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Collaborative Framework of Decision Support System using Co-PPGIS for Asset Management of Public Water Utilities of Lahore

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Abstract
The proficient management of public water utilities is vital for ensuring a sustainable and reliable water supply to urban populations. In Lahore, Pakistan, where swift urbanization and population growth pose significant challenges to water infrastructure, the implementation of a Co-PPGIS (Collaborative Public Participatory Geographic Information System) has emerged as a transformative approach for Water and Sanitation Agency (WASA). This study highlights the key features and benefits of a Co-PPGIS-based asset management system tailored to Lahore's public water utilities. The Co-PPGIS-based asset management system integrates geospatial technology, participatory mapping, and public engagement to enhance the decision-making process for water infrastructure management. Eventually, it will embark on the development of Collaborative Decision Support System (Co-DSS) with Geo-visualization, data analytics tool to engage general public. This approach facilitates real-time monitoring, maintenance priorities, and data-driven investment planning. Through this collaborative effort, the system helps public water utilities in Lahore optimize resource allocation, reduce water losses, and improve service quality, ultimately leading to a more resilient and sustainable urban water supply system. In conclusion, the Co-PPGIS-based asset management system offers a promising solution to address the challenges faced by public water utilities in Lahore, promoting efficient water resource management, infrastructure, sustainability, and citizen engagement.

Keywords– *Co-DSS, Co-PPGIS, Data Analytics Tools, Geo-spatial Technology, WASA*

1. Introduction

Public water utilities play a critical role in providing safe and reliable water supply services to urban and rural populations worldwide. Efficient management of water assets is essential to ensure the continuous delivery of high-quality water services to meet the increasing demand of growing urban areas. Lahore, the second-largest city in Pakistan, is no exception to the challenges faced by public water utilities in managing their assets effectively.

Traditional asset management systems often rely on static data and do not consider the dynamic nature of urban infrastructure, leading to inefficient allocation of resources and increased maintenance costs. The models of public control in democratic nations emphasize an increasingly vital function of society in decision-making processes (Healey, 1999). The participation of residents in those methods is described as public participation, the position of that is intently associated with the evolution of public control fashions and adjustments in society (Quick & Bryson, 2016). In recent years, there has been a growing interest in participatory geographic information systems (PPGIS) as a means to improve asset management and engage with the community in decision-making processes. The last couple decades of the Western and non-Western world has witnessed a growing interest in the participatory mapping approaches, implemented in quite a few fields of studies and practice (Nora Fagerholm, 2021). Participatory mapping now has become a global practice of students and practitioners, invested in its integrity, accuracy, record collection, and the equitable distribution of knowledge (The International Society of Participatory Mapping, 2020).

Public participation may be described as using various formal and casual instruments, permitting residents to offer their values, expectations, and choices to the authorities (Banyan, 2007). Citizen participation has been a part of land use making plans and decision-making for many years and has been applied in diverse ways (Arnstein, 1969; Jankowski, 2009). Variously labelled as, Participatory GIS (PGIS), Public Participation GIS (PPGIS), and Collaborative mapping those more modern tactics are context- and issue-pushed as opposed to technology-led and are seeking to emphasize network involvement within side the manufacturing and/or use of geographic information (Dunn, 2007). Applying PPGIS is anticipated to create data that make a contribution to decision-making tactics in various public and private sector organizations (Sini Kantola, 2023). It provides a collective effort to achieve goals in different phases or steps. Nowadays, land use making plans is interactive in many nations among participants (e.g. inhabitants, groups and land owners) and planners, and participatory strategies and equipment had been evolved and researched broadly (Bäcklund, 2017). This technique is in particular centered at the methodological and formal view of participation; however, public participation ought to be taken into consideration as citizens 'contributions to decision-making processes, primarily based totally on verbal exchange and dialogue (Bryson, Quick, Slotterback, & Crosby, 2013).

One of the assumed roles of PPGIS are to guide public participation now no longer simply in phases of the wide variety of stakeholders, However, mainly in phases of the effect on selection while making decision (Bąkowska-Waldmann & Kaczmarek, 2021). PPGIS mapping gives a cost-

effective technique to facilitate spatial selection making, permitting park businesses to prioritize destiny traveler control actions (I.D. Wolf, 2015). Similarly, PPGIS may be employed to manage resources and assets of water supply lines, pumping stations, disposal stations, etc. It greatly helps to locate and relocate assets while planning and making decisions are made to cope future challenges. Involvement of general public in management of assets can raise the trust level on public sector utility management like water utility. Public participation can revamp the acceptance level of public and popularity of decisions with spatial implications and alleviate worries of the network while changing their environment (Christopher M. Raymond a e, 2009).

