its surrounding natural environment in which the historical town was identified as located within the geographical center of city (see Figure. 5). The city during the British era consisted of an informal housing and commercial areas within the geographic center of city.

Whereas formal cantonment area was evident in the form of railways colony in the north of city along with a railway station and residential block. The spatial structure of historic Qambar indicated that administrative offices were situated in northeastern side, which were later shifted to the eastern edge of city, and there were nine different trade routes developed that led to different urban and rural regions of Sindh.

Another morphological element investigated in Qambar were the existing water bodies, their status, and nature of existence, which is quite central in relation to sustainable urban future (see Figure. 6).

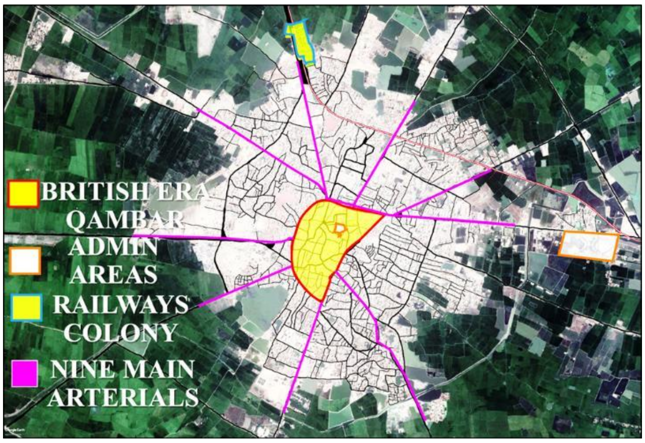

Figure 5. Morphological Map of British Era Historical Spatial Structure in Qambar, Sindh.

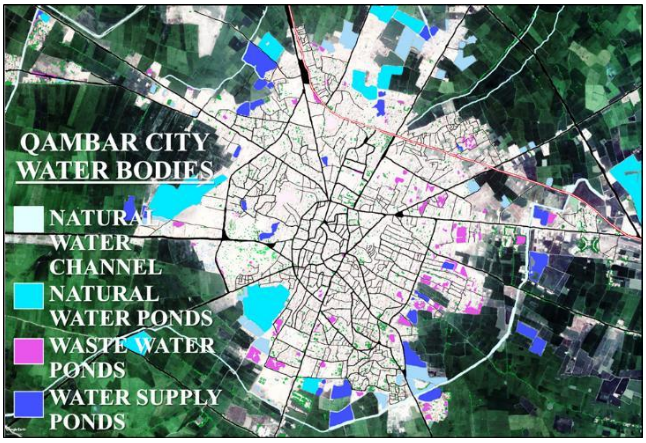

Figure 6. Morphological Map of exiting Water Bodies in Qambar, Sindh.

Concerning water bodies in Qambar, there are different natural water channels that completely filled in case of floods occurring in the Indus River and during the situations of heavy rains. The other water bodies are the natural water ponds, which work as water reserves for the city and are the lifeline for the sustainable urban future of Qambar. Additional water bodies are the existing natural water ponds, used for the supply of water to the citizens by formal sector institutions. In addition, the underwater channels also exist in city. As a repercussion, there emerged water wells within housing settlements. The city being the center of rice industry caused the presence of various wastewater ponds and as the city has an informal wastewater disposal system these wastewater ponds further existed within residential settlements. Wastewater disposal is the major concern of citizens and a vital issue for city administration. Especially for sustainable urban future of Qambar, it is quite necessary that existing natural water bodies get apt attention and appropriate wastewater systems be designed and developed.

The next morphological element scrutinized within the city of Qambar was the spatial arrangement of dominant social and cultural spaces such as religious buildings and graveyards (see Figure 7).

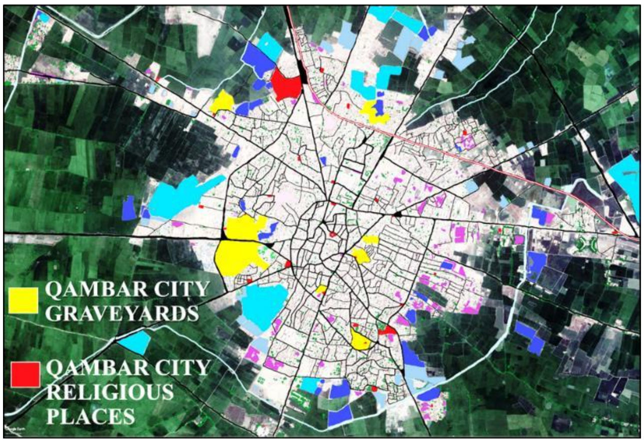

Figure 7. Morphological Map of existing Graveyards & Religious Places in Qambar, Sindh.

The religious buildings and graveyards make a regular pattern of movement and work as social edifying spaces. In order to have sustainable urban future it is quite substantial that the city may grow socially, economically, and environmentally and need of such spaces would grow with the population and built-up structures. The other morphological element investigated is the industrial units within Qambar (see Figure 8).

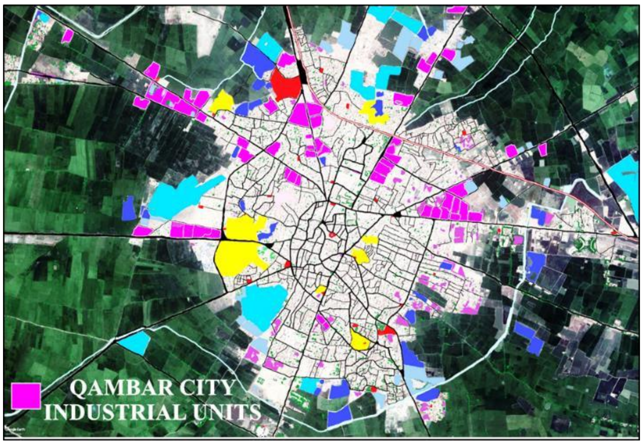

Figure 8. Morphological Map of existing Industrial Units in Qambar, Sindh.

Most of the industrial units in Qambar consists of rice mills for regional and foreign trade and there exist light industry or minor industry for local population. For sustainable urban future the growth and development of industrial and manufacturing units with regular local and regional trade and commerce is a prerequisite. There is an abject need that local industrial units must sustain and further develop via mitigation of its adverse effects on built environment of Qambar. The industrial units in Qambar depict a declining tendency over the last two decades and a trend of land use conversions from industry into housing is swelling due to weak administrative control of building activity, the local real estate development, and formal sector policies.

The next morphological element investigated in Qambar was development of future housing schemes that are emerging in city since last two decades (see Figure 9).

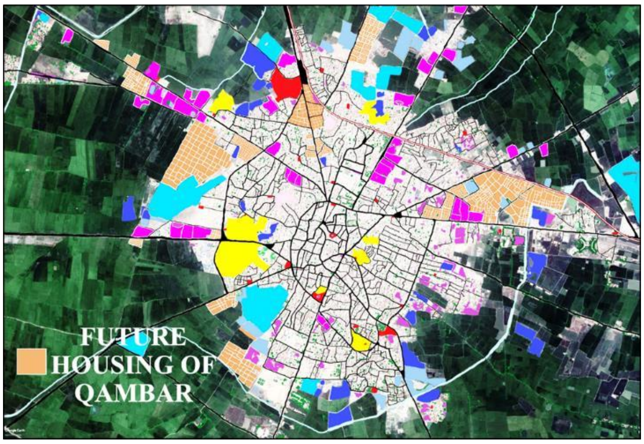

Figure 9. Morphological Map of Future Housing Development in Qambar, Sindh.

The trend of middle-income housing emerged within the city center, where 4-story apartment buildings are emerging within earlier industrial units or rice mills whereas high-income elite class housing is developing in the suburban areas within agricultural lands of eastern and western fringes. Concerning a sustainable urban future, the major issue is of agricultural land conversions into housing and housing demand that has increased in the city after status of Qambar became district headquarters. The issue of land conversions emerged due to low prices of agricultural lands as compared to housing development, which increases the real estate value. As a repercussion, this process got rapid pace and affected the natural ecosystem of city, and there is a need to install surveillance systems on land conversions in secondary cities of Sindh. Another morphological element of Qambar studied was urban parks and playgrounds (see Figure 10).

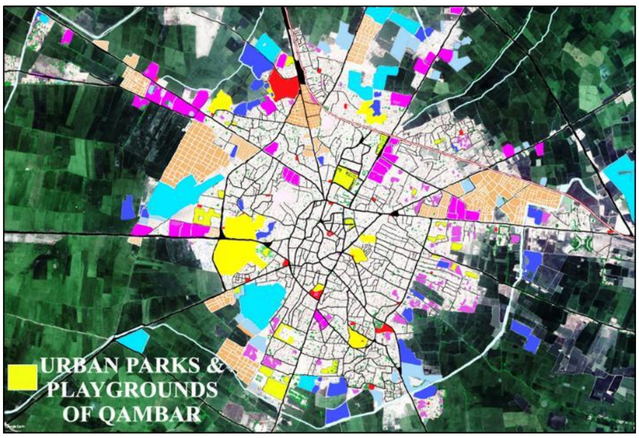

Figure 10. Morphological Map of Urban Parks & Playgrounds in Qambar, Sindh.

There are mainly one large playground and one municipal park in Qambar whereas regarding a sustainable urban future, parks, open spaces and playgrounds are prime essential elements. Thus, each neighbourhood of Qambar entails a public park for the healthy and liveable environment in the future.

Another analysed morphological element was the existing brick making and block-making yards in Qambar (see Figure 11).

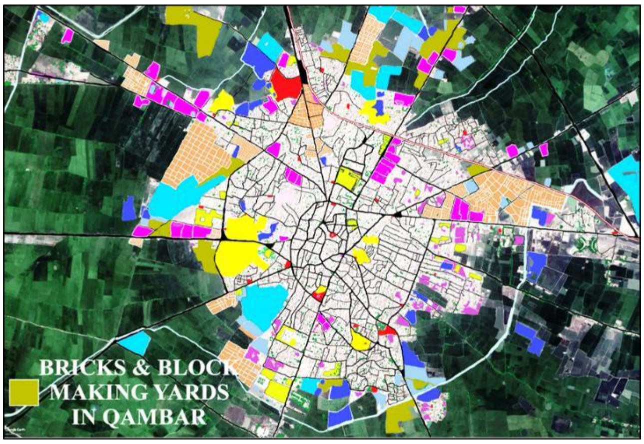

Figure 11. Morphological Map of Bricks & Blocks Making Yards in Qambar, Sindh.

