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Effective dashboards for urban water security monitoring and evaluation

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ABSTRACT

This paper reviews the factors affecting effective dashboards for urban water security monitoring and evaluation. Urban water security is a constantly evolving field influenced by several factors, including changes in climate, ecosystems, socio-economic status, and human beings. Although urban water security has been discussed in some parts of the literature, there has been minimal literature review that focused on the factors of urban water security and the effective dashboards for monitoring and evaluation. Using systematic literature review (SLR) and preferred reporting items for systematic reviews and meta-analysis (PRISMA), this paper reviewed 143 articles. The result shows growth in the environmental informatics landscape since the last ten years when the first article on the urban water management dashboard was published. The visual design was the most frequently discussed factor for dashboards, followed by user customization. It also shows that this topic can go deeper to integrate both factors and design an effective environmental dashboard. The discussion identified three potential opportunities for future research in water security and informatics: i) exploring other dimensions of effective dashboards, ii) considering more research on the environmental dashboard, and iii) investigating the real-life application of dashboards in urban water security.

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1. INTRODUCTION

As part of the basic human need, water is the most valuable asset for society and nation. One of the United Nations' sustainable development goals for water (SDG6) is to guarantee the availability and sustainable management of water and sanitation for all. However, in 2020, billions of people will lack access to safe drinking water, sanitation, and hygiene [1]. An estimated 129 nations are pending implementing sustainably managed water resources by 2030 [1]. It is a global challenge to appropriately manage water resources, specifically to avoid water scarcity in urban and rural areas. This is where the dashboard monitors and evaluates the water resources data based on the availability of data. Monitoring and evaluation are different purposes, yet they complement each other [2], [3]. Monitoring checks the progress against the plans, while evaluation analyses the data and informs decisions. Both monitoring and evaluation are common tasks in dashboards, usually presenting environmental data in a user-friendly design.

In today's data-driven environment, dashboards are omnipresent and crucial, that an untold number of corporations, non-profit organizations, and community groups rely on dashboards to perform daily tasks [4]. Dashboards are offered as a valuable tool for decision-making and performance assessment [5]. Existing literature reviews on dashboards have discussed the criteria of effective dashboards within the past ten years. Some researchers focused more on display regarding how the dashboard should look, technicality and functionality with multiple users.

Last but not least, the different types of dashboards lead to decision-making. Previous research on dashboards in urban water security focuses on presenting and comparing data. Although urban water security has been discussed in some parts of the literature, there has been minimal literature review focused on the factors influencing effective dashboards for urban water security monitoring and evaluation. Exploring the relationship between factors and indicators [6] through increasing generated data can improve dashboards' effectiveness [7]. In recent studies, dashboard assessments used indicators to analyze performance [8] and perform diagnostics [6]. Less has been described on the identification of associated indicators of each factor. There is a missing question in the literature, as no such guide can be used as the main reference in building an effective environmental dashboard. Thus, this paper aims to present the literature review findings and suggest opportunities based on past research.

2. METHOD

The review is conducted using a systematic literature review (SLR). SLR is a well-defined methodology that identifies and synthesizes research themes fairly and transparently [9]. The preferred reporting items for systematic reviews and meta-analysis (PRISMA) followed the SLR in choosing the articles. There are four stages in PRISMA: identification, screening, eligibility, and inclusion. All relevant articles are gathered and skimmed through to find the most discussed factors in the past ten years to see their relevance until today. Figure 1 shows the overall steps that were conducted using the PRISMA technique.

In the identification stage, intensive papers are searched from scientific databases such as Scopus, IEEE, and Google Scholar. The following keywords were used when searching for the papers: urban water security, dashboard, water security, monitoring, evaluation, and monitoring and evaluation. If the paper contains one or more of these keywords, it is included in this stage. Besides that, connectedpapers.com was utilized to discover related papers. It assists in getting the keyword overview through a selected index paper. The search recorded 261 papers.