This research paper explores the potential of a co-PPGIS-based asset management system for public water utilities in Lahore. The study aims to evaluate the effectiveness of integrating PPGIS with the existing asset management framework, with a particular focus on enhancing community engagement and data accuracy. Collaborative geospatial decision support systems (C-GDSS) can be the effective tool to do justice in any institution, by keeping democratic framework and resource allocation (Bailey, 2010). The concept of collaborative geographical information system, computer-supported cooperative work (CSCW), and collaborative decision support systems (Co-DSS) turned into a spatial information using technology to offer understanding pertaining to spatial implications and offer computer-based spatial decision-making (Armstrong MP., 1993). CSCW tools has ended up more vital for the assist of real-time map sharing output. Accordingly, the development of map-based applications for real-time collaborative is one powerful step taken via way of means of researchers who're successfully operating in lots of fields, e.g. urban planning, emergency management system, municipality management, GIS data production, tracking of urban sprawl and epidemic spread trend, and lots of more that assimilate collaborative role (Al-Kodmany K., 2002) (Brail RK, 2001) (Klosterman RE, 2001).

The paper instigates by providing an overview of the current challenges faced by public water utilities in Lahore in managing their assets efficiently. It then introduces the concept of Co-PPGIS and its relevance in the context of asset management. Studies discussed above revealed their applications in tourism and municipality in general using PPGIS technology. This study introduced comparatively new aspect of Collaborative Public Participatory GIS in asset management of WASA (Water and Sanitation Authority) Lahore. The whole idea behind this research is enhance public interest and engagement to improve the quality of service delivery eventually, to alleviate trust deficit on public sector institution. The methodology section outlines the research approach, data collection methods, and analysis techniques used in the study. The findings of the research are presented, followed by a discussion of the implications and recommendations for implementing a co-PPGIS-based asset management system in Lahore.

By examining the potential benefits and challenges of such a system, this research paper contributes to the ongoing discourse on improving the sustainability and performance of public water utilities in Lahore and serves as a valuable reference for other cities facing similar challenges in asset management.

2. Existing Public Level Engagement in Planning and Decision Making

To stay updated with public demand and impart quality water supply and sanitation service, there should be seamless planning and decision making at managerial level. Public involvement in resolving urban planning process has been pivotal importance for last decade which enables to make sustainable decision making (Kingston, 2007). It will strengthen and trustworthy the whole decision making process for customers. Because public participation enhance not only the collaborative role in decision making (Goodspeed, 2008). Currently, WASA is relying on printed and electronic media to disseminate information for engaging public to communicate key messages and through their toll free numbers keeping themselves in jurisdiction notified by the Provincial Government.

Moreover, most resource being utilized for communication bank on one-way communication or indirect two-way communication. For efficient public participation, there should be two-way communication process which usually involves sending messages to public first and get their concerns and proposition back in context of information (Godschalk, 1994). Traditional methods to engage general public are shown in Table 1 (Goodspeed, 2008)

Table 1: Pros and Cons of Current Public Participation Platforms

Method	Description	Pros	Cons
Printed/Electronic Media	Television, Radio, Newspaper, News Press Release	Information in real-time	No response or communication from the general public
Public Hearings	Authorized Personnel publicize news and reports	It is an open call for general public to join and share their opinion	Narrow approach to reach out public
Workshop	Expensive option for engaging the public	Two-way communication	A limited public can join

3. Research Objectives

Following study will be focusing on the objectives stated below:

- To assess the current state of asset management in public water utilities.
- To propose a conceptual and architectural model Co-PPGIS based Collaborative Decision Support System (Co-DSS)
- To evaluate the effectiveness of Co-PPGIS in enhancing asset management in Co-DSS.
- To identify challenges and opportunities in implementing Co-PPGIS for asset management in public water utilities.

4. Materials and Methods

Above objectives can be achieved through following headings:

1. Study Area

Lahore is located in the eastern a part of Punjab province with spatial role 31°32'59"N and 74°20'37"E as shown on this Figure 1. Land in Lahore district contains over undeniable region and bounded fertile alluvial plains. Lahore has 2.17 million population in 1971 which has prolonged as much as 9.75 million in 2014 with an immense jump of 350% in step with cent. This big increment was hindering to fulfill the needs of denizen. Built up region blanketed 103.42 Km^2 in 1972 which has extended to 1772.53 Km^2 in 2012 with an addition of 1613% in step with cent on this span. Such a speedy increase in land cover has unfavorable impacts of weather accordingly. So the needs for residential constructing and administrative functions has also enhanced in outer region in particular in Southeast of Lahore. (Shirazi, 2014).