There are numerous building materials provision yards in the city developed in the last two decades, and their business is booming in Qambar. These building materials providers give materials on credit and contributed towards increased pace of construction activities, housing, and commercial areas development in Qambar.

The next morphological element evaluated in Qambar was education and health institutions (see Figure 12).

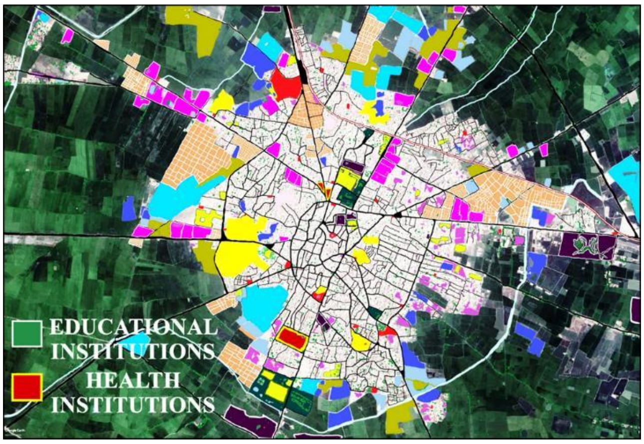

Figure 12. Morphological Map of Education & Health Institutions in Qambar, Sindh.

Concerning educational institutions, there are primary and secondary schools and the civil hospital in Qambar since the British period, whereas degree colleges developed in the post-British period. Over the last two decades, there arose two major trends of developing university campuses and health institutions in secondary cities of Sindh, especially in district headquarters. The Government of Sindh upgraded and expanded health facilities for people by developing DHQ hospitals in all district headquarters, and it is evident from morphological analysis of health and education institutions in Qambar.

The final morphological element dissected in Qambar was commercial and market spaces (see Figure 13).

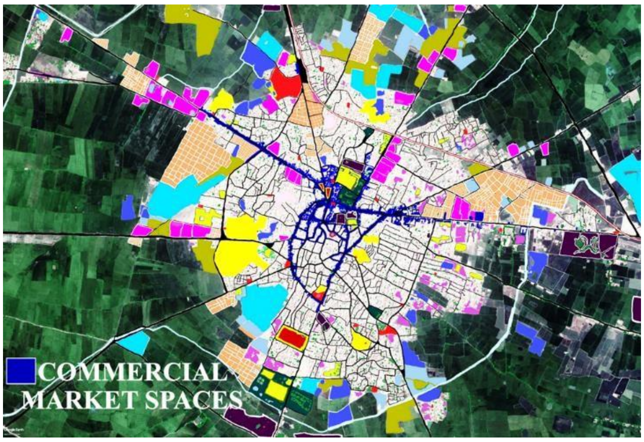

Figure 13. Morphological Map of Commercial Market Spaces in Qambar, Sindh.

Concerning commercial and market spaces, there exists a ribbon development pattern. All the major urban roads surrounding the geographic heart of Qambar consists of commercial markets, shops and residential cum commercial development. Although there exist no vertical shopping malls or commercial buildings, major commercial growth and expansion was of shops, hotels, restaurants, mobile franchises, trade, transport, and transit-oriented development to cater the needs of emerging markets, businesses, institutions, and administrative offices in the city center of Qambar. The above-mentioned analysis concerning urban morphology of Qambar entangled various urban elements and morphological components. It may be further drawn-out to address various other aspects related to sustainable urban future. For instance, the sustainability paradigm addresses five essential rudiments in terms of futuristic planning and urban design such as the physical development, social integration, economic growth, environmental protection, and future technological advancements. In this respect, the case of Qambar identified the morphological dimensions of these essentials with the application of singular urban information technology. It is because within the secondary cities of Sindh even basic information and baseline maps about morphological elements are not available for planners and urban designers to make apt decisions for a sustainable urban future and develop smart urban communities. Consequently, it is necessary that all secondary cities of Sindh at least investigated in terms of urban morphology through different technology applications to develop smart urban communities and ensure sustainable urban future with urban planning and design.

4 Conclusions and Recommendations

In the beginning of this paper, four research questions generated and addressed their answers through literature review and a morphological case study. According to which, urban informatics is the study and application of data, information and communication technologies to improve urban environments. It integrates urban science, geomatics and informatics to create smart sustainable cities. It encompasses the three realms of people, places and technology. Its application spans urban planning, sociology, architecture, geography and software engineering to address urban challenges through technology. Moreover, Urban Information Systems (UISs) are essential for long term urban planning and management offering insights into the interrelations of environmental, social and the economic factors. For morphological enquiries, Decision Support Systems (DSS) and the Planning Support Systems (PSS) are key technologies. These systems are crucial for addressing challenges of land management and rapid urbanization, especially in developing regions. Furthermore, morphological investigations are crucial for secondary cities of Sindh due to lack of devolution and decentralization policies for their physical, social and economic development. In addition, these cities need recognition and planning for the sustainable urban growth, and the UISs, and GIS can identify analyse and understand their development needs. Finally, the integrated application of the locally available urban information systems (UISs) and geographic information systems (GIS) on a secondary city of Qambar, Sindh, resulted in various urban morphological maps and created the new detailed information about existing ground realities of the investigated urban context. This generated information is quite significant for futuristic planning, development, and urban design of Qambar. Furthermore, if similar exploration carried out in all primary, secondary, and tertiary cities of

Sindh, it would generate a big data that can be useful for future planning and urban design system of this developing region in south Asia. This newly created big data about urban context of Sindh would work as the decision support systems (DSS) and planning support systems (PSS) for the urban administrators, urban planners, ur-ban designers, and professionals conducting urban research. It is quite necessary for sustainable urban future of Sindh that a DSS and PSS developed because it is currently non-existent at mass scale within the local urban context of secondary and tertiary cities of Sindh. This research has identified various information technologies and systems for local developing urban region of Sindh for making smart urban communities and for leading to sustainable urban future. However, conducting urban morphological investigations with integrated use of UISs & GIS are quite essential and very useful endeavors for secondary and tertiary cities of Sindh. Because planning and urban design in the local urban context of Sindh is at its primitive stage and there are quite little and limited efforts evident in this direction. Thus, this research highlights the need for technology driven urban planning in secondary cities of Sindh and study of Qambar serves as a model for investigating other secondary cities in Sindh.

Moreover, there is an abject need that a scientific debate shall be generated for the emergence of futuristic smart and sustainable cities in Sindh with the use and application of urban information technologies in fast pace to make sure sustainable urban future.

Acknowledgment

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Analyzing the Spatial Variation of Groundwater Quality Parameters with Respect to Seashore of District Sujawal

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ABSTRACT

Water quality in the coastal areas is susceptible to deterioration and seawater damage. This variation reduces spatially with the increase in distance from the coastal belt. In this research zone of influence is found up to which seawater has a significant impact on the characteristics of groundwater. Groundwater samples were collected from Taluka Kharo Chan and Shah Bunder of district Sujawal from various distances with respect to the seashore. Various physical and chemical properties like Total Dissolved Solids (TDS), Electrical Conductivity (EC), hardness, acidity, chloride concentration, and pH values were evaluated and compared with WHO standards. It was revealed from the results that seawater has an influence on the groundwater quality parameters upto 7 km from the seashore. Most of the water quality parameters were not complying with the standards up to this distance. The EC of the water varied from 18750 µS/cm to 746 µS/cm. Hardness and chloride concentration have similar trends, these parameters were beyond the acceptable range of the WHO standards up to 7km from the seashore. After 7 km these parameters showed slight variations, hence confirming the actual groundwater characteristics beyond this distance.

1. Introduction

Approximately 70% of the Earth's surface is covered with water, with a significant portion found in the oceans, accounting for about 97.25% of the total water. The remaining freshwater is primarily found in ice caps and glaciers, and a mere 3% exists as fresh water. According to the World Water Development Report 2011, this 3% is further allocated with 70% utilized for agriculture, 20% for industrial purposes, and 10% for domestic use (Javed et al., 2017). Moreover, only around 3% of the global population relies on groundwater as a source of drinking water (Solangi et al., 2020).

The utilization of water is contingent upon its quality, as unsuitable characteristics render it unfit for specific purposes. Water serves not only as a drinking resource but also plays a vital role in irrigation, agriculture, and power generation. Regrettably, water quality is deteriorating worldwide, including in Pakistan (Memon et al., 2011). Coastal regions face even more significant challenges due to the intrusion of seawater (Solangi et al., 2019). With approximately 620,000 kilometers of coastal line, the Indus Delta, encompassing an area of 600,000 hectares along the Pakistan coast, holds immense ecological and cultural significance. However, individuals residing in coastal areas struggle to sustain life due to the scarcity of key resources resulting from the influence of the ocean. Access to quality water remains a pervasive issue in these coastal regions. The continuously changing climate further exacerbates the situation, posing a severe threat to groundwater aquifers (Solangi et al., 2020).

Seawater intrusion, the movement of saline water into freshwater sources, presents numerous challenges in terms of water quality. Pakistan is grappling with a severe water crisis due to the scarcity of fresh surface and groundwater caused by declining groundwater levels and rising seawater levels. Seawater intrusion is primarily a consequence of coastal well pumping and the construction of navigation or oil field channels. As a result, the quality and quantity of freshwater supplies diminish. This phenomenon leads to elevated levels of major ions, particularly chlorides, in the water, which can result in digestive problems, throat discomfort, and corrosion issues (Sarfraz et al., 2018). The significance of this issue is further compounded by the fact that many people already lack access to freshwater, and seawater intrusion further contributes to the loss of freshwater vegetation in affected areas.