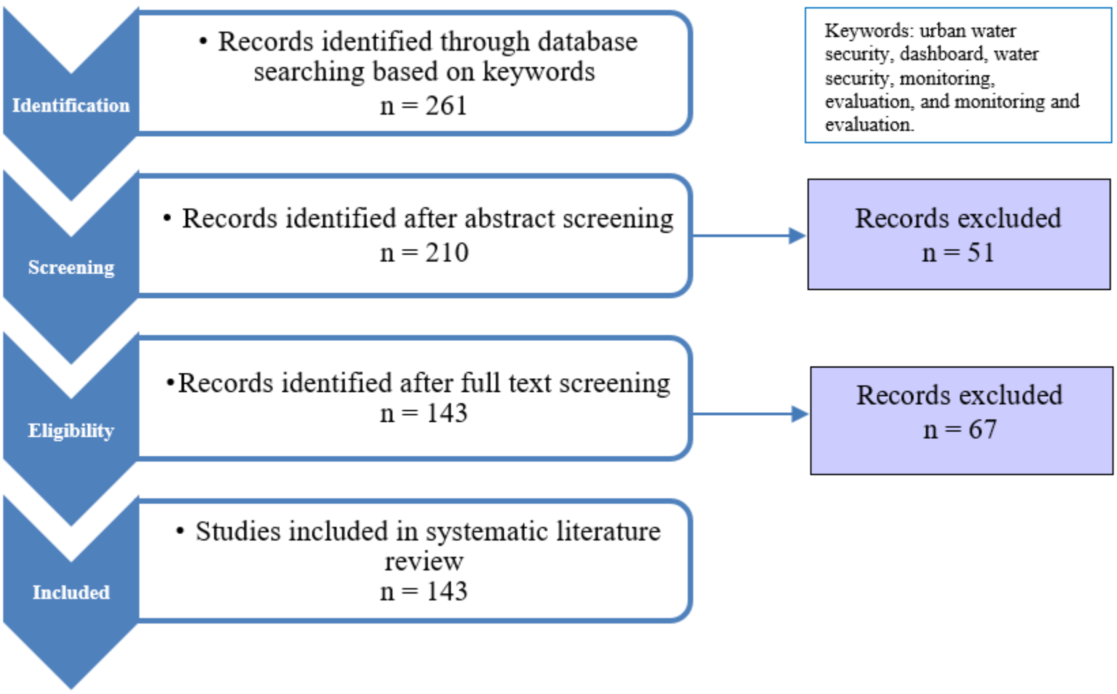

Figure 1. Systematic literature review flow diagram

The papers then undergo a screening process. In this process, abstracts and titles are examined to determine whether the paper is related to the investigated scope of the study. Based on the screening, 51 papers were excluded during this stage because it was not related to the scope of the review, and 210 were eligible for full-text screening. During the eligibility stage, 143 papers were shortlisted, and 67 papers were excluded as the context was irrelevant to this review. The selected papers were analyzed, and the main information, such as the factors for urban water and dashboards, types of dashboards, and the definition of water security, were extracted.

The inclusion stage filtered out the 143 papers. A total of 33 papers were included in the quantitative synthesis, and others were used to support the literature arguments and sentences. Twelve papers have discussed the factors of the dashboard, and 21 papers present the factors that include urban water security. A literature synthesis is produced and presented in Tables 1 and 2 in the next section.

3. FINDINGS

This section contains the information extracted from the literature review. There are four sections: dashboard, factors of effective dashboards, urban water security dashboards for monitoring and evaluation, and urban water security. The literature synthesis on factors of effective dashboards includes eight main factors which are user customization, knowledge discovery, security, information delivery, alerting, visual design, and system connectivity and integration. The discussion of the factors, subfactors, and indicators are described and presented in the respective sections below.

3.1. Dashboard

There are various meanings for a dashboard, and the most cited in the literature is by Stephen Few, the main researcher in the field of data visualization. Few mentioned a data dashboard is a visual display of the most important information needed to achieve one or more objectives, with the data consolidated and arranged on a single screen to monitor the information at a glance [10]. Few explained that it is critical to understand what information would be most captivating and what sorts of data are feasible and accessible, such as direct, indirect, and dashboard indicators [10]. The definition was revised in 2021 to a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfil a specific role [11]. The amendment highlighted the need for a dashboard as a rapid monitoring display requiring a quick reaction. One of the challenges of dashboard design is deciding which information to display on a dashboard rather than the types of information displayed. Wexler *et al.* [12] defined a dashboard from a different perspective, a visual display of data used to monitor conditions and/or facilitate understanding, which may consist of graphical components or narrative visualizations.