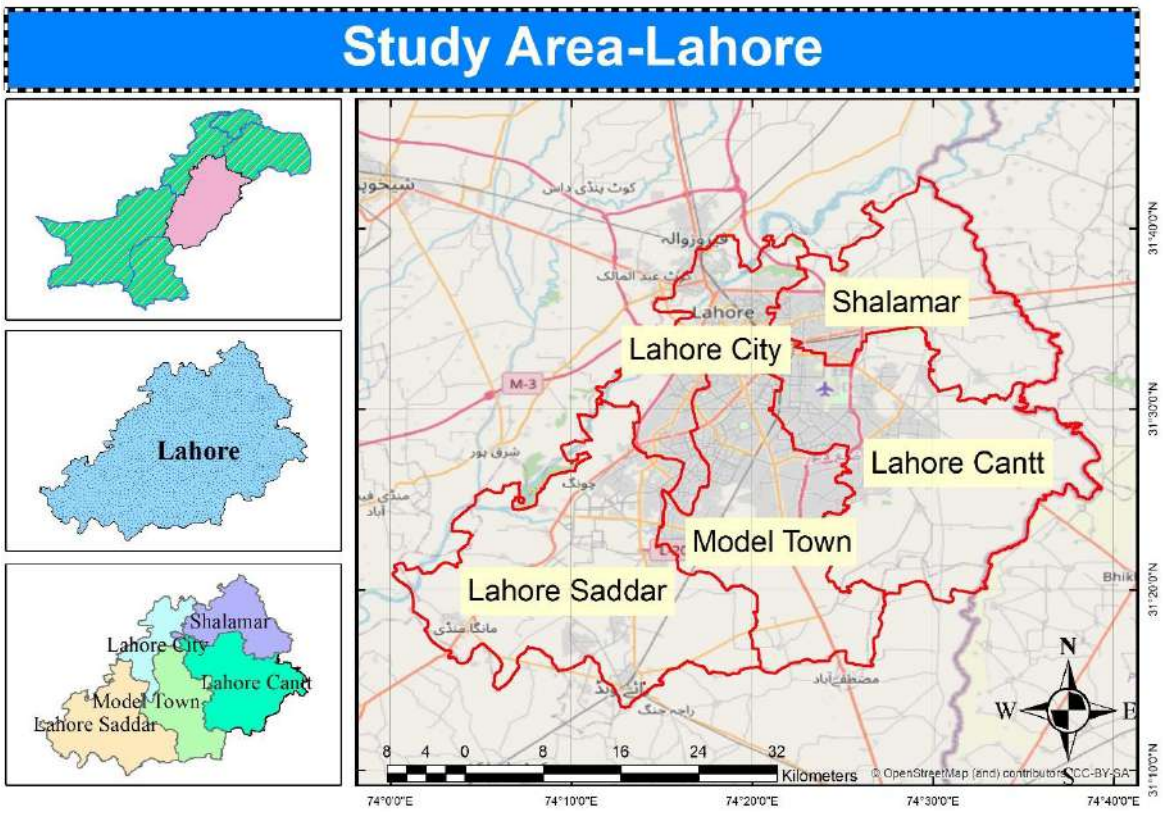

Figure 1: Study Area Lahore, Pakistan

2. Data Collection

Data collection entails collection of current maps and area water supply lines, sewage and drainage station. In Lahore, Water and Sanitation Agency (WASA) is accountable to run and keep those utilities. Currently, there are 316 tube wells which can be used for water delivery. Pipe lines' period 3"-20" diameter is 3200 Km in the complete city. Tube wells are generating 329 MGD (Million Gallons in step with Day) in well-described hours of the clock. From this water, approximately 4.11 M customers are getting advantages out yet. This huge community may be

participation in decision making and wellbeing of themselves. Cantonment, Defense Housing Authority (DHA), Model, Railway Colonies and GORs are excluded from the WASA service area. (Irwansyah, 2013).

As for as sewerage assets are concerned, 11 major pumping stations are owned and run at a key area in the city. The pumping capacity of the stations is around 2456 Cusec. Lift station are 61 at different region in every town. Sewers length is 3610 Km that is getting used at present serving approximately 80% of the whole population. Total drain's length in Lahore is 180 Km constituting 8 primary drains wherein 76 tributaries drain is feeding the primary drain. The general potential of those drains is set 6474 Cusec. Pumping stations used for drainage are 4 for consistent flow draining process (WASA, 2023) as shown in the Table 2 as follow.

Table-2 Major Assets Details

1	Number of tube wells	316
2	Pipe lines' length 3"-20" dia	3,200 Km
3	Major pump stations	11
4	Lift stations	61
5	Sewers length	3610 Km
6	Drainage pumping stations	4

Source: WASA Lahore

4.2.1 Spatial and Non-Spatial Database Preparation

Secondary data pertaining to assets have been collected from WASA. This data was subjected from software ARC GIS 10.4 in order to prepare datasets of all types assets in terms of point, line or polygon. Likewise, tube well, aquifer, pumping stations etc. data layers are represented by points as per their spatial presence in real world. Dataset of each assets was then lead to Geo-database where non-spatial data (attribute) are joined. Database of pumping stations is shown in the Table 3 which elaborate the attribute of various pumping stations situated in different towns and subdivisions of Lahore.