This study focuses on the assessment of groundwater quality variation by moving in an upstream direction with reference to the seashore. It has been hypothesized that the groundwater quality will improve as it gets out of the influence of seawater intrusion. However, the distance up to which the significant influence of seawater prevails for the study area is of concern and is targeted in this research.

Through this study, a boundary for the high-risk zone is indicated beyond which groundwater quality will be susceptible to deterioration. The study area is less developed and mostly possesses rural populations, which purely depend on groundwater for their basic needs. Population from these areas is facing many challenges regarding the key elements of life in different sectors including environmental, social, engineering, educational, and economic sectors (Alamgir et al., 2016), hence the distance of the zone of seawater influence is crucial to be determined. To that people may avoid the use of groundwater for drinking from that zone.

2 Material and Methods

A qualitative approach has opted to identify the major physiochemical water properties over seven established stations from which the water samples were obtained. It has been targeted to identify the intrusion length, as the huge population of the area solely depends upon groundwater for their household chores and other needs.

2.1 Time Period

Samples were collected during the pre-monsoon season of 2022 including March and April.

2.3 Study Area

Subdivisions of Shah Bander and Kharo Chan of District Sujawal which are located at the sea side of the district are considered in this study. In dry periods, these areas are prone to seawater intrusion (Khuhawar et al., 2018) as belong to the Ramser site of Sindh. District Sujawal is one of the four southern districts of Sindh at which the Indus Delta is located.

Fig. 1. The Area marked with red indicates Indus Delta

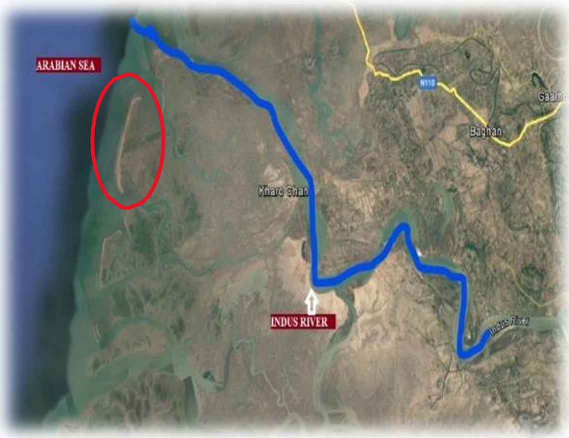
Fig. 2. The Area highlighted indicates the study area.

2.3 Sample Planning

The area has been surveyed and existing water pumps and handpumps are highlighted. Based on their locations, locations have been planned to act as stations at which sampling has been done.

2.4 Water Sampling Preparation

These pumps and hand pumps are allowed to run for 5 minutes, so that any traces of contamination in the pump of the pipe may be discarded and then representative samples be taken.



2.5 Site Sampling

Seven groundwater samples were collected from handpumps and wells. After collection, the samples were transported to the laboratory in pre-washed, clean, and dry plastic bottles of 1.5 L capacity. The bottles were sealed immediately to ensure sample integrity during transportation and later brought to the laboratory for analysis.

2.6 Water Testing

The following water quality tests were performed to analyze the physiochemical characteristics of water.

2.6.1 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) refers to the amount of organic and solid particles in the water. TDS in water is a mixture of organic and inorganic elements, such as minerals and ions, dissolved in an exact amount of water. Particles are absorbed into the water as it flows over stones, pipes, and other surfaces. It was calculated using a Digital TDS meter.

2.6.2 Electrical Conductivity (EC)

Electrical conductivity (EC) is the physical property, the ability of water to pass the electric current. The main scenario behind it is that when pure water conducts electricity neutrally it can be influenced by the presence of many ions in the water. EC was calculated through a digital EC meter.

2.6.3 pH

It's a measurement of how acidic or basic aqueous or other liquid solutions are in general. It's also one of the most crucial factors in determining the quality of water. According to WHO recommendations, the pH of drinking water should be between 6.5 and 8.5. pH was calculated using a digital pH meter.

2.6.4 Acidity

The ability of water to react with a strong base up to a certain pH value is known as acidity. Total acidity is assessed by titration with NaOH until a pink hue appears. The amounts of titrant used are recorded. After all of the observations have been made, calculations have been done in the end

2.6.5 Hardness

Water hardness is caused by the presence of soluble bicarbonates, chlorides, and calcium and magnesium sulfates. Calcium carbonate at a concentration of 0 to 60 mg/L (milligrams per liter) is defined as soft, 61 to 120 mg/L as moderately hard, 121 to 180 mg/L as hard, and more than 180 mg/L as very hard. Hardness was determined by titrating the collected water sample against Ethylene-Diamine-Tetra-Acetic-Acid (EDTA) in the presence of ammonium buffer until the EDTA complex is formed and indicated by color change. Calculations have been made to find hardness.

2.6.6 Chloride Concentration

The concentration of chloride ions in any of their compound forms is referred to as chloride concentration. The WHO permissible limit for chloride is 250 mg/L. Chloride concentration was determined by titrating the collected water sample against Silver Nitrate (AgNO3) in the presence of K_2CrO_4.

2.7 Data Analysis

Spatial variation of water quality parameters with respect to the seashore in District Sujawal is assessed by taking the groundwater samples from the existing pumping wells used by the community for various purposes.

To meet the indemnity standard for a certain water system, the samples were collected from different areas which represent the water for the whole area. But there might be a possibility of slight variations with the change in area. Hence every area needs specific consideration. Different areas of sampling were considered as individual representatives of the source of water and the areas of sampling were carefully chosen, considering that one area of sampling should represent the parameter and properties of that area. Coordinates of the sampling sites were noted, and distance from the seashore was found using GPS calculations with the help of online tools provided by Google Earth. Samples were preserved and brought to the laboratory for analysis. The adopted methodology of this work is presented in Figure 3.

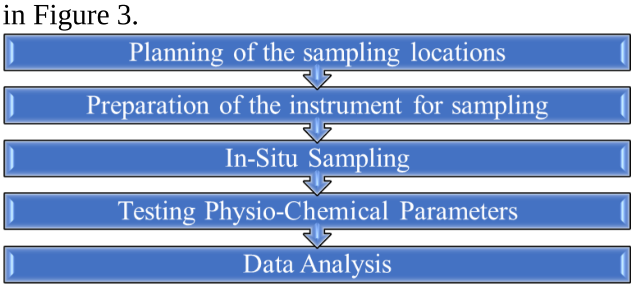


Fig. 3. Computational Steps for analyzing the parameters

Normally groundwater samples are colorless, odorless, and have zero or very slight turbidity (Jamali et al., 2022). However, groundwater is susceptible to containing high TDS values, significant hardness, and sufficient electrical conductivity. Groundwater near seashores may also have high chloride concentrations and high acidity values. Moreover, (Khan et al., 2020) also determined groundwater quality for Karachi through the evaluation of pH, TDS, EC, Hardness, and several chemicals including chloride, Consequently, these parameters are targeted in this study through standard methods in the literature and summarized as below subsections. The observed values were then compared with WHO standards as compared by (Akram et al., 2020)

3. Results and Discussion

The key parameters of the samples collected are presented in Table 1. A detailed analysis of the results is presented below. Figure 4 presents the comparison among the parameters along with the seashore and their mean error, whereas Table 2 presents the allowable limits of these parameters in drinking water by WHO.

Table 1. Observed water quality parameters of the samples.

Name	Location	Longitudes (E)	Latitudes (N)	Distance from sea KM	pH	TDS ppm	EC µS/cm	Acidity mg/L	Hardness mg/L	Chloride mg/L
GW-1	Qasim Samejo	67.9	24.22	4.3	7.38	15000	18750	180	2400	9216
GW-2	Qasim Samjeo	67.9	24.23	5.5	8.08	3250	5000	172	1920	1120
GW-3	Haji Magsi	67.9	24.24	7	7.32	2502	3850	164	480	400
GW-4	Hashim Kehar	67.91	24.27	8.5	7.11	2330	3584	152	441	360
GW-5	Jongo Jalbani	67.92	24.28	10	7.78	965	1484	112	353	252
GW-6	M. Rind	67.975	24.38	18	8.2	739	1136	105	336	243
GW-7	Sanjrani Village	67.979	24.388	20	7.41	497	746	92	240	234

Table 2. WHO recommended values

Parameters	WHO Recommendation
PH	6.5 – 8.5
TDS	1000 mg/L
EC	1500 µS/cm
Acidity	Not specified
Hardness	500 mg/L
Chloride	250 mg/L

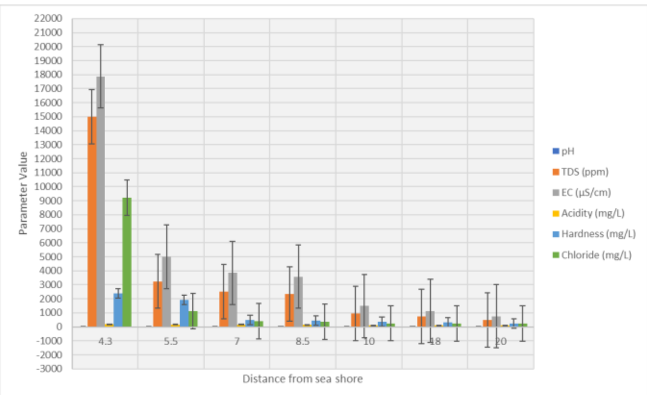


Fig. 4. Variation of various parameters with respect to the distance from the seashore

3.1 Total Dissolved Solids (TDS)

Values of TDS were observed in the range of 497 ppm to 15000 ppm varying linearly with respect to the seashore. It was observed that up to the distance of 8.3 km from the seashore, the values of TDS were beyond the WHO standards for drinking water. A decrease in TDS values was observed as going away from the seashore. Out of 7 collected samples, 4 samples were beyond the limits of standards. The variation of TDS with respect to the sea belt is shown in Figure 5.

