GISWaterMap: Drinking Water Mapping with Decision Support System

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ABSTRACT: Water quality and assessments, being the primordial health need of a person have attracted many researchers across the globe. This study focused on mapping of drinking water thru GIS, and its assessment as a primary input to yield an inhibiting factor to evidence-based decision making. The study will be utilizing the software development method and descriptive research design wherein data collection, data analysis and system development using Design Science Research (DSR) model and integrate GIS tools. Concerned LGU personnel and members of the community households whether owner or recipient of sources of drinking water was surveyed and interviewed to elicit problems and issues. The assessment of the developed system to its extent of compliance to ISO 25010:2011 software quality characteristics will be obtained through a validated 5-point Likert survey questionnaire among 10 IT experts. ISO 25023:2016 was also used to measure the usability acceptance level of the system assessed by the users. Drinking water maps obtained from GIS-based results will be beneficial providing meaningful and reliable information to governing bodies to unveil facts on the status of sources of drinking water as well as to address the necessity of effectively monitoring, managing, and operation in ensuring the quality of water. It will further be adopted by decision-makers to implement strategies and will serve as a decision-support tool akin to health risks for reconsidering surveillance of drinking water resources in Aparri, Cagayan, Philippines towards sustainability.

KEYWORDS: drinking water, Decision Support System, Design Science Research, GIS, health risks

I. INTRODUCTION

Water quality and assessments, being the primordial health need of a person, have attracted many researchers across the globe. The harmonized National Research Agenda (2017-2022), one of its priority areas and programs includes water security (water quality) which geared towards an output: water quality assessment for policy per geographical area [1]. In the Philippines, being a developing country, records of the water.org, showed that out of 105 million Filipinos, nearly seven million rely on unimproved, unsafe and unsustainable water sources and more than 24 million lack access to improved sanitation and it appears that nationally the MDG of 86.6 percent of the population [2].

Provision of quality drinking water in adequate quantity and quality is a primary national and international concern. MDG met its target relating to access to safe drinking-water. An increase of 14% from 90% of the population in 2012 used an improved source of drinking-water compared with 76% in 1990 [3]. United Nations Development Programme (UNDP) set the 17 Sustainable Development Goals (SDGs) including Goal 6: Ensure Access to Water and Sanitation for All [4]. The Regional Development Council (RDC) review focused in terms of consistency with and responsiveness to the desired development outcomes and strategies as enunciated in the Regional Development Plan 2017-2022. Approved budgets for 2019 include Department of the Interior and Local Government (DILG) - Php446.255 million. DILG's proposed budget was allocated for expenditures in its programs that will implement the provision of potable water supply to poor and waterless communities thru its Sagana at Ligtas na Tubig Program [5]. The Regional Department of the Interior and Local Government (DILG) monitor's government's funded projects cascaded to LGU's, especially to disadvantaged municipalities, addressing the pressing challenges brought about by unsafe potable water. And according to the Regional Director Jonathan Paul M. Leusen Jr, most challenging projects under Locally-Funded Projects is the implementation of the water system [6]. Also the National Water Resource Board (NWRB) Listahang Tubig (Water Register) program, United States Agency for International Development (USAID)-Be secure (Water Security for Resilient

Economic Growth and Stability) has committed to conduct the survey in 6 focus provinces: **Cagayan**, Iloilo, Leyte, Misamis Oriental, Maguindanao and Basilan [7].

Unfortunately, it is becoming more difficult to provide quality drinking water to the rapidly expanding human population thus, increasing pollution making it toxic for the consumption of the water consumers. Water pollution has very negative effects that are regarded as detrimental to public health that it should never be compromised. The issues associated with water quality and health can be seen in the study of Aryal, J., et. al (2012), it was concluded that coliform contamination, a microbiological analysis, to be a major problem with drinking water. He further says that morbidity and mortality rates from water-borne diseases are considered high particularity among Children below the age of five. Water pollution is the most serious public health issues. He also stated that, it was recently proven to be the biggest health threat worldwide, that every person has the right to be informed [8]. According to United Nations Development Program (UNDP), one of the 10 facts and figures it stated is, each day nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases. A report of Morbidity and Mortality Weekly Report (MMWR), during 2013–2014, a total of 42 drinking water–associated outbreaks were reported to Centers for Disease Control and Prevention (CDC), resulting in at least 1,006 cases of illness, 124 hospitalizations, and 13 deaths [9]. In the region, it is important to note that the DOH statistical report on water-borne diseases significantly increased to 20.57% as of 2018 compared to 2017, from 1123 to 1354 cases of acute bloody diarrhea [10]. And in Aparri, water-borne diseases ranked 5th and 6th from the ten leading causes of mortality and morbidity cases respectively [11].