Total_Capa	Type	Name	Town	Sub_Divisi	No_of_Pum	Make	Generators	Feed	Transforme
75 CFS	Disposal Station	Chotta Ravi	Gunj Bakhsh Town	Ravi Road	6	1 Horizontal, 5	NILL	1	200 KVA
14 CFS	Lift Station	S Block	Nishter Town	Township	2	2 Horizontal	NILL	1	100 KVA
125 CFS	Disposal Station	LMP	Nishter Town	Township	6	2 Horizontal, 4	1000 KVA	2	1260 KVA
83 CFS	Disposal Station	Sattukatla	Nishter Town	Township	4	2 Horizontal, 2	500 KVA	1	430 KVA
103 CFS	Disposal Station	Tajpura	Aziz Bhatti Town	Tajpura	6	Vertical and Hc	2	2	2
55 CFS	Lift Station	B-Block	Aziz Bhatti Town	Tajpura	5	Vertical and Hc	2000 KVA	1	1
12 CFS	Disposal Station	Joray Pull	Aziz Bhatti Town	Tajpura	2	Horizontal	1000 KVA	1	1
12 CFS	Lift Station	Taj Bagh	Aziz Bhatti Town	Tajpura	2	Vertical and Hc	NILL	1	1
12CFS	Lift Station	Ghazi Mohalla	Gulberg Town	Shimla Hill	3	KSB/Horizontal	200 KVA	1	100 KVA
6 CFS	Lift Station	Mohammad Na	Gulberg Town	Shimla Hill	1	KSB/Horizontal	200 KVA	1	100 KVA
12 CFS	Lift Station	Larex Colony	Gulberg Town	Shimla Hill	3	KSB/Horizontal	200 KVA	1	100 KVA
40 CFS	Disposal Station	Bird Market	Gulberg Town	Shimla Hill	3	Submersible	300 KVA	1	200 KVA

Table 3: Attribute Data of Pumping Stations (WASA Lahore)

4.2.2 Online Survey for PPGIS Data Collection

To design a framework like Collaborative PPGIS that enables Water and Sanitation service users to participate and become an integral part of it has been a challenging for implementation side. The challenges with the usage of PPGIS is that information mostly held at the extent of data collection without deeper and concrete use of it (Sini Kantola, 2023). In this regard, online survey method to gather data is a cost effective, efficient and trustworthy way in connection to Co-PPGIS concept implementation. This will surely define the extent of data collection with ease and real-time. Online PPGIS surveys had been applied all over the world (M. Kahila-Tani et al., 2019) Online map surveys are designed by numerous companies or they can be got from distinct organizations with various tools of data collection, Surveys and Crowdsourcing, and mapping and data management (International Society for Participatory Mapping, 2023). The idea behind the online survey is to collect data from respondent regarding PPGIS survey without visiting door to door or any specific target place and time. PPGIS surveys may include open ended, structured, multiple choice questions or opt to ratings of claims. This information will then be subjected through GIS environment which will show these responses on map in form of point or drawing line or polygon on that particular assets. Respondent may provide extra information regarding marked location on map banking on the type of information.

3. Conceptual Frame Work

To realize the data into Co-PPGIS environment, it is necessary to draw a conceptual frame work which will ensure how the data is fed into the system shown in Figure 2. It may help developers to design a web application from scratch. Frame work provide basic architecture of application and give insight about the possible tools and functions need to meet the objective of applications.

4. Community Response Integration with Asset's Geospatial Data:

- **Geospatial Information of Assets:** Geospatial data pertaining to assets gathered and maintained accurate information about the water utility's infrastructure including pipelines, water pumps, valves, filtration plants, disposal stations, manholes and waste water treatment plants as shown in the Figure 4. All this activity was managed in ARC GIS 10.7.1 software which was enabled enough to subject spatial data to multiple tools for better Geo-visualization. It results a dataset of assets which feeds into a geo-database. Spatial data structure comprises over various spatial entities and spatial index (Su, Liu, & Wu, 2008). Spatial entities is an geographical model, comprising point, line and polygon (Booth, Everman, Kuo, Sprague, & Murphy, 2011). It is then fed into geo-database in the form of datasets of WASA assets. In the context of geo-database, datasets are of vital standing to all succeeding evaluation and calculations, it is very significant to develop a database structure to establish, store, recover and analyze data through DSS design and development (Staudenrauch & Flügel, 2001). To build relational database (RDB), there are plenty of choices to be made like MS Access, Oracle and other database management software (Ahmad, Azhar, & Lukauskis, 2004). In this study, MS Access has been employed

to deal datasets of assets and store and manage data. Hence, Database is developed and all the spatial data of assets is stored to interact with public and decision makers.