The dashboards must be functional at their core first [13]; they should largely consist of high-level summaries so that users may rapidly get an overview of activities. Dashboards feature display techniques that are brief, clear, and straightforward to fit on a single screen. The dashboards' information may be tailored to the needs of the users. Additional criteria to consider are an individual's or organization’s metrics or key performance indicators (KPIs), real-time data presentation, and the ability to view on a web browser or other platforms. Dashboard contents may be in the form of tables, graphics, or visual KPIs [14]. Some types of dashboards include strategic, operational, and analytical. The strategic dashboard monitors the key performance indicators. The operational dashboard displays the day-to-day immediate performance, and the analytical dashboard analyses a large amount of data to find trends and insights. Analytical information that employs visual information can draw user attention to critical situations, trends, and exceptions [15].

3.2. Factors of effective dashboards

The effectiveness of dashboards can be measured based on user customization, knowledge discovery, security, information delivery, alerting, visual design, and system connectivity and integration [16]. Effective dashboards include choosing accurate data visualization to display clear and concise information on a task. The accomplishment of the task can be used to support decision-making or monitoring. The visualization should be easy to interpret without an explanation, so only important text (like graph titles, category labels, or data values) should be on the dashboard. The dashboard also allows users to adjust the display of data in terms of construction, composition, and multipage by utilizing a tab layout and interactive interface that allows the selection of the appropriate elements for views or analysis in terms of visual aspects and interaction.

There are seven factors for effective dashboards, as shown in Table 1. The current literature is synthesized into main factors, subfactors, and/or indicators using the notions of effective dashboards established by Karami *et al.* [16]. The first subfactor is user customization. User customization is divided into three subfactors: customizing definitions, categorizations, and feedback. Customizing definitions include goals, objectives, metrics, end targets, calculations, and correlations among metrics. Most existing research supports that goal is an important indicator in identifying the type of dashboards, as in Table 1. Followed by other indicators, including objectives and metrics to ascertain the end target [4], [14], [16], [17]. Calculations are also mentioned in the literature [16] and the correlation among metrics [14], [16]. It is important to identify the purpose of using the dashboard [14], [16], [17] and whether dashboards are used for decision-making, awareness or motivation, and learning. The user's background in visual literacy or domain expertise [4] is also considered. The next subfactor is categorization, which is access restricted by user level and a group of users assigned to a set of dashboards [4], [14], [16]–[19]. The other subfactors for this factor are user feedback, either by attaching comments to metrics [14] or the discussion forum among users [16], [20].

Table 1. Factor, subfactors, and indicators for effective dashboards

Factors adapted from [16]	Subfactors/Indicators		Sources/References
User customization	Customizing Definitions	Goals	[4], [14], [16]–[25]
		Objectives	[4], [14], [16], [17]
		Metrics	[4], [14], [16], [17]
		End users	[4], [14], [16], [17]
		Calculations	[16]
		Correlation among metrics	[14], [16]
	Categorization	Access is restricted by the level of user	[4], [14], [16]–[19]
		A group of users assigned to a set of dashboards	[4], [14], [16]–[19]
	Feedback	Comments attached	[14], [16], [20]
		Forum of discussion	[16], [20]
Knowledge discovery	Drill-down capabilities		[4], [14], [16]–[18], [20]
	Hierarchies and levels in dimensional modelling		[4], [14], [16]–[18], [20]
	Dependency analysis		[4], [14], [18], [16], [23], [24]
	What-if analysis		[4], [14], [16]–[18], [20]
	A shift from the monitoring layer to the analytical layer		[14], [16]
Security	Authenticate and authorize techniques		[4], [16]
	Procedures for backing up and restoring		[16]
	Versioning/history control		[16], [23]
	Trail of audits		[16]
	Integrity		[16]
	Role-based security defined		[16]
	User roles and permissions		[4], [14], [16]–[19]
Information delivery	Tolerable latency and response time		[4], [14], [16], [18]–[20], [23], [24]
	Customize printing layout		[16]
	Export files to other formats		[16], [20], [25]
	Filtering data		[4], [14], [16], [17], [23]
	Report sorting		[16]
	Insert/remove columns		[4], [16]
	Automated report scheduling		[16]
	Report updated		[4], [16]
Visual design	Regions and values that highlighted		[4], [14], [16]–[25]
	Table and graphs on the same page		[14], [16]–[19], [23], [25]
	Changing the view from tabular to chart		[4], [14], [16]–[19], [23]
	Resizing, maximizing/minimizing, re-ordering of zones		[14], [16], [23]
	Arrange in various layouts		[4], [14], [16], [17], [19], [23], [25]
	Definition and calculation of metrics included		[16]
	Metrics and aim linked		[14],[16]
	Metrics linked		[4], [14], [16], [19], [21], [24], [25]
	Metadata and guidance		[16], [25]
	No scrolling on a single screen		[14], [16], [18], [19]
Alerting	Customizing and managing the alerts	Alert defined	[4], [14], [16]–[18], [23], [25]
		Effective color coding	[4], [14], [16], [17], [23]
		Alert notifications	[4], [16], [25]
		Contextualizing alerts	[4], [14], [16], [25]
	Alert delivered through	Dashboard website	[16]
		Email	[16]
		Pager	[16]
		Mobile phone	[14], [16]
	Next step demonstrating		[14], [16], [20], [23]
	Identify the problem in a text		[16], [20], [23]
System connectivity and integration	Data sources connectivity		[4], [16]
	Various operating systems supported		[14], [16]–[18]
	Portals integrating		[14], [16]
	Application integration		[16]
	Recover from an internal or external crash		[16]
	Data and metadata integration with programmatic APIs		[16]