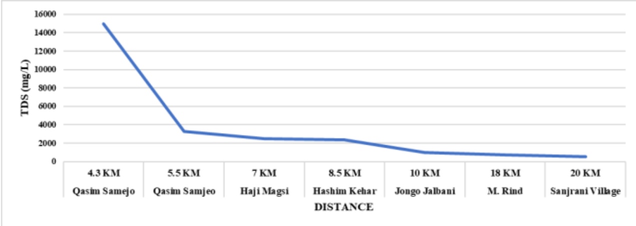


Fig. 5. Spatial Variation of TDS with respect to the Seashore

3.2 Electrical Conductivity

It is observed that collected samples near to sea have a high value of electrical conductivity. Linear variation in electrical conductivity observed with respect to distance from the sea. Out of 7 collected groundwater samples, 4 samples were highly contaminated having a high value of EC. The WHO's ideal EC level for drinking water is 1500 µS/cm. The observed values ranged from 746 µS/cm to 18750 µS/cm, as shown in Figure 6, in which 3 samples were in the range of WHO standards while the other four were beyond the limits. After a distance of 8.5 km, electric conductivity and total dissolved solids have lower values, indicating a minimal ionic load and pollutants in the water.

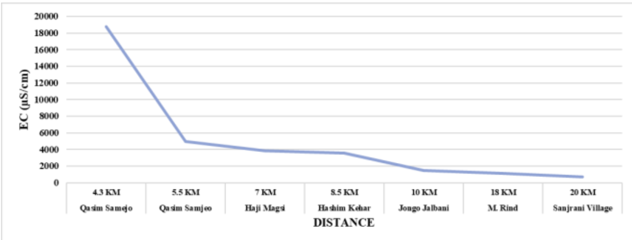


Fig. 6. Spatial Variation of EC with respect to the Seashore

3.3 Chlorides

It is observed that all the samples were out of the range specified by WHO for drinking water for chloride concentration. Samples near to sea were highly contaminated and had a high value of chloride. As we moved away from the sea belt, a decrease in chloride values has been observed. It has been observed that the water quality of aquifers in the coastal region is highly influenced by seawater. The chloride concentration of collected samples ranged between 234 to 9216 mg/L, while the WHO permissible limit for chloride concentration is 250 mg/L. The graphical variation of chloride concentration is displayed in Figure 7.

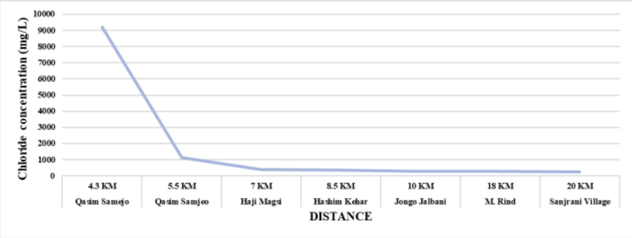


Fig. 7. Spatial Variation of Chloride Concentration with respect to the Seashore

3.4 Total Hardness

Increased hardness of the water may degrade the quality of clothes and other stuff washed from hard water as well as may cause skin irritations. In this study, it was observed that samples that were collected from the near sea belt had high values of total hardness and as we moved away from the sea it decreased linearly. The total hardness of collected groundwater samples ranged between 240 mg/L to 2400 mg/L. The WHO recommends that the hardness of drinking water should not exceed 600 mg/L. Hence, out of seven collected groundwater samples, five are in range while two of them have observed high concentrations of hardness. The variation is presented in Figure 8.

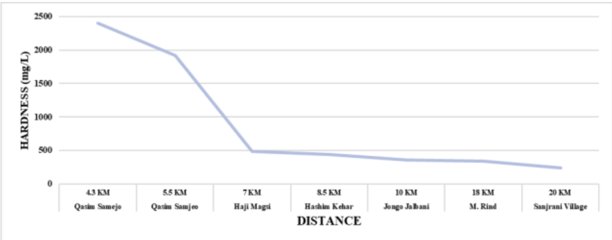


Fig. 8. Spatial Variation of Hardness with respect to the Seashore

3.5 pH

In this study, it has been observed that the value of pH did not vary too much from location to location with respect to distance from the sea belt. The pH of collected samples ranged from 7.11 to 8.2, while the sample that has high pH was at the 18 KM distance from the sea belt. The WHO recommends the range of pH from 6.5 to 8.5 and all collected samples were in range. Figure 9 displays the variation in pH with the variation of the distances.

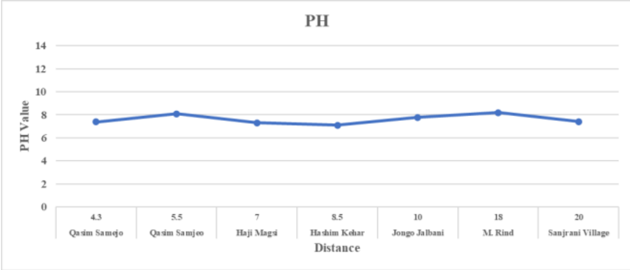


Fig. 9. Spatial Variation of pH with respect to the Seashore

3.6 Acidity

It has been observed that the value of acidity also varies from location to location with respect to distance from the sea belt. The acidity of collected groundwater samples ranged between 92 mg/L to 180 mg/L. the linear variation is observed in Figure 10.

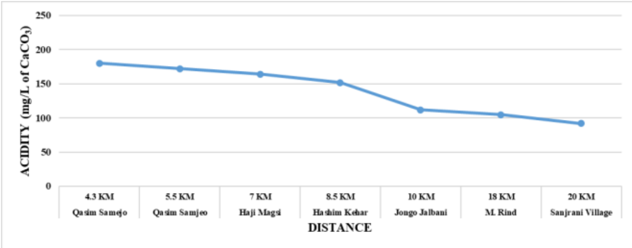


Fig. 10. Spatial Variation of Acidity with respect to the Seashore

4. Conclusions

The objective of the study is to analyze the spatial variation of groundwater quality by moving away from the sea. The key conclusion is that there is a significant variation in the physical and chemical parameters of groundwater with respect to the distance from the sea. The collected samples did not satisfy the WHO standards of drinking water. Data reveals that these parameters are within an acceptable range after the distance of 8.5 km from the sea, indicating the suitability of this water for a variety of uses. The values of TDS and EC were quite high as compared to the limits up to 8.5 km, afterwards, then they were complying with WHO standards. Similarly, the chloride concentration was extremely high as compared to specified limits up to the distance of 7 km.; afterwards, it was within the limits. In the same way effect of seawater on the hardness of the groundwater was observed till 5.5 km, afterwards, this varied linearly and reduced up to 240 mg/L. pH was almost constant and no significant effect of seawater intrusion on the groundwater characteristics has been found in terms of pH.

5. Recommendations

From the conclusion it has been noted that the quality of groundwater up to 7 km from the sea belt was observed to be very poor. During the sampling in the field, we noticed that a huge number of the population was relying on the same water, which is highly contaminated; it seems that groundwater aquifers near to this distance are being deteriorated abruptly by seawater intrusion. Hence, it is recommended that the population of this region should avoid the use of water for drinking as well as agricultural purposes up to 7 km from the sea as it is highly contaminated, and can cause many diseases and ill effects. It is also recommended that a water desalination or water treatment plant should be installed for the usage of healthy water if the use from this region cannot be voided. It also observed that near to sea belt many groundwater aquifers are being deteriorated by seawater intrusion; to prevent this phenomenon, it is recommended to coastal development authorities that some valuable and energetic measures should be taken accordingly.

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Investigation of Algae Growth Using Photo Bio Reactor

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Humidity,
Light,
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ABSTRACT

The world's population is expected to grow by around 9 Billion by 2060. With an increase in population at such a huge level comes the need for more energy and food. Many researchers have proposed algae as the best solution. Algae is essentially a plant, Absorbs CO2 and releases the O2. Furthermore, if lipid content within algae is greater than 40% biodiesel can be extracted. The rest of the waste mass can be used for chicken farming, fish farming, and fertilizer. However, the growth of algal biomass at the production level is still a challenging task for researchers around the world. Many methods have been proposed to enhance algal biomass growth at a higher level. In this study photo bioreactor method was used and the reactor was fabricated with acrylic tubes to allow light to penetrate into algal biomass. Different sensors such as flow rate meters, salinity meters, and Ph. Meter have been used to monitor the effect of various parameters such as temperature, humidity, light, salinity, and Ph. Oxygen negatively affects the growth of biomass hence a sensor placed at top of the bioreactor to monitor the amount of O2. The key objective of this experimental study was to identify the best local specie that can grow quickly and optimize the bioreactor productivity by analyzing the behavior of algae while changing affecting parameters suitably experimentally and numerically. Several challenges were faced while fabricating and assembling the photo bioreactor—leakage within acrylic tubes at the bending section and PVC and acrylic pipe dia differences. To solve the CO2 cylinder 20 bar pressure flow rate meter was installed before entering the CO2 into the bioreactor. This study shows that a significant amount of algal biomass can be produced with suitable nutrients and conditions. This study has focused on local species and concluded that some local species might be a suitable candidate for future algal biomass plant. But to mass produce with cost effective outcome more advanced equipment is required for careful monitoring. Nonetheless, significant growth and lipid content has been observed and presented in this study.

1. Introduction

Fossil fuel consumption as an energy source have generated a number of challenges for the future of life including Climate change, Global Warming, Air pollution, diminishing energy sources, food scarcity, water pollution etc. which are now proven threats to life on the earth. To curb the above-mentioned challenges, renewable energy resources have been investigated the best alternatives for energy/food needs and security [1]. Among other renewable sources, algae are one of the most promising and long-lasting sources of energy/food which could accomplish energy/food needs for thousands of decades assuring sustainable development on the earth planet. Algae biomass not only can produce biodiesel but also cleans polluted water. Moreover, the residue can be utilized to increase fertility of soil or as food source for fishes and algae itself [2].