To address this, the widest dissemination of information and strict implementation on efficient monitoring of drinking water through technological advancements could be made. Thus, GIS-based mapping on drinking water with decision-support system is timely and must be developed to support the assessment of drinking water in Aparri as its primary input and in terms of its pathogen attributes by consolidating available datasets under a relational database, facilitating data entry and simple decision-making algorithm, offering easy access to raw data, and providing processed results or generated reports.

II.   OBJECTIVES

General Objectives:

This study focused on mapping of drinking water, and its assessment as a primary input to yield an inhibiting factor to evidence-based decision making in Aparri to be integrated into the design, development, and implementation of a Geographic Information System with a decision support system.

Specific Objectives:

Specifically, this study aims to provide answers to the following problems:

1. What are the problems and issues encountered in the practices/processes, and management of the quality of water in Aparri, Cagayan?

2. What proposed system can be developed to address the identified problems and issues?

3. What is the level of compliance of the developed system to ISO 25010:2011 software quality standards as assessed by the experts and end-users in terms of software characteristics?

4. What is the usability acceptance level of the developed application to ISO 25010 Software Quality Standards as assessed by the IT expert and Users?

5. What enhancement can be done to improve the developed system?

III.   METHODOLOGY

A. Research Design

The study utilized the Design Science Research (DSR) for Information Systems (IS) following the six steps which identify a problem and motivate, define objectives of a solution, design, and development, demonstration, evaluation, and communication. It involves a rigorous process to design artifacts to solve observed problems, to make research contributions, to evaluate the designs, and to communicate the results to appropriate audiences.

The application was composed of the user interface, GIS-based management system, the geographical information system, and the decision-support system. The geographical information system in the proposed system will project the virtual representation of the locale in a map form. The map will show the geographical location, type of source, water quality status and possible illnesses/diseases in the area. The Decision Support System shows statistics of

the occurrences of water contaminants through a trend or graphical form that could be easily understood by the system administrators and users. Showing the statistics from the database will be useful in the formulation of policies and appropriate decisions regarding drinking water, monitoring, and management in risk mitigation, and its sustainable development. The overall functionality of the system enables the users to add, edit, delete, search and print records.

In its development, XAMPP, CSS3, and HTML5 were used. In the unit testing stage, the developed system was tested in major web browsers. Google Maps API was mainly used to run dynamically maps embedded in the system.

B. Participants

The participants were delineated according to their role in the study. The first sets were the households in the community who owns or recipient of the different sources of drinking water within the pilot study area, and LGU personnel and barangay officials for management-level issues and documentary analysis involved in the determination of problems, issues, and challenges in the monitoring of drinking water. The other set were the respondents for the post-survey, system's assessment, and was categorized into two groups namely (a) the group of experts, composed of IT experts and (b) the end-users of the system composed of the LGU-MHU specifically the Sanitary Inspector and its staff, the barangay captains, and Barangay Health Workers in the pilot study a of Aparri.

C. Measures

The researcher used interview guides in identifying the problems and issues. Results from the interview were used to identify the features and functionality of the system.

Likewise, the questionnaire was also used to gather the effectiveness of the system. IT experts assessed the system in compliance with ISO 25010:2011 Software Characteristics standards while the users assessed the usability acceptance level of the developed system using the ISO 25023:2016 Measure of Usability.

D. Procedure

Formal communications will be extended to concerned agencies. The researcher went to the Municipal Hall-Aparri for approval from the Mayor to conduct, and redirected to the concerned office. An intensive interview was done to elicit problems and issues on monitoring of drinking water. The researcher repeatedly did the same way as data is needed for validation and clarification until the completion of the system's features and functionality.

For the assessment of the developed system, the questionnaires were distributed to the experts and end-users to evaluate the system in terms of satisfaction and acceptability. In assessing the system, the study took into consideration the suggestions of the experts with the viability of the system.