The next factor is knowledge discovery which has five subfactors: drill-down capabilities with hierarchies and levels in dimensional modelling, dependence analysis, what-if analysis, and the ability to shift from the monitoring to the analytical layer. The indicator deemed significant based on research [4], [14], [16]–[18], [20] are drill-down capabilities, hierarchies and levels in dimensional modelling and what-if analysis. Several researchers mentioned dependency analysis [4], [14], [16], [18], [23], [24]. Two research studies have mentioned shifting from the monitoring to the analytical layer [14], [16].

The third factor of an effective dashboard is security. The seven subfactors are authenticating and authorizing techniques, procedures for backing up and restoring, history control, audit trails, integrity, role-based security defined, and user roles and permissions. The effective dashboard concept [16] ranks the indicators for each factor. All of the subfactors in security factors are ranked 1 (highest rank), except version control is ranked 5 (lowest rank) [16]. The appropriate authentication and authorization methods for building a dashboard are supported by [4], [16]. The ability of the user to control the dashboards has been specified by [16], [23]. Additionally, only [16] states the subfactors such as backing up and restoring procedures, audit trails, integrity, and role-based security. The last subfactor, automatic accessibility changes in user roles or groups, have been addressed in the majority of research [4], [14], [16]–[19].

Information delivery is also one of the factors of an effective dashboard [16]. Eight subfactors include tolerable latency and response time, customizing printing layout, exporting files to other formats, filtering function, sorting reports, inserting/removing columns, automatic report scheduling and updated reports. Reasonable response time and latency refer to decision-makers having data and timely access to the correct data [4], [14]. Besides that, response time also involves the amount of data perceived in the shortest period, the efficiency of the system, system status [4], [14], [16], [18]–[20], [23], and system response time to a few milliseconds [17]. The next subfactor is exporting files like spreadsheets, presentation slides, word, PDF, and others that are stated by [16], [20], [25]. Researchers raise the importance of having data filtering so users can easily access the data [4], [14], [16], [17], [23]. Inserting/deleting columns and updating the reports are also raised by [4], [16]. Last, only [16] mentions customizing printing layout, sorting data on the report and scheduling automatic reports.

An essential component of a dashboard is visual design or visualization. Visual design or visualization aims to convey messages via the use of appealing visual display techniques. Highlighting sections and values can increase the usability of a dashboard [4], [14], [16]–[25] and show the table or graphs without scrolling on the same page [14], [16]–[19], [23], [25]. Switching between tabular and chart views is one of the other signs [4], [14], [16]–[19], [23] and features like resizing, maximizing/minimizing, re-ordering of zones [14], [16], [23]. According to previous studies, the flexibility of customization, such as providing alternative dashboard layouts is also important [4], [14], [16], [17], [19], [23], [25]. A dashboard may become cluttered with too much data; prioritizing key data through metrics can assist in displaying organizational performance statistics. Metric subfactors contain metrics linking metrics together [4], [14], [16], [19], [21], [24], [25] objectives linking with metrics [14], [16] and metrics calculations displayed [16]. The last subfactor is displaying instructions and user guides on dashboards, as well as metadata and guidance [16].