- **Non-Spatial Data of Assets:** After fetching geospatial data, such as maps, spatial data into GIS environment, attributes of the all the assets were acquired from WASA which were elaborated in Table 1. Existing system of WASA managed this data in Excel and handed over to each divisions in hard forms.
- **Community Real-time Response:** Online forms, a state of the art survey technique will be applying to collect data related to community preferences, concerns, and needs which will ultimately be embedded in Co-PPGIS web based application. It will be integrated into Co-DSS real-time map sharing mechanism.
- **Integration of Data into Co-PPGIS Environment:**

A web based application having all the required tools necessary for Collaboration and Public Participation in the context of current study will be designed and developed under the conceptual framework of Co-PPGIS shown in the Figure 3. It will also be a platform where real-time data captured from consumers of water and sanitation services can share their views and suggestions. Community under the WASA jurisdiction may also interact directly to planning and decision making personnel to incorporate their proposition. Later on, public data gathered through online source is integrated with spatial data in Co-PPGIS framework. Latest improvements in GIS technology enable the smooth assimilation of GIS and computer-based DSS (Ahmad & Simonovic, 2006) (Park, et al., 2011)

5. Design and Development of Co-PPGIS

The prosperity of growing and organizing a geospatial-enabled Co-PPGIS, for boosting the capacity of human participation in collaborative decision-making for the duration of control workflows and plans in water supply and sanitation sector especially should be an integral part. It offers participation of network on the time of municipal development, making plans, and management, and 2nd vital subject is on useful and nonfunctional necessities that are diagnosed with the aid of using present PPGIS and which might be associated to investigate models, which might be developed for the duration of municipality control to assist public participatory tactics. (Muhammad Atif Butt, 2018). It begins with an evidence and evaluation of a Co-PPGIS concept, which executes the function of a real-time synchronous and asynchronous participatory method to assist the decision-makers to make selections in assimilating the function of humans on the time of a water supply and sanitation related plans process. It also enables authorities to locate assets and plans to relocate resource in a better geo-visualization on web map services developed for Co-PPGIS. For the development of web application, HTML, CSS, Javascript/Python may be proved the best languages in this regard along with map handling APIs.

6. Collaborative Decision Support System (Co-DSS) Development and Implementation

The idea of development of Decision Support System was initiated in the 1970s when it was put forward a computerized system to address structured or semi-structured problems aroused in any institutional level (Gorry & Morton, 1971) (Mysiak, Giupponi, & Rosato, 2005). Decision Support System has also played key role in water and resource management. Various DSS has

been carved out like SWQAT (Sharma, Naidu, & Sargaonkar, 2013), Elbe-DSS (Lautenbach, Berlekamp, Seppelt, & M., 2009), MULINO Decision Support System (Fassio, Giupponi, Hiederer, & Simota, 2005), WaterWare (Jamieson & Fedra, 1996) and RiverSpill (Samuels, Amstutz, Bahadur, & Pickus, 2006) in the field of water quality and river water management. In this study, Co-DSS will incorporate all the elements that are core parts of decision making process like Graphical User Interface (GUI), Geo-visualization map view, editing tools, geo-tagging facility, and data analytics modules which enables personnel of WASA to locate desired assets and help to make decisions evidence based instead of just paper work.

5. Results and Discussions

The following section will elaborate the results generated during the above explained methodology in the context of the current study.

5.1 Design of Conceptual Collaborative Public Participatory Framework

Conceptual framework of any system is as important as design and implementation of application as it disseminate scope of work to be done and compelled to be within domain of objectives. Following framework exhibits how stakeholders interact among themselves.