Despite having significant number of applications algae growth systems have low efficiency and cost becomes an important factor in study of algae growth for commercial purposes. Algae is still facing commercialization challenges because of its low growth and low output yield. The real challenge associated with algae is mass production of algae with economical methods [3]. Another challenge linked with algae is that they only produce biodiesel when lipids are above 40% in ratio with other entities with algae itself. The temperature and humidity also play vital role in growth of algae. Hence, every rise in PBE model temperature causes the significant changes on algae growth. The higher the ambient temperature the higher will be risk of algae depletion [4-6]. Algae have lately attracted significant interest worldwide, due to their wide-ranging application potential in the renewable energy, biopharmaceutical, and Agriculture sector. Algae are renewable, sustainable, and economical sources of biofuels, bioactive medicinal yields, and food ingredients [7]. Several microalgae types have been studied for their potential as value-added yields with remarkable qualities. As biofuels, they are a flawless additional to liquid fossil fuels with respect to cost, renewability, and environmental concerns. Algae have a substantial capability to transform atmospheric CO2 to useful products such as carbohydrates, lipids, and other bioactive metabolites [8]. Although microalgae are achievable sources for bioenergy and biopharmaceuticals in general, some restrictions and challenges remain, which must be overcome to improve the knowledge from pilot-phase to industrial level. The greatest challenging and critical concerns are enhancing microalgae growth proportion and product synthesis, dewatering algae culture for biomass production, pretreating biomass, and improving the fermentation practice in case of algal bioethanol production. The present review defines the benefits of microalgae for the production of biofuels and numerous bioactive amalgams and argues culturing parameters [9].

There are two key techniques that algae reproduce. Several algae are unicellular and demonstrate the simplest possible life cycles. Note that there is a generative stage and a vegetative stage. During the generative stage, cysts are freed. The cysts open to form gametes and then form the zygote. From there, the vegetative stage occurs so the plant cultivates and fresh cysts can form. Utmost algae have two familiar stage, sporophyte and gametophyte. The key dissimilarity is a male and female form is prerequisite to form the zygote [10-13].

The growth rate is determined by many factors. The temperature fluctuates with the types of algae. For microorganisms cultures the ideal temperature range is from 20-30°C. For a number of algae, mainly green microalgae, temperatures beyond 35 0C can be dangerous. The algae can grow gradually at temperatures below 16°C [14]. Moreover, Sun Light also disturbs algae growth, it should not be too strong or weak. Algae only have need of 1/10 of direct sunlight in most algal growth crops. Light enters just the top 7-10 cm of water of most water sources. This is because of the algal mass that obstructs light from penetrating deeper water [15].

Another factor affecting algae development is mixing. In order to combine algal cultures, agitation or circulation is vital. A deep mixing systems are used as an agitator. For open pond structures, paddle wheels are used, and for the photo tube system 900 or different angle piping is used [16]. Algae need to expand successfully nutrients and the correct ph. Carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, iron and trace elements are necessary for the auto-growth process. Development is dramatically decreased and lipid aggregation caused under nutrient restricted circumstances. Algae prefer a pH to alkaline from acidic [17]. Unique steps are being taken for the production of biodiesel. The first step is algae farming, containing site collection, choosing algal cultures and optimizing processes. Optimization of the process comprises the bioreactor architecture and the required algal cell growth components (nutrients, light, and mass transfer) [18]. Once the algae surpass the suitable volume, they are harvested. In order to remove water, thicken and dry the algae, it is important to refine the biomass in first to remove the fuel oil which is converted into biodiesel. Based on oil mining and biodiesel processing cycle, the biomass process is distinct. In Lesson 9, you heard mostly about trans esterification in order to manufacture biodiesel, but other processes are under research and development [19].

An ordinary differential equation (Chen Sh et al., 2009) indicates the growth of the algae population below [20].

$$\frac{dx}{dt} = \mu(t,x) - \delta(t,x)$$

$$\frac{dR}{dt} = -A.X$$

$$\frac{dQ}{dt} = A - \mu.Q$$

In the literature mostly on evolution of living matter, the statistical models of form come from the standard model that only indicates the rate of development on the right side. The population increases monotonously while the growth rate is solely positive. The following processes will be carried out during the production process for both the characterization process for the algae growth [21]. The algal biomass can be categorized on basis of their habitat. They are classified as macro algae and micro algae. Lipids and proteins are found in lesser quantity in macro algae but they are full of carbohydrate and water. On the other hand, micro algae are full of acids, proteins, lipids, and carbohydrates as well. Micro algae are also used for reducing carbon foot print because they are primary source to produce oxygen.

2. CULTIVATION, HARVESTING AND COST ANALYSIS

The cultivation and harvesting of micro algae for commercial purpose requires better understanding of algae and ambient conditions impact on algae. The sun light, temperature, water condition and several other factors affect lipid and protein contents inside algal biomass hence affecting overall success rate. Thus, it is observed and recommended by researchers that careful monitoring is necessary for proper and suitable algal biomass growth to compete with other market stakeholder. Although, much work has been in the field of algae growth but cost effectiveness and suitable mineral growth inside algal biomass still poses serious challenge to researchers.

Pretreatment, genetic engineering and several other techniques have also been used to reduce impact of ambient conditions on algae growth and lipid contents inside it. However, such studies have not yet found much significant specie yet which can bring algae into market competition. Capital investment for plant is such high and yield is still low that without considering environmental and ecological benefits of algae growth its cultivation still seems lost business. Nonetheless, countries like Pakistan which is converting fertile land into housing projects at staggering rate will suffer huge food crises in near future. Algae and agriculture growth are future of developing countries. Algae will become part of food chain as it can be utilized for feedstock for fisheries and poultry industry as well. Although algae do not require pure drinking water neither it requires fertilizer for its cultivation and growth yet mass production is still not so cost effective process.

3. PHOTO BIO REACTOR

In this study the photo bioreactor has been used to study algae growth and cultivation. Along with it different sensors have been used to monitor the salinity and TDS in algal biomass. The photo bioreactor uses acrylic tube, which can conduct light and heat to certain extent. The sensors such as saline meter and flow meters were used for effective condition monitoring and flow. The 90-degree bend in pipe is critical in photo bio reactor design it enhances the mixing of algal biomass. The effectiveness of mixing through pipe bend can be measured with help of velocimetry technique. However, mixing through pipe bend is not sufficient hence discontinuous flow is required. For that purpose, different controllers were installed which essentially controlled the flow of algal biomass through pipe with different intervals of time and sequence.

Figure 1: The algae photo bioreactor

Table 01. The Photo Bioreactor Equipment Details

Equipment Name	**Specification**
Main wooden frame	5ft height, 3ft width, 1.5ft breath
Salinity meter/pH meter	Digital
Relay/timer	220volt 4 way timer
Flexible pipes	2.5 inch steel wire support
Acrylic tubes	50mm x 40mm x 12ft
Flow meter	0-10 L/min
CO_2 cylinder	6kg
Cementex glue/flex tape	Quarter liter/4 inch x ft
Water pump	12v 8w, 10L/min
Solenoid valve	Model UD-08, 220v, ¼ inch
Additional equipment	Jubilee clamp, zip tie, paint, flow meter adapter, PVC elbows

There are various conversion technologies of biomass into biodiesel and other products. These technologies include thermochemical conversion, chemical conversion, and biochemical conversion on broader perspective. Thermochemical is further sub divided into liquefaction, pyrolysis, gasification, hydrogenation. The biochemical process however involves the aerobic digestion, photo biological method, and fermentation process. Chemical technique is not used in many studies and not strongly recommended by any researcher.

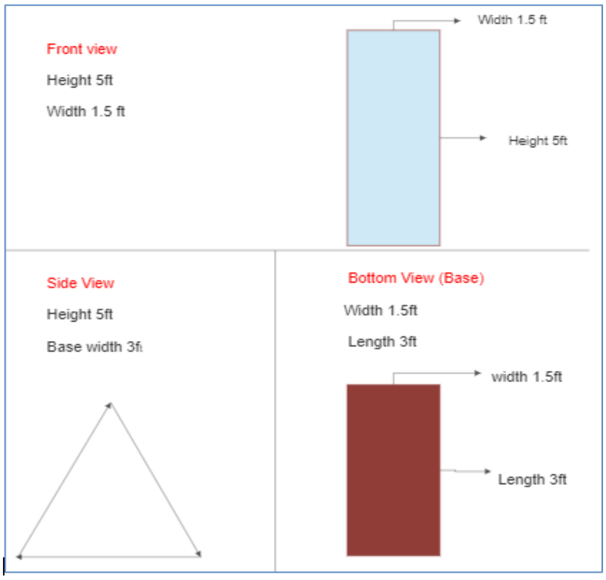

Figure 2: dimensions of photo bioreactor

The carbon dioxide cylinder is utilized for effective CO2 feed using controlled valve. The algae utilize light, CO2 and contamination inside water to grow. It also feeds on algae dead mass as well.

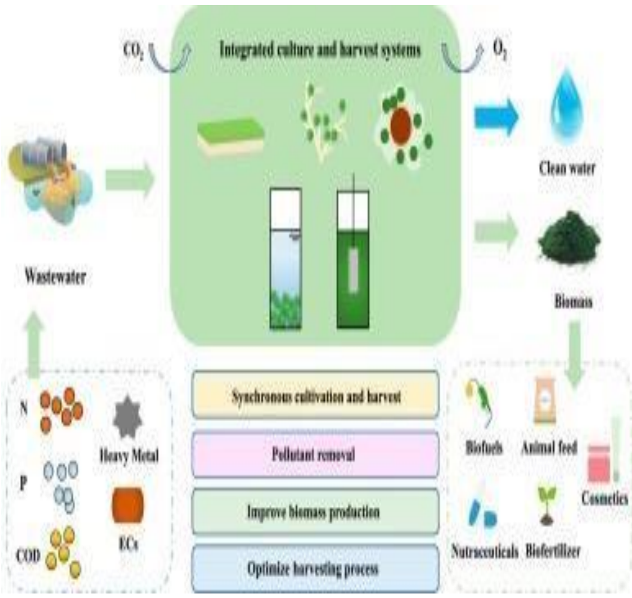

Figure 3: The algal biomass growth pattern

4 Result and Discussion

The factors that affects algal biomass growth are ph., salinity, temperature, light, nutrients, carbon di oxide, agitation, and buffering capacity of water. The temperature sensor and ph. meters were used to measure respective parameters. The carbon di oxide cylinder was used for suitable CO_2 provision. In initial stage of study different algal biomass species were allowed to grow in open environment. This was done to understand the specie nature and monitor resilience to survive in given environment.