There are numerous subfactors of the alerting factor. The factor is divided into four subfactors: customizing and managing alerts, alerts delivered through the next-step demo, and problem identification in text. Customizing and managing the alerts have four subfactors: alert defined, effective color coding, alert notifications, and contextualizing the alerts. It is essential to define the alerts on the dashboard and use color coding to define the key performance indicators (KPI) to show the importance of the data [4], [14], [16]–[18], [23], [25]. Determining the timing of alerts may show the urgency and put context or hint to the alert [4], [14], [16], [25]. Next, delivering the alerts through multiple mediums whereas [16] gives options through dashboard website, email, pager and mobile phone [14]. Showing what is the next step to undertake and explaining the problem using text to the user while using the dashboards is also mentioned in the literature [14], [16], [20], [23].

The last factor is system connectivity and integration. There are six subfactors in total. The first subfactor is connectivity to various data sources like online analytical processing (OLAP) cubes, databases, lists, and spreadsheets, which are updated regularly [4], [16]. Backup and restore will ensure smooth recovery from software or hardware crashes [16]. Then, dashboards need to be supporting different operating systems so that when opened on the desktop are the same as on the phone [14], [16]–[18]. After that, integrating with other portals [14], [16] means hyperlinks to other relevant information and with other applications and integrating with programmatic application programmatic interfaces (APIs) for data and metadata [16].

3.3. Water security dashboards for monitoring and evaluation

Creating and building a balanced dashboard for monitoring and evaluation [3] can maintain consistency, planning, communication, and monitoring as the dashboard's primary goals [26]. Monitoring is a systematic method of gathering, interpreting, and using data to track a program's progress toward its goals and influence management decisions. At the same time, evaluation assesses or estimates the quality, significance, quantity, or value. There are multiple types of monitoring, such as result monitoring, process (activity) monitoring, organizational monitoring, and context (situation) monitoring. This review focuses on context (situation) monitoring, which tracks the data through the activities. Monitoring and evaluation complement one another. Monitoring reviews all the progress as opposed to the plans, while evaluation will analyze the relationship deeper and conclude the project. A monitoring dashboard is a collection of metric groups or custom views used to track the performance of the systems against goals over time, which can be accessed weekly, monthly, or annually. Dashboards for monitoring and evaluation are being used in water security as in Table 2.

Table 2. The features of the dashboard in the water security domain

Domain	Purpose	Features	Authors
Water security	Monitoring and evaluation	– A dashboard of indicators based on the pressure-state-impact-response (PSIR) framework (EEA 1999) – 56 indicators – Comparison analysis between 10 cities	[8]
		– Visualization of 52 variables for data in water security – A diagnostic dashboard – Allow comparative cross-country analysis	[6]

3.4. Urban water security

Water is essential in our daily life. It is used for drinking, bathing, and washing. It is undeniable that water is vital in sustainable energy operations and food production. The distribution of water resources in the urban and rural areas is also included. However, the distribution is unbalanced nowadays, and people are moving into metropolitan areas, making the water demand higher than in rural areas. This situation is what we call the need for water demand management to provide better management by reducing water usage rather than just increasing supply. Water security can be defined as "sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health" [27]. There are three popular definitions of water security. First, the Global Water Partnership emphasizes water security at any level-from the household to the global. Every person has access to enough safe water at an affordable cost to lead a clean, healthy, and productive life while ensuring that the natural environment is protected and enhanced [28]. Second, Grey and Sadoff [29] focused that water security is defined as the availability of sufficient quantities and water quality for health, living, environs, and manufacture, as well as people's exposure to water-related dangers, surroundings, and economy.

Another definition based on United Nations Water (UN-Water) [30] defines water security as a population's ability to ensure long-term access to a sufficient quantity and adequate water quality for sustaining a living, the well-being of humans, and economic and social development, to defend against water-borne pollution and disasters caused by water, and to protect ecosystems in a peaceful and stable political environment. There is no common understanding of water security terms since various fields use different methods [31]. As reported by Asian Development Bank (ADB) [32], there are five determinants: a rural household, an economic, urban, environmental, and water-related disaster that results from National Water Security Index for a country. Some developing countries such as Malaysia are in category 3 in the capable stage to access safe drinking water and improving sanitation facilities, moderate economic water security, moderate environmental governance, and clear pressure on the ecosystem and there are some institutional commitments to reduce disaster risk. Urban water security can be defined as maintaining access to affordable, clean, and unlimited water resources and protection from threats such as pollution and disasters within the governance of water management systems and stakeholders to support the sustainability of the ecosystem and political steadiness [33]. Table 3 shows the factor, subfactors, and/or indicators for urban water security. There are four factors for assessing urban water security: human beings and drinking water, ecosystems, water-related hazards and climate change, and socioeconomic development [33].