The information gathered was subjected to data treatment. The responses obtained via the quantitative and qualitative devices were categorized, organized, analyzed and interpreted.

E. Data analysis

a. **Thematic Analysis.** This was used to analyze data by examining and recording patterns of themes within the data. Themes are patterns across data sets that are important to the description of a phenomenon and are associated with a specific research question. The identification of the common pattern of the statement will be identified in the study by commonalities of ideas.

b. **Weighted Mean**. This was used to analyze the extent of compliance to ISO 25010:2011 of the developed GIS-based Mapping of Drinking Water with Decision Support System in Aparri. The extent of compliance of the system 5-used point Likert scale.

IV.   RESULTS AND DISCUSSION

A. Current practices/processes, and management involved in monitoring drinking water resources.

The current practices/processes, and management in the monitoring of drinking water resources in terms of its quality for the consumption of the community is presented in the foregoing paragraphs. From the interview conducted, the following were the issues and problems noted:

1. The monitoring of drinking water sources carried out by the Sanitary Inspector cascaded to the barangay health workers was conducted by taking a survey categorizing into different types of water sources, the number of households, and populations served. The results was written in loose sheets. These were consolidated and generated for reporting purposes in printed loose sheets and in a bulletin board.

2. Water refilling stations were regularly subjected for laboratory testing. The Sanitary Inspector reached out to Purified Water refilling stations; get a sample with its corresponding fees for testing in an accredited laboratory. He also evaluates the laboratory results if it has complied with the standards and conducts regular or immediate sanitary survey during the existence of a potential cause of contamination. Thus, it is in conformance to the mandate to continue providing capacity building programs and technical assistance to WSPs on water and sanitation. The United Nations Development Plan (UNDP) sets the 17 Sustainable Development Goals (SDGs) including Goal 6: Ensure Access to Water and Sanitation for All. The results were just kept in a filing cabinet. There was no pronouncements of issues on the quality of drinking water in the locality and no releasing of necessary corresponding advisories. The water consumers generally acknowledged that water from water refilling stations has always been microbiologically tested and free from contaminants.

3. The water sample laboratory testing was only done to purified water refilling stations. All other water sources, home wells (shallow pump well and open dug well), were not tested and no assessment mechanism was applied. Water consumers using this type had a notion that they were "used to it" without checking and testing for safe consumption. This is a non-compliance with the SDG Goal 6: Ensure Access to Water and Sanitation for all; national strategies cascaded to the LGU to monitor potable water supply of selected poor communities through Tap Watch Program; and complete the groundwater resource inventory/assessment in major urban areas and surface water in rural areas. Thus, the Sanitary Inspector convinces owners/recipients to do some laboratory testing but it was not prioritized due to financial constraints though they are willing to undergo such process. Despite the fact that, owners/recipients may request for disinfection-by-products like Chlorine from the Municipal Health Unit.

4. The LGU provided pump wells to different barangays but there was no regular and strict observance of remedial technical measures to correct the deficiency of the water system. Hence, it is not in compliance with the law mandated such as the sharing of responsibility of providing local quality drinking water service among local government units. Specifically, Sec. 17 of the law mandated the barangays to maintain water supply systems; the municipalities and cities to put up small water-impounding projects, artesian wells, spring development, rainwater collectors and other water supply systems. Such non-compliance was due to no follow-up monitoring on the maintenance of provided pumps. Home wells (shallow pump well and open dug well) were treated using the usual/traditional way of maintenance.

5. Barangay Health workers used to conduct informal interview to the water sources owners/recipients but sometimes they gather inaccurate data due to inability or unwillingness to provide actual data by the well owners and even denial of the actual scenario like the real source of their drinking water and its effects.

6. There is no geographical point location on the sources of drinking water in Aparri where people can easily locate areas of quality source of drinking water and make it known or available to the poor and waterless households.

7. There is no enforncement of local policies concerning implementation of water quality surveillance program like confering designation of the members of TWG for proper monitoring. Like Executive Order (EO) 421 of 2005 that refocused the LWUA's mandates, functions, and organizational structure as envisioned in EO 279. Likewise, there is no endorsement for annual work and financial plan on water quality surveillance to the municipal council. Moreover, there was no regular meeting to conduct water quality audit.