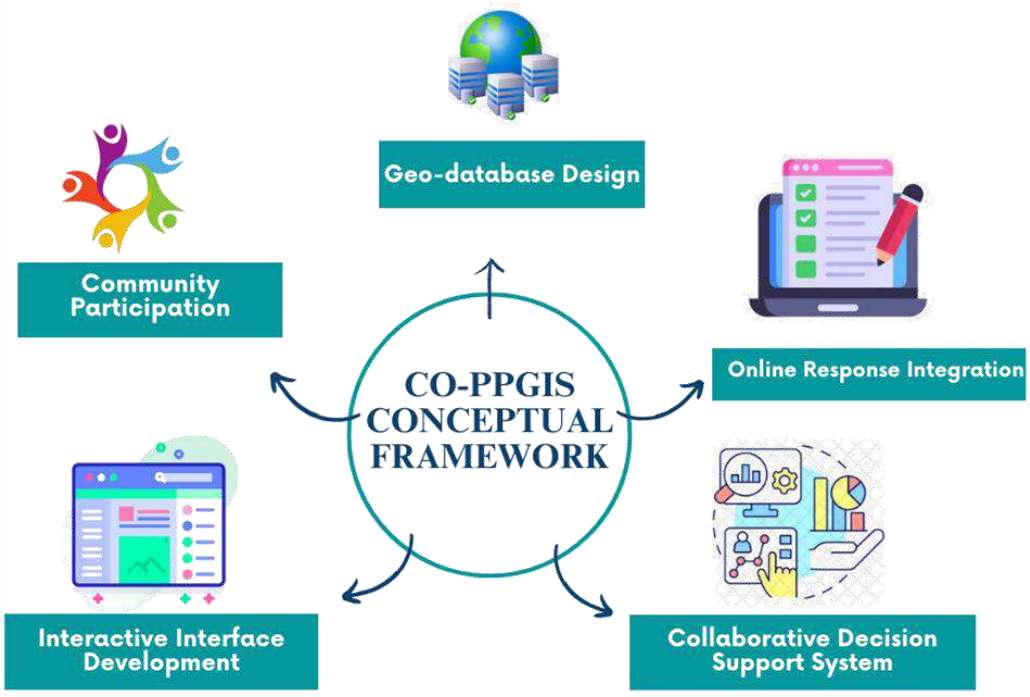

Figure 2: Conceptual Framework of Co-PPGIS for Water Utility

Conceptual Framework of Co-PPGIS devised for water supply and sanitation shown in the Figure 2 has laid the foundation stone for development of Co-DSS. It exhibits the key elements to be employed in the development of PPGIS based framework. Geodatabase Design phase marks the beginning of the journey of application design which includes collection of spatial and non-spatial data and further embedded into Geodatabase. This phase is the backbone of the whole activities

that are to be carried out in later part of the framework. Later on, public participatory carrying facility web application is developed to cater public opinions with the integration of online survey polls. The application enables decision makers to have integrated view of both public and WASA assets spatial information. It also provides tool box to conducts spatial analysis on the data and exports these results for ready references to make it evidence based planning and decision making. Hence, this framework has proved valuable for stepping into the designing phase of application.

5.2 Geospatial Distribution of Assets of WASA

This section involves the bird's eye of assets distribution in various town of district Lahore. Upper left window of Figure 3 represent locations of disposal stations distributed predominantly in Lahore city and Shalimar town.

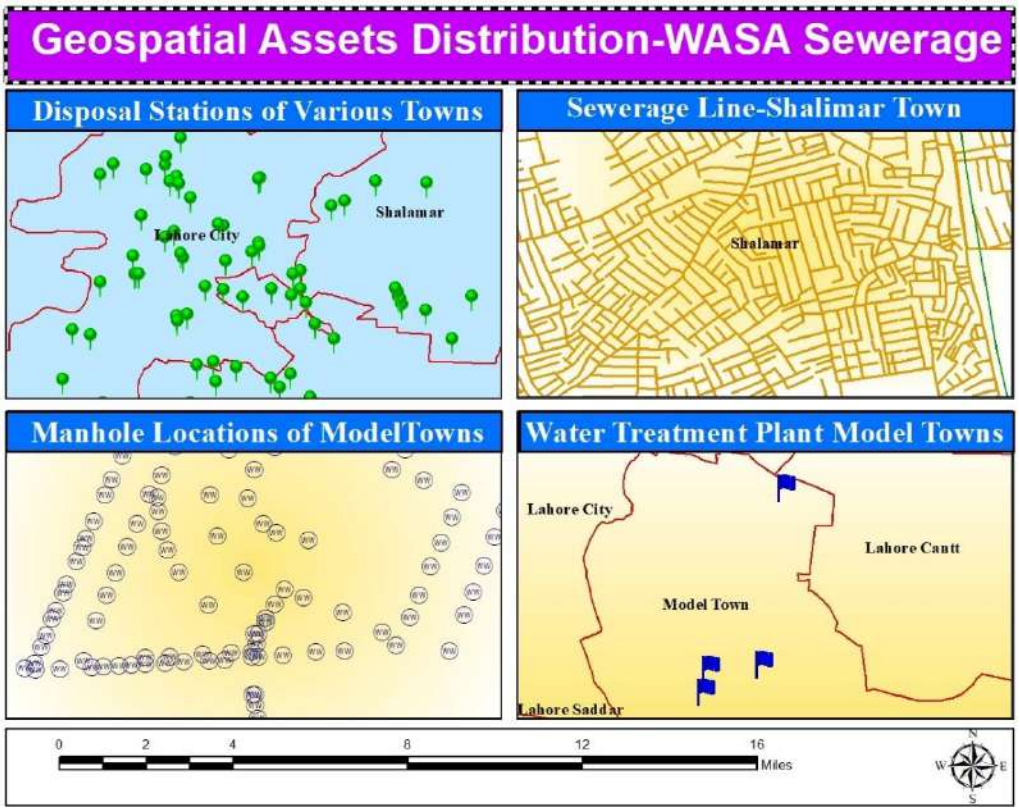

Figure 3: Geospatial Distribution of WASA assets in various Towns of Lahore

Dataset of Sewerage line interconnected and laid in the city shown in the upper right map window. Lower left window of map shows the locations of manhole spread over different towns or tehsils. Geospatial information of water treatment plants marked in the lower left map. Consequently, from these map views, one can take a quick look of assets spatial distribution on which collaborative decision support system to be applied.