Table 3. Factor and subfactors/indicators for urban water security

Factors	Subfactors/Indicators		Sources/References
Drinking Water and Human Beings	Water quantity	Reliability	[33], [34]
		Consumption	[33]–[38]
		Diversity	[33], [35], [39]
		Availability	[33], [36], [37], [40]–[42]
	Accessibility	Sanitation services	[33], [43]
		Drinking water services	[33], [43]
	Water quality	Drinking water	[33]
		Sewerage treatment plant	[33]
	Water dependency ratio		[33], [37], [44]
	Adequacy and equity		[33], [43]
Ecosystem	State of pollution		[45], [33], [46]
	Water quality (environments)		[33]
	Changes in the size of the water-related environment across time		[33]
	Eco-roofs		[33]
	Green areas by drainage		[33]
	Storm network effectiveness		[33]
Climate Change and Water-Related Hazards	GHG emissions released by the system		[33]
	Public health for water disease		[33]
	Number of flash floods		[33], [47]–[53]
	Number of droughts		[33], [53]
	Flood-prone regions		[33], [51], [52], [54]
	Yearly average rainfall		[33], [55]–[57]
	Yearly average temperature		[33], [56], [57]
Socio-Economic	Customer’s complaints		[33]
	Illegal user		[33]
	Cost recovery		[33]
	National budget directed to Water and Wastewater Services (WWS)		[33]
	Affordability		[33]
	Sanitation tariffs		[33]
	Water tariffs		[33], [36], [38]
	Wastewater energy consumption		[33]
	Water energy consumption		[33]

4. DISCUSSION AND OPPORTUNITIES

Seven factors have influenced effective dashboards: i) user customization, ii) knowledge discovery, iii) security, iv) information delivery, v) visual design, vi) alerting, and vii) system connectivity and integration, as shown in Table 1. Most researchers highlight the visual design factor, followed by user customization, while security is the least. These factors can be used as the main factors to benchmark when building a dashboard. Table 3 shows the four factors reviewed in the previous sections. It can be concluded that the drinking water and human-being factor dominate the literature on urban water security. There are five subfactors: i) water quality, ii) adequacy and equity, iii) the water dependency ratio, iv) water quantity, and v) accessibility. This corresponds with the several targets in Goal 6 in SDG: safe drinking water, sanitation for all, better water quality, more efficient water use, and integrated water management. The major challenge for Goal 6 in SDG is to ensure availability and sustainable management of water and sanitation for all [58]. Water quantity is the most highlighted area by the researchers.

4.1. Research trends based on the overall dashboard factors in 2011–2021

Figure 2 shows the research trend related to all the factors for effective dashboards by year-this research trend includes all the subfactors. The years have been divided into three five-year phases, except the last phase is only for one year. The chart shows that the topic has increased during the past years, especially in the second phase. In the first phase, it can be seen that only two or three papers are on the dashboards. Then, it doubled in number over the next five years. In 2021, all topics were discussed except for system connectivity, integration, and security.

4.2. Research trends based on the user customization factor in 2011–2021

Figure 3 shows the research trends related to the subfactors for user customization by year. The user customization factor contains ten subfactors. This chart also had three phases divided into five years, except the last phase is only for one year. This chart shows that goals are the most discussed topic throughout the year—followed by the categorization group, where the dashboard’s need to access is restricted by user level and a group of users assigned to a set of dashboards. The least is the calculations.