The increase in cell density and ph. value was observed during test 1. The biomass continued to increase for 91 hours and then suddenly started to decline after 135-hour time. It is assumed that ph. value is related to algal biomass growth and some NaOH was added in next test for ph. value enhancement.

Flow meter was responsible to measure the flow of algal biomass. The sensors were recalibrated with calibration kit in order to measure accurate and valid results.

Table 2: Different measurements during growth tests

Date	**Time**	**Temperature**	**Salinity**	**TDS**	**pH**	**Humidity**	**Solar Radiation**
17/01/2023	11:15 AM	26°C	344ppm	340ppm	6.3	29%	437w/m2
8:00PM	22°C	350ppm	345ppm	6.2	33%	0	
18/01/2023	11:00 AM	25.8°C	355ppm	347ppm	6.45	29%	417.3w/m2
8:15PM	22.5°C	320ppm	324ppm	6.95	35%	0	
19/01/2023	11:15 AM	26.1°C	365ppm	359ppm	6.4	54%	448.5w/m2
3:30PM	24.8°C	386ppm	380ppm	6.07	44%	318.3w/m2	
20/01/2023	10:00 AM	22.2°C	392ppm	390ppm	6.24	83%	265.8w/m2
3:45PM	28.4°C	417ppm	420ppm	5.7	53%	277.1w/m2	
21/01/2023	12:45 PM	29.9°C	940ppm	1060ppm	9.39	33%	518w/m2
3:30PM	26°C	964ppm	1087 ppm	9.4	42%	324w/m2	

4 Conclusion

i. Unicellular microalgae are famous for high lipid production. This makes it suitable for biodiesel production. On the other hand, growing algae at faster rate with suitable lipid content is difficult and challenging process. Consequently, growth, extraction and conversion must be cost effective as well.

ii. This study has focused on local species and concluded that some local species might be a suitable candidate for future algal biomass plant. But to mass produce with cost effective outcome more advanced equipment is required for careful monitoring. Nonetheless, significant growth and lipid content has been observed and presented in this study.

iii The challenges are still there and proper infrastructure and environment is must needed in future studies

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Fabrication of Electrospun Silk Nanofibers and Reassembly into Ultralight 3-D Structured Silk Nanofiber

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Filtration Application

ABSTRACT

Many studies have already been carried out on conventional 2D electrospinning for various applications, but recently, 3D structured electropsun materials gained much attention due to light weight and increased microporosity. Herein, silk nanofiber has been fabricated via electrospinning and then reassembled into 3D structured materials using freeze drying method. Field emission scanning electronic microscopic (FE-SEM) images showed that silk nanofibers have smooth and bead-free nanofibrous morphology having an average fiber diameter of 200 nm. After several mechanical interactions during reassembling fibers, like high-speed homogenizing and freeze drying, the nanofibers successfully retain their nanofibrous morphology and FE-SEM images showed clear increased microporosity in reassembled 3D silk nanofibers. Further, the FTIR results confirms the chemical composition of silk nanofibers before and after 3D silk nanofibers morphology. The average density of 3D silk nanofibers was decreased due to increased air gaps present in 3D silk nanofibers and hence ultra-light weight was found in 3D structured silk nanofibers. Therefore, the above prescribed results suggest a simple route to fabricate 3D structured silk nanofibers and have potential applications for various fields including continuous filtration.

1. Introduction

Nanofibers are fibers with a diameter of less than a nanometer. Nanofibers can be made from a variety of polymers and thus have a variety of physical properties and applications [1, 2]. Nanofibers are normally developed into 2D (two dimensional) nanofiber mesh deposits, which have some flaws. 2D nanofibers can't be used for high-performance applications including liquid absorption ratios and material performance due to their lower porosity [3-8]. Meanwhile, ultralight 3D (three dimensional) nanofibers have successfully attracted a lot of interest because of their unusual structural properties and efficiency benefits [9-13]. Multilayering electrospinning liquid, template-assisted electrospinning, porogen incorporated electrospinning, and post-treated electrospinning are some of the techniques for fabricating 3D electrospun nanofibres that have been recorded [14]. Post -treated electrospinning is the basic setup for fabricating 3D electrospun nanofibers and more attracted due to the fact that its vast flexibility for fabricating nanofibers into desirable shapes and mechanical properties is good compared to other techniques introduced [15].

Driven by the mechanical high strength, good biocompatibility with cell proliferation, and adhesion makes silk an interesting area of research for scientists and researchers [16-19]. Silk is a natural protein fiber produced by the silkworm. Aromatic repeat units and the presence of amino acid groups endow excellent physical and chemical properties to the silk fibers [20,21]. Also, silk nanofibers have been produced via electrospinning recently [22].

Therefore, in this study, promising properties of silk, especially the presence of amino groups and carboxyl in their aromatic ring and the large surface area of electrospun silk nanofibers, inspired us to reassemble 2D silk nanofibers membrane into 3D structured silk nanofibers using the freeze drying method. The surface morphology and chemical properties of 3D structured nanofibers were characterizations using FE-SEM and FTIR. We believe that these azo functional groups and carboxyl sites present in the aromatic ring of 3D structured silk nanofibers will be potential material for various applications including continuous filtration.

2. 2 Experimental Work

2.1 Materials

We bought cocoons from Bombyx mori silkworms in Shanghai, China. Hexa fluro-2-propanol (99 %) was bought from 3A chemicals Ltd., China. Absolute ethanol (98 %) was bought from Sinopharm Chemical Reagent Ltd., China. Without any additional purification, each and every chemical and reagent was utilized in its raw form.

2.2 Preparation of silk precursor

A formerly available method was followed to prepare silk precursor [17]. Briefly, B. mori silkworm cocoons were boiled in an aqueous solution of 0.5 % (w/v) NaHCO3 for 1 hour and washed with deionized (DI) water several times to remove sericin maintaining the temperature of 60 ℃. The degummed SF fibers were dissolved in 9.3 $mol\cdot L^{-1}$ LiBr solution at 60 ℃ for 1 hour. The regenerated SF aqueous solution was obtained after dialysis in DI water using dialysis tube (MWCO 6000-8000 Da, Spectra/Por, USA.) for 3 days to remove the LiBr salts. Finally, the obtained solution was lyophilized to get the silk fibrins.

2.3 Preparation of silk nanofibers

The silk precursor was put in hexafluoro 2 propanol with a concentration of 4% w/w% and left for stirring for 12 hours at room temperature to achieve an electrospinning solution. The silk nanofibers were obtained via electrospinning as shown in Figure 1a below. Briefly, the solution was placed in a 5 ml syringe with a 22 gauge needle. A 12 kV voltage was applied on needle at0.8 ml/hr feed rate. Electrospun nanofibers were collected on a rotating drum covered with aluminum foil, which was placed at a distance of 12 cm from the needle tip. The nanofiberous membrane was peeled off and dried at a fume hood (overnight). Finally, the membrane was immersed in 75% ethanol for one hour in order to achieve crosslinked silk nanofibers.

2.4 Preparation of 3D structured silk nanofibers

In order to have reassembled nanofibers, 500 mg of electrospun nanofibers were cut into small pieces (approx. 1*1 cm^2). 50 mL of tert-butanol was added to nanofibers and strong shear forces were applied by using a high-speed homogenizer LB-10HSH at 13000 rpm for 20 min. The obtained slurry solution was quickly frozen using liquid nitrogen and placed in a refrigerator having a temperature of -80 ˚C for 24 hours. The frozen slurry was dried in a freeze dryer machine for a further 48 hours, and hence 3D structured silk nanofibers were achieved.

2.5 Material characterization

SEM samples were coated with gold and examined at an accelerating voltage of 15 kV on FE-SEM (S-4800; Hitachi Ltd. Japan) in order to analyze surface morphology of 2D and 3D silk nanofibers. The Chemical structure of 2D and 3D silk nanofibers were assessed using FTIR spectroscopy (Thermo Nicolet 5700, Thermo Fisher Scientific Inc. USA).

3 Results and Discussion

3.1 Physical and Surface Morphology

Physical and surface morphology of 2D electrospun silk nanofibers are shown in Fig. 1 a-b respectively. The photograph of 2D electrospun silk nanofibers showed a uniform membrane of electrospun nanofibers and can be produced at bulk scale. It was observed that 2D electrospun silk nanofibers having an average diameter of 200 nm, were uniform and bead free [22]. After reassembling silk nanofibers into 3D structured silk nanofibers (Fig. 1 c-d), the morphology of nanofiber structure remained unaffected and stable. The photograph showed that silk nanofibers clearly obtained the desired volume and the SEM image showed a clear increase in micro pores in silk nanofibers. This increase in micro pores is due to reassembling of nanofibers after high-speed shear force and the results are quite satisfactory with other studies [15].

Further, the obtained 3D structured silk nanofibers were examined for ultra-light weight (density) and photographs of ultra-light 3D structured silk nanofibers is shown in Fig. 2. The results showed that obtained 3D structured silk nanofibers contain low density as 7.8 mg/cm^3. This low density suggests increased in porosity with in fiber to fiber and maximum air gaps (aerogels structure) attend by 3D structured silk nanofibers [9].

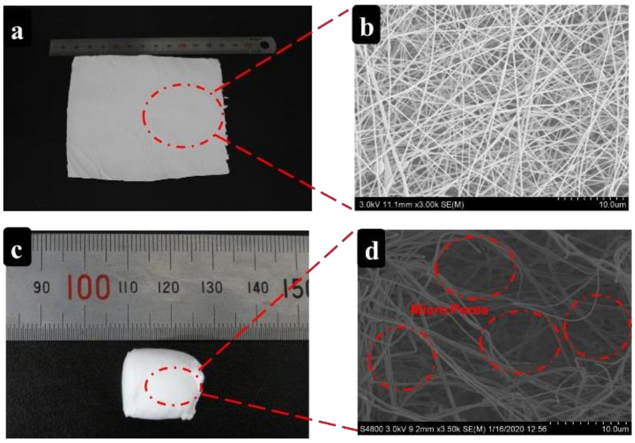

Fig. 1 A) Photograph of 2D electrospun silk nanofibers, B) SEM image of 2D electrospun silk nanofibers, B) Photograph of 3D structured silk nanofibers, and D) SEM image of 3D structured silk nanofibers.