B. The Developed System

The analysis, design, development implementation of the system was fully customized integrating effective, efficient and secured data management of drinking water as well as the implementation of a decision support mechanism and effective information bulletin was developed in order to address the identified problem and issues in the existing system. After a careful review of the documents, practices, interviews, and observation made a viable information system (GISWaterMap) which hopes to aid the Sanitary Inspector, in particular, in addressing

the identified problems and issues encountered, makes use as an advocacy material for possible health implications acquired from contaminated drinking water, and information for policy-makers to take actions on the issues, problems and challenges on the monitoring of quality drinking water. The user interface of the system is shown in below figures.

Figure 1. Login Page

Figure 2. Main Page

C. Summary Table on the Assessment of the Developed GISWaterMap using ISO 25010:2011 by IT Experts

Software Characteristics	IT Experts	
	Weighted Mean	Descriptive Interpretation
1. Functional Suitability	3.72	High Extent
2. Reliability	3.78	High Extent
3. Usability	3.82	High Extent
4. Performance Efficiency	3.87	High Extent
5. Maintainability	3.92	High Extent
6. Portability	3.90	High Extent
7. Security	3.48	High Extent
8. Compatibility	3.57	High Extent
Overall Mean	**3.72**	**High Extent**

The table presents the overall assessment of IT experts with a weighted mean of 3.72 and a descriptive interpretation of "high extent", the GISWaterMap has sustained a significant level of conformity to software quality standards. Similarly, the perceived compliance with the norm reflects the overall positive impression [12]. Further, the results are in agreement with Abdelaziz that systems should not only conform to but extends beyond standards of the ISO 25010 [13].

The findings suggest that the users highly recognized the potential of the GISWaterMap considering its potential for providing useful information, GIS-based maps for management purposes, and provision of a decision-support tool for the users. It is believed that with the complementation viewed by the extent of compliance of the GISWaterMap, the decision-support structure, in support of the findings of Teniwut and Marimin [14] and Carrick and Ostendorf [15], is hoped to provide information and decision alternatives. In addition, the use of GISWaterMap as a decision support system, agrees with the suggestions of Tidwell, Moreland, Shaneyfelt, and Kobos [16], and Truong, Rothschild, and Azadivar [17], to assist with the dissemination of data allowing interested parties access to view, explore, and download the data along drinking water. This may contribute to decision making and reducing time in searching drinking water attributes as proven by Nurdin, Mustapha, Lihan, & Ghaffa [18].

D. Summary Table of Usability Acceptance Level of the developed GISWaterMap to ISO 25023 as assessed by the users

The findings suggest that the users highly recognize the potential of the GISWaterMap considering its potential for providing useful information to the water consumers, GIS-based maps for management purposes, and provision of a decision-support tool for the users. It is assumed that with the complementation viewed by the extent of compliance of the GISWaterMap by the users, the decision- support structure, in support to the findings of Teniwut (2013), is hoped to provide information and decision alternatives to all stakeholders related to water resource management in Aparri, Cagayan, Philippines. In addition, the use of GISWaterMap as a decision-support system agrees with the suggestions of Tidwell (2017), to assist in the dissemination of data allowing interested parties to access, view, explore, and download the data on water resources which is beneficial to the water consumers. This also may contribute to decision making and searching water status and informative details with speed and accuracy.

Criteria	Weighted Mean	Descriptive Interpretation
1. Appropriateness Recognizability	4.33	Very High Extent
2. Learnability	4.37	Very High Extent
3. Operability	4.39	Very High Extent
4. User Error Protection	4.50	Very High Extent
5. User interface Aesthetics	4.24	Very High Extent
Overall Weighted Mean	**4.37**	**Very High Extent**

E. A suggested enhancement that can be made for the developed system application

Based on the suggestions made, additional features to be contained for the enhancement of the developed GISWaterMap includes automatic SMS notification updates on the status of drinking water and improving to more mobile-friendly interfaces.

V.   CONCLUSION

Based on the findings in this study, the researcher therefore concludes that the analysis, design, development and testing of the Geographical Information System (GIS)-Based Mapping of Drinking Water, as a decision-support and management tool developed to address the prevailing issues and problems along monitoring in operations and management of drinking water. The results could be very useful and valuable to respective authorities to be more proactive in ensuring quality drinking water.

VI.   REFERENCES

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