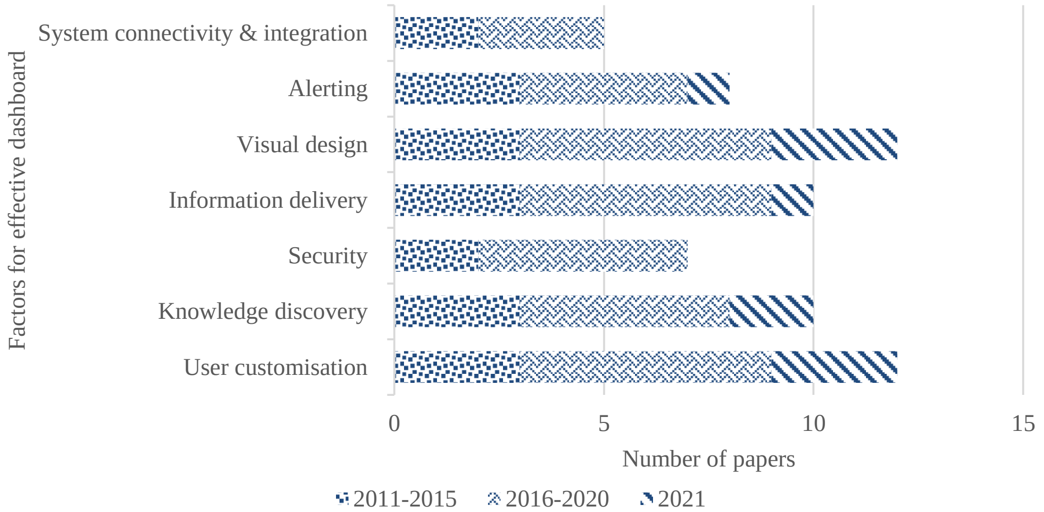

Figure 2. Research trends related to the factors for effective dashboard by year

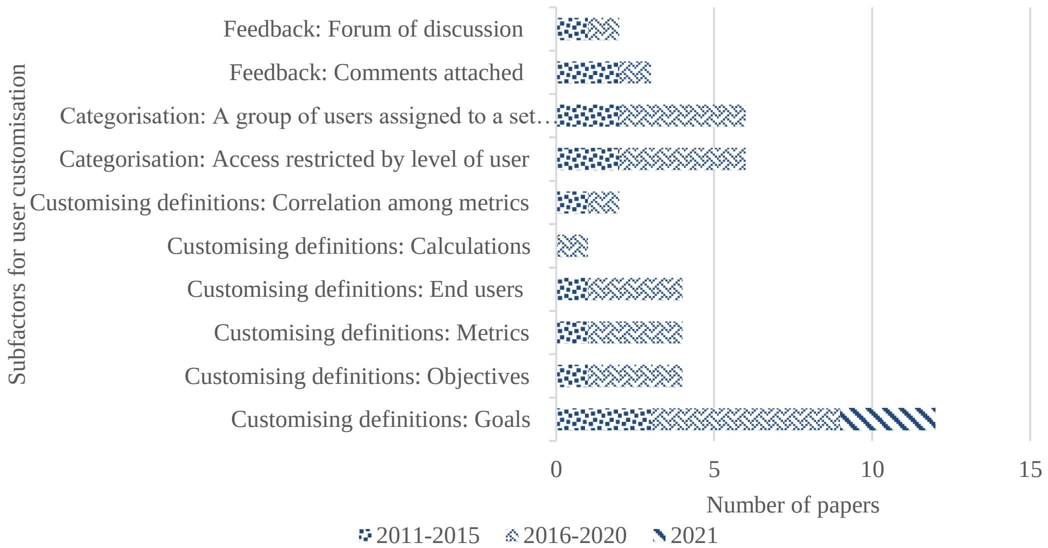

Figure 3. Research trends related to the subfactors for user customization by year

4.3. Research trends based on the knowledge discovery factor in 2011–2021

Figure 4 shows the research trend related to the knowledge discovery factor by year. There are five subfactors: a shift from the monitoring layer to the analytical layer, what-if analysis, dependency analysis, hierarchies and levels in dimensional modelling and drill-down capabilities. This chart also has three phases divided into five years, except the last phase is only for one year. This chart shows that all subfactors are being discussed actively in the last two phases; none of these was discussed last year. Only one paper discussed in each phase the ability of the dashboard to shift from the monitoring layer to the analytical layer [14], [16].

4.4. Research trends based on the security factor in 2011–2021

Figure 5 shows the research trend related to the security factor by year. User roles and permissions, role-based security defined, integrity, the trail of audits, versioning/history control, backing up and restoring procedures, and then the authenticate and authorize techniques are the subfactors. This chart is divided into five years, except the last phase is only for one year. From this chart, it can be seen clearly that all the subfactors are being discussed only in phase two, except for user roles and permissions. This subfactor shows a significant rise when the papers double from first to second. None of these subfactors was published last year.