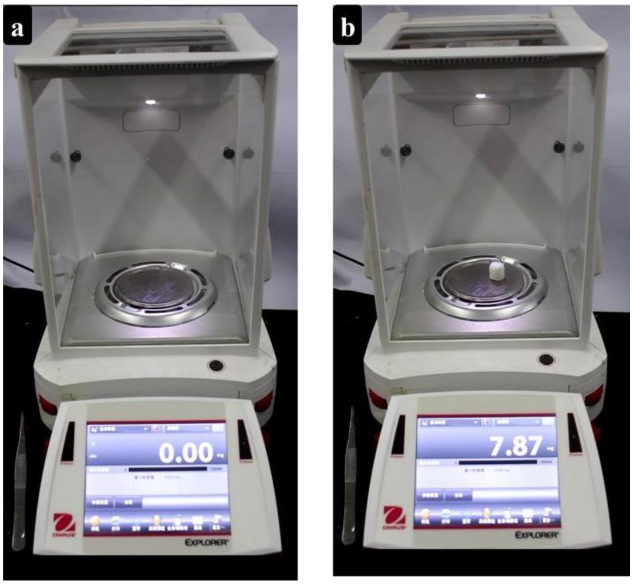

Fig. 2 Light weight measurement photograph of 3D structured silk nanofibers.

3.2 Chemical analysis

Fourier transform infrared spectroscopy (FTIR) of 2D electrospun silk nanofibers and 3D structured silk nanofibers was taken, in order to evaluate the chemical structure of 2D silk nanofibers and if any changes in chemical structure, occurred after post treatment (solvent interaction, high-speed shear forces and freeze drying). Fig. 3 a, two strong peaks with their Centre around 1647 cm-1 (amide I) and 1546 cm-1 (amide II) along with several regions of proteins between 2800 cm-1 – 3650 cm-1 of 2D silk nanofibers were observed, are in good agreement with previous reported works of silk nanofibers [23,24]. Whereas, these adsorption peaks of amide I (at 1647 cm-1) and amide II (at 1546 cm-1) were unaffected after post treatment (Fig. 3b) confirms that there is no such structural deformity and silk nanofibers retained its chemical structure [25, 26].

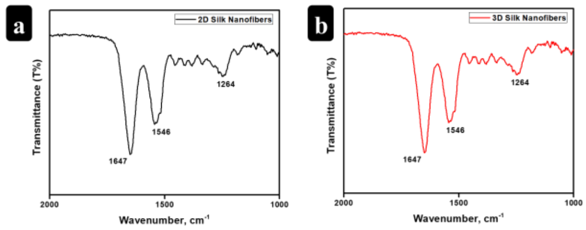

Fig. 3 A) FTIR spectra of 2D electrospun silk nanofibers, and B) FTIR spectrum of 3D structured silk nanofibers.

4 Conclusions

We have successfully prepared silk nanofibers via electrospinning and reassembled them into 3D structured silk nanofibers using post treatment (homogenizing and freeze drying). SEM images showed smooth and bead free electrospun nanofibers. 3D structured silk nanofibers retained nanofiber morphology after several high shear forces and clear micro pores were observed in 3D structured silk nanofibers. Meanwhile, FTIR results indicates that there is no such chemical structure change after reassembling silk nanofibers into 3D structured silk nanofibers. Moreover, obtained 3D structured silk nanofibers showed low density of 7.8 mg/cm3. Therefore, our proposed 3D structured silk nanofibers will be potential material for various advanced applications including continuous filtration.

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Innovative Strategies in Biomedical Engineering: An Exploration of the Influencing Factors for Sustainable Technology Management Protocols in Pakistan

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Innovative strategies, Biomedical Engineering, Sustainable Technology Management, Technology Protocols

ABSTRACT

A key component of improving medical treatment is the incorporation of cutting-edge biomedical technologies within medical practices. However, in Pakistan, there are obstacles to the sustainable management of such innovations that are brought about by a number of factors. The rationale of this study is to explore the factors that have a bearing on the sustainable management of technology within the biomedical engineering domain in Pakistan. Given the pivotal role that technological innovations play in creating the healthcare and medical interventions environment, it is vital to comprehend the ways in which diverse aspects impact the sustainable integration of novel technologies. This research will investigate the connection between biomedical engineering and technology management, with a focus on influencing innovative factors that promote sustainability and creativity. A qualitative methodology has been adopted to conduct this research. Thematic analysis has been applied as a tool for data transcription and developing themes. The themes obtained through transcribed interviews are life cycle assessment for understanding environmental and social impact of technology, Adaptability of digital health protocols in complex environment, Barriers of stringent regulatory processes for technology implementation, Patient data security under future strategic mapping. All of the factors that have been explored play a part in the development, use, and long-term viability of multiple practices in biomedical engineering.

1. Introduction

Combining engineering concepts with biomedical sciences, biomedical engineering is a multidisciplinary field of engineering and technology [1]. This field encompasses a wide range of applications where biomedical engineers work to improve goods and services and practice medicine, regenerative medicine, and related subjects [1]. The practice of applying engineering concepts to biological systems is known as biomedical engineering. Within the field of bioengineering, biomedical engineering focuses on applying engineering techniques to the development of medical devices and protocols that improve patient outcomes [2,3].The materials' suitability for medical devices is determined by engineers, who also evaluate the materials' biocompatibility and biodegradability. It is expected that this sector will offer proficiency in material design, modelling, and simulation [4-6]. Developments in biomedical engineering have been greatly aided by the creation of medications, surgical robots, better prostheses, artificial organs, and renal dialyzers [7–9]. Biomedical engineering is a highly sought-after multidisciplinary field due to notable advancements in research, health, and technology. The use of technical and scientific approaches, the research and provision of medical treatment, and biological and physiological challenges are all covered in the exciting field of biomedical engineering, health and hospital management.

The technology evaluation is a strategic and crucial component of a hospital's complicated management framework that is necessary to maintain high-quality clinical activity and maximize available resources [10]. In order to effectively manage technological breakthroughs, interdisciplinary evaluations of the technology are becoming more and more important. These evaluations must address the standard investments and disinvestments while also considering the impact, advantages, and risks on the hospital [10].

Since the turn of the 20th century, medical innovation has not only fuelled a tremendous "biomedical imagination," but it has also shaped the expensive healthcare systems of today [11][12]. Medical equipment, which include a variety of therapeutic and diagnostic products like hip implants, infusion pumps, and electrocardiographs (ECGs), help to drive up health spending even if they are not the only source of it [13].

A key component of improving medical treatment is the incorporation of cutting-edge biomedical technologies within medical practices. However, In Pakistan, there are obstacles to the sustainable management of such innovations that are brought about by a number of factors.

The rationale of this research is to explore the factors that have a bearing on the sustainable management of technology within the biomedical engineering domain in Pakistan. Given the pivotal role that technological innovations play in creating the healthcare and medical interventions environment, it is vital to comprehend the ways in which diverse aspects impact the sustainable integration of novel technologies. This research will investigate the connection between biomedical engineering and technology management, with a focus on influencing innovative factors that promote sustainability.

This research is important since it will help improve Pakistan's healthcare system. The study can lead to the creation and application of cutting-edge biomedical technology, ultimately enhancing patient care and results, by identifying and addressing affecting factors. Pakistan's socioeconomic circumstances and healthcare concerns are distinct. This research is important because it may be used to customize creative approaches that are especially appropriate for the local environment. Tailored approaches can effectively tackle the unique requirements and limitations of the healthcare system in Pakistan. This research is important because it has the potential to bring about beneficial changes in Pakistan's biomedical engineering landscape, which would ultimately lead to better healthcare, economic prosperity, and a sustainable and moral approach to technology innovation.

2. Methodology

2.1 Research Design

The present study utilizes a qualitative research design to investigate the aspects that contribute to sustainable technology management protocols in Pakistani biomedical engineering. Because of the inductive nature of the study methodology, a detailed comprehension of the viewpoints and experiences of biological area specialists is possible. The main method used in the study to find and examine recurrent themes in the data is a thematic analysis, which offers a thorough and in-depth examination of the research topics.

Sampling Technique

To select people with in-depth knowledge and experience in Pakistani biomedical engineering, purposive sampling is used. The objective is to guarantee that participants possess pertinent knowledge about the variables impacting protocols for sustainable technology management. The selection criteria encompass a range of factors, such as professional background, proficiency in implementing technology, and acquaintance with the ethical and regulatory aspects of biomedical engineering.

Data Collection

Interviews that are semi-structured are the main way that information is gathered. In order to collect qualitative information on biomedical field experts' experiences, viewpoints, and thoughts about sustainable technology management in the Pakistani context, ten interviews are done with them. Because the interviews are meant to be open-ended, participants are free to share their opinions and supply specific details.

Triangulation

A triangulation technique is used to increase the study's rigor and trustworthiness. This entails using a variety of data sources and techniques to cross-check and validate results. Apart from semi-structured interviews, relevant literature, papers, and reports are consulted for additional data collection and analysis. The study's findings are more robust and bias is reduced thanks to the multi-method approach.

Data Analysis

To find, examine, and present patterns (themes) in the qualitative data, thematic analysis is utilized. Getting acquainted with the data, creating preliminary codes, looking for themes, evaluating themes, identifying and labelling themes, and creating the final report are all steps in the process. An extensive investigation of the variables impacting sustainable technology management in Pakistan's biomedical industry is made possible by this iterative process.

Step 1. Data Familiarization

Firstly, a deep dive into the data gathered from semi-structured interviews kicks off the process. For the purpose of fully comprehending the material and spotting reoccurring concepts, expressions, and trends linked to sustainable technology management in biomedical engineering, all interview transcripts are carefully studied and reread.