5.3 Architecture of Collaborative Decision Support System (Co-DSS)

Architecture modelling approach in development of Co-DSS will be elaborated in this

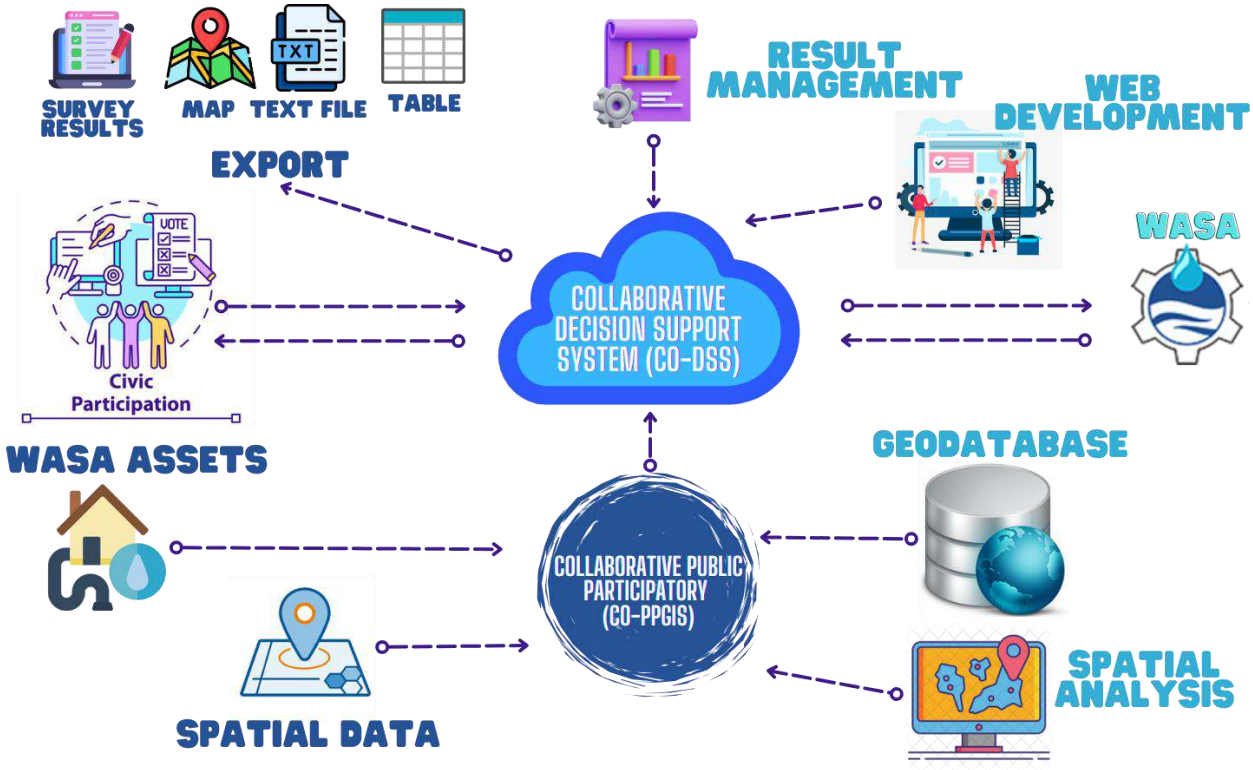

Figure 4: Collaborative Decision Support System Architecture of WASA Co-PPGIS

particular section of the study. To realize these objectives, Figure 4 explains the overall activities which are involved in Co-DSS designing, development and participation of public. This framework is divided into two major parts, first part consists of Co-PPGIS development and second part involves the development of Co-DSS which offer a platform to interact public and personnel from the WASA authority. Co-DSS is an interactive way which offers communication services between general public and decision makers. When discussing the significance of consultation process results, it's crucial to consider the representativeness of participants (Tulloch & Shapiro, 2013) (Bryson, 2004). It also facilitates participants to exports data analytics outcomes and results into desired format and predefined layout for maps. Consequently, it helps to understand the system thoroughly and provide a fundamental architecture that marks the beginning of development and implement phase of web application.

5.4 Collaborative Decision Support System Interface

A web based application catering all the functionalities and tools are developed to overcome the lapse in planning and management of assets. Interactive visualization of the application is shown in the figure 5 which depicts the spatial distribution of tube wells.