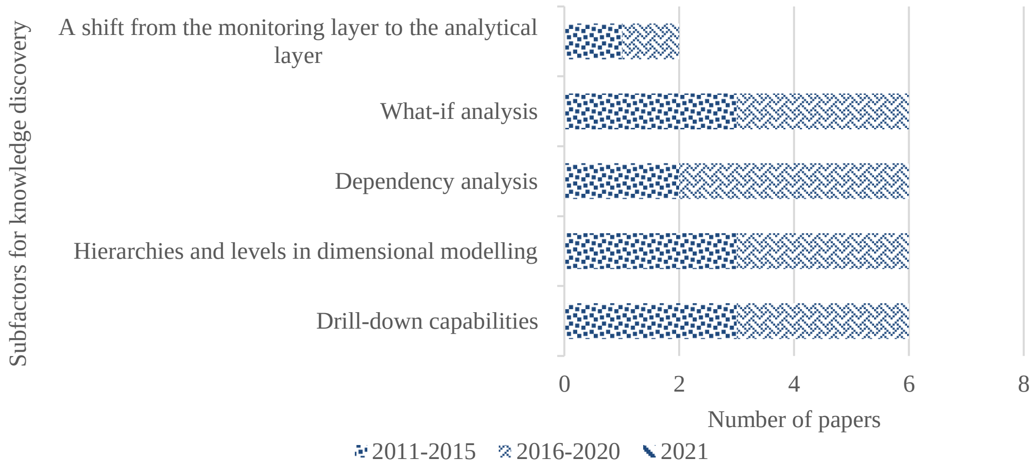

Figure 4. Research trend related to the subfactors for knowledge discovery by year

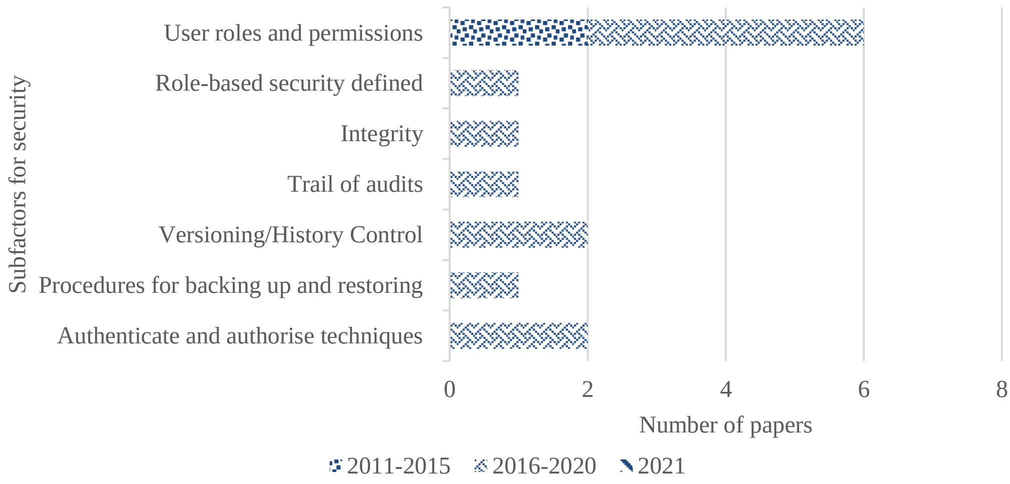

Figure 5. Research trends related to the subfactors for security by year

4.5. Research trends based on the information delivery factor in 2011–2021

Figure 6 shows the research trend related to the information delivery factor by year. There are eight subfactors: report updated, automated report scheduling, insert/remove columns, report sorting, filtering data, exporting files to other formats, customizing the printing layout and the tolerance of latency and response time. This is also divided into five years, except the last phase is only for one year. From this chart, it can be seen that eight papers write about the tolerable latency and response time for the dashboard [4], [14], [16], [18]–[20], [23], [24]. Only export files to other formats have one paper for each phase [16], [20], [25]. Automated report scheduling, report sorting, and customized printing layout have the minor paper, which is one paper in the second phase.

4.6. Research trends based on the visual design factor in 2011–2021

Figure 7 shows the research trend for subfactors of visual design by year. There are ten subfactors. This also had three phases divided into five years, except the last phase is only for one year. From this chart, it can be seen that there are three papers in the last year [21], [22], [25] that suggest the metadata and guidance, metrics linked, the dashboard is arranged in various layouts, and the table and charts on the same pages and the regions and values that highlighted.