Step 2. Generating initial codes

Based on the repeating elements and patterns found in the data, codes are generated. A distinct concept or idea pertaining to the influencing elements of sustainable technology management is represented by each code. To make further analysis easier, data segments are methodically labelled and categorized during the coding process.

Step 3. Themes Searching

Next, codes are categorized into possible themes according to common ideas or interpretations. This is a methodical search for overarching themes and relationships within codes. Higher-order constructs known as themes arise that encapsulate the core of the data according to the research goal.

Step 4. Themes Review

To verify consistency and relevance to the study topics, the identified themes are reevaluated and improved. In order to improve the thematic map and determine how well each theme represents the underlying data, this stage entails critically analyzing the links between codes and themes.

Step 5. Theme labelling and Defining

Every theme has a precise definition, and a label summarizing its main points is assigned. Creating accurate and insightful descriptions for every theme is the task at hand, with the goal of accurately capturing the context and content of the data.

Step 6. Final Report Production

All of the identified themes are included in the final thematic map that is created. The findings are summarized in the report, which also presents a narrative that highlights the links among the various themes. In order to support and highlight each theme, rich and illustrative excerpts from the interview data are merged, giving the analysis additional depth and context.

Result Characteristics

Following are the interview Characteristics

Table:1 Interview Characteristics

Respondent Code	Gender	Method
KZ_1	Male	Face to face
MQ_2	Male	Face to face
GF_3	Male	Face to face
MJK_4	Female	Face to face
WA_5	Male	Face to face
WS_6	Male	Face to face
RY_7	Female	Face to face
FP_8	Female	Face to face
KH_9	Male	Face to face
UM_10	Male	Face to face

3 Results

The following themes are formulated from factors from transcribed data. The themes are life cycle assessment for understanding environmental and social impact of technology, adaptability of digital health protocols in complex environment, barriers of stringent regulatory processes for technology implementation, and patient data security under future strategic mapping.

Theme 1: Life cycle assessment for understanding the environmental and social impact of technology

Subtheme 1.1: Thorough Assessment of Environmental Impact

"We must consider a technology's advantages beyond its immediate advantages. Ensuring the sustainability of a product or service requires a thorough life cycle analysis in order to make well-informed decisions. It's about the complete process, from idea to disposal, not simply the finished product‖ WA_5.

Subtheme 1.2: Life Cycle Assessment's Social and Ethical Aspects

―The impact that technology has on people's lives is more important than the technology itself. Are we making sure that these advancements are accessible to all? Do we honor the needs of the community and cultural values? These inquiries ought to be fundamental to our frameworks for assessment" MQ_2.

Theme 2: Adaptability of digital health protocols in complex environment

Subtheme 2.1: Resource Adaptation and Technological Infrastructure

"We need to design our digital health practices as a modular framework. Whether it's a modern hospital or a small, rural clinic with little resources, they should fit well in with the current infrastructure. Our technology's practical impact is determined by its adaptability‖ FP_8.

Subtheme 2.2: Cultural Sensitivity and User-Centric Design

―Ensuring that technology is useful and usable for those who use it is more important than simply owning the newest models. It is essential to be sensitive to cultural differences. If a digital health procedure doesn't align with the cultural norms and expectations of a group, it might not be successful in that demographic‖ MJK_4.

Theme 3: Barriers of stringent regulatory processes for technology implementation

Subtheme 3.1: The obstacles of Regulatory Compliance in Biomedical Innovation

"The regulatory environment can present significant challenges. There are other obstacles, including the protracted approval procedures and the ever-changing requirements. Not only must the requirements be met, but they must be met in a way that preserves the prompt supply of essential healthcare technologies" GF_3.

Subtheme 3.2: The Effects of Access and Innovation on Regulatory Barriers

"Regulations are necessary to ensure patient safety, but their strict procedures may unintentionally impede the adoption of novel solutions. This directly affects patient access, particularly in areas where prompt technology adoption can have a major influence on healthcare results" KZ_1.

Theme 4: Patient data security under future strategic mapping

Subtheme 4.1: Challenges to Data Security and Emerging Technologies

"The attack surface for possible breaches grows as AI and IoT are incorporated into healthcare. Given the changing nature of cyber threats, strategic mapping for patient data security needs to be proactive. It's important to anticipate and reduce hazards in the future in addition to implementing present precautions" MQ_2.

Subtheme 4.2: Privacy Concerns for Patients and Ethical Considerations in Strategic Mapping

―The essential values of patient autonomy and privacy shouldn't be jeopardized by strategic mapping. Strategic planning must include ethical frameworks as we navigate the protection of patient data in the future. Patients have to have confidence that their information is treated with the highest care and that their rights are respected‖ MJK_4.

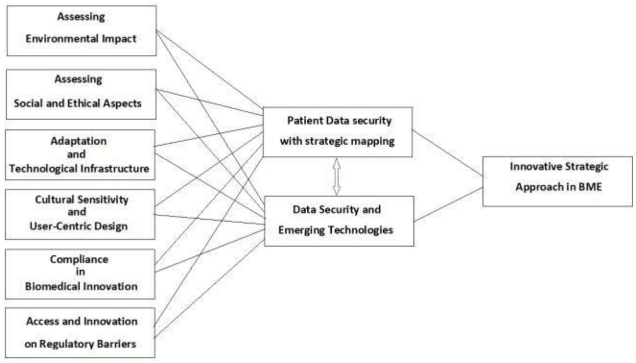

Figure 1: Sustainable Technology Management Protocol Model (STeMP Model)

Discussion

The importance of carrying out a thorough environmental impact analysis was emphasized by participants while discussing the life cycle assessment for biomedical innovations. The initial subtheme is concerned with measuring the environmental consequences of innovations, motivated by the necessity to comprehend their ecological impact. In order to assess the use of resources, environmental impact, and sustainability over the course of a technology's life cycle, participants stressed the significance of tools and frameworks. The field note highlights the need of taking into account a technology's complete lifecycle, from conception to disposal, and stresses the holistic approach. Environmental and social variables are interrelated, as evidenced by the second sub-theme, which centers on ethical and social factors in life cycle assessment. One important element that emerged was the adaptation of digital health procedures in complicated situations. The first subtheme explores resource adaptability and technology infrastructure, highlighting the necessity for adaptable solutions. Subtheme 2.1 clarified the significance of developing digital health procedures that blend well with various technology environments, guaranteeing optimal performance in a range of healthcare contexts. The focus of subtheme 2.2 is on cultural sensitivity and user-centric design, which highlights the adaptation of digital health protocols from a human perspective.

The difficulties in applying biomedical technologies due to strict regulatory procedures were brought up by the participants. The challenges of regulatory compliance are the subject of Subtheme 3.1, which clarifies matters like protracted approval processes and imprecise rules. Its field note highlights observations that highlight the difficulties healthcare organizations and technology developers have in meeting regulatory standards. The influence of regulatory constraints on innovation and access is examined in more detail in Subtheme 3.2. The viewpoint of the participant highlights the careful balancing act needed to guarantee safety through laws while cultivating an atmosphere that stimulates the prompt implementation of state-of-the-art technologies, particularly in areas where swift adoption could have a substantial influence on healthcare results. The Subtheme 4.1 of future strategic mapping addresses developing technologies and related security problems, and patient data protection emerged as a major theme. The necessity for proactive initiatives to address possible weaknesses is highlighted by field note insights, particularly as technology such as AI and IoT become more and more integrated into healthcare. Subtheme 4.2 explores patient privacy and ethical issues in strategic mapping, highlighting the significance of protecting patient rights. The field note emphasizes how important it is to incorporate standards of ethics into strategic planning, in order to guarantee patient confidence and trust when handling private health information.

4 Conclusions

In summary, this thorough investigation of the variables that influence sustainable technology management practices in biomedical engineering within the framework of Pakistan clarifies the various opportunities and difficulties that the healthcare industry faces. Purposive sampling and inductive reasoning were used in the qualitative methodology of the study, which explored issues including patient data protection, limitations posed by strict regulatory processes, adaptation of digital health protocols, and life cycle evaluation. The triangulation method and semi-structured interviews supplemented the thematic analysis, which provided deep insights into the viewpoints of biological field experts.

The results highlight how interdependent the impacting factors are, highlighting the necessity of approaching the creation and application of biomedical advances from a holistic perspective. Sustainable technology management necessitates balancing the effects on society and the environment, resolving regulatory issues, and making sure patient-centric methods are taken when using digital health technologies. Field notes from experts in the field—from bioethicists to regulatory affairs specialists—offer subtle insights that distil their knowledge and experiences. These results guide the creation of sustainable technology management protocols that are in line with the particular opportunities and challenges found in Pakistan's healthcare ecosystem, providing policymakers, researchers, and practitioners with an invaluable resource as the country's healthcare landscape changes.

Policy Implications

1. The optimization and streamlining of biomedical technology regulation procedures should be taken into consideration by policymakers. This can entail forming task groups or specialized regulatory bodies with the goal of accelerating approvals while upholding strict safety regulations. Efficient and transparent standards, along with regular assessments to guarantee their applicability and effectiveness, can help accelerate the adoption of cutting-edge technologies in the healthcare sector.

2. Academic, business, and healthcare institutions should collaborate transdisciplinary and be encouraged by policymakers. Initiatives that promote resource sharing, collaborative research, and information transfer can hasten the creation and application of sustainable biomedical technology. The ecosystem can be improved by developing funding channels that are especially meant to assist cooperative ventures and encouraging an open innovation culture.

3. As the use of digital health technologies grows, legislators ought to create and implement strict data security regulations. This entails working with cyber security specialists to create policies that safeguard patient data privacy and security while addressing new risks. These guidelines can be regularly reviewed and updated to stay up with the latest developments in technology and changing cyber threats.

4. By establishing specialized biomedical engineering innovation hubs and incubators, policymakers may promote innovation. These areas

can offer infrastructure, resources, and assistance to academics and companies developing sustainable biomedical technology. Fostering an entrepreneurial culture and advancing technological growth can be further enhanced by providing financial incentives, tax exemptions, and reduced administrative procedures to businesses involved in creative biomedical ventures.

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