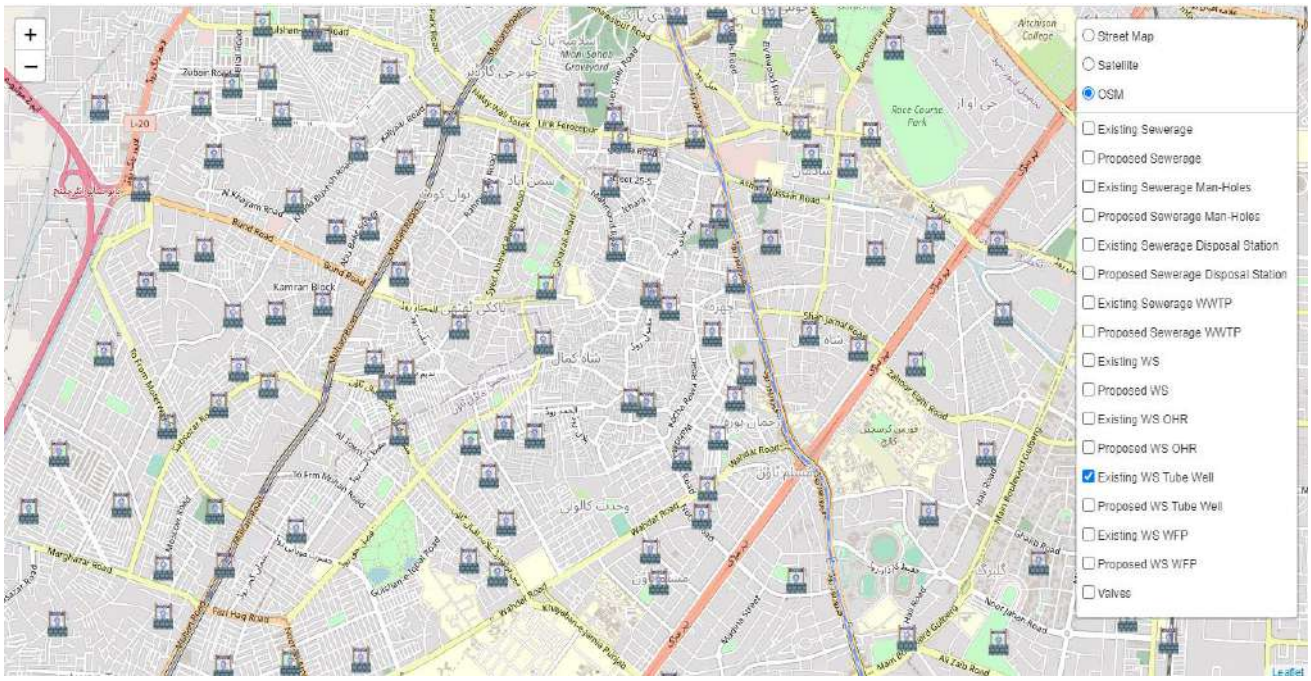

Figure 5: Collaborative Decision Support System Interface with Tube Well Location

This application also incorporates the layers of other assets of WASA like Manhole, Sewerage Network, water treatment plants etc. This interface offers a geo-visualization and tools to drill down the information with ease and plan proposed location to spread network for future concerns.

6. Concluding Remarks

This research paper has shed light on the significance of integrating Collaborative Public Participatory Geographic Information Systems (Co-PPGIS) into the asset management of public water utilities in Lahore, Pakistan. It is evident that traditional asset management systems often fall short in addressing the dynamic nature of urban infrastructure, leading to resource allocation inefficiencies and increased maintenance costs. The participatory mapping approaches, such as PPGIS, have gained global recognition as powerful tools for enhancing asset management while engaging communities in the decision-making processes.

Public participation has the potential to revamp public sector utility management, improve the acceptance level of decisions with spatial implications, and alleviate community concerns about changes in their environment. By introducing a Co-PPGIS-based asset management system, this

study aims to enhance community engagement, data accuracy, and ultimately, the quality of public water services in Lahore.

Through an in-depth examination of the challenges faced by public water utilities and the current methods of public engagement in decision-making, the study has established a strong rationale for the adoption of Co-PPGIS. It is evident that the current methods of public engagement, such as printed and electronic media, public hearings, and workshops, lack the interactivity and real-time capabilities required for effective participation.

The research objectives have been clearly defined, encompassing the assessment of the current state of asset management, the proposal of a Co-PPGIS-based Collaborative Decision Support System (Co-DSS), the evaluation of Co-PPGIS effectiveness, and the identification of challenges and opportunities in implementing Co-PPGIS for asset management in public water utilities.

The materials and methods section outlines the data collection process, including the creation of spatial and non-spatial databases and online surveys for PPGIS data collection. The conceptual framework for Co-PPGIS provides a comprehensive view of how stakeholders interact in the system, ensuring that the objectives are met and all essential components are incorporated into the application.

The geospatial distribution of assets in Lahore showcases the extensive network of water supply and sanitation infrastructure, setting the stage for the Co-DSS implementation. The architecture of Co-DSS has been explained, illustrating its interactive nature, which facilitates communication between the public and decision-makers and empowers participants to export data analytics results.

In essence, the study has presented a promising framework for enhancing public water utility asset management through the incorporation of Co-PPGIS and Co-DSS. This research contributes to the ongoing discourse on improving the sustainability and performance of public water utilities in Lahore and serves as a valuable reference for other cities grappling with similar asset management challenges.

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Data Availability declaration

There is no data available which is associated with this study.

Conflict of Interest

The authors declare no conflict of interest pertaining to this particular study.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors did not use any tool or service based on AI and AI-assisted technologies.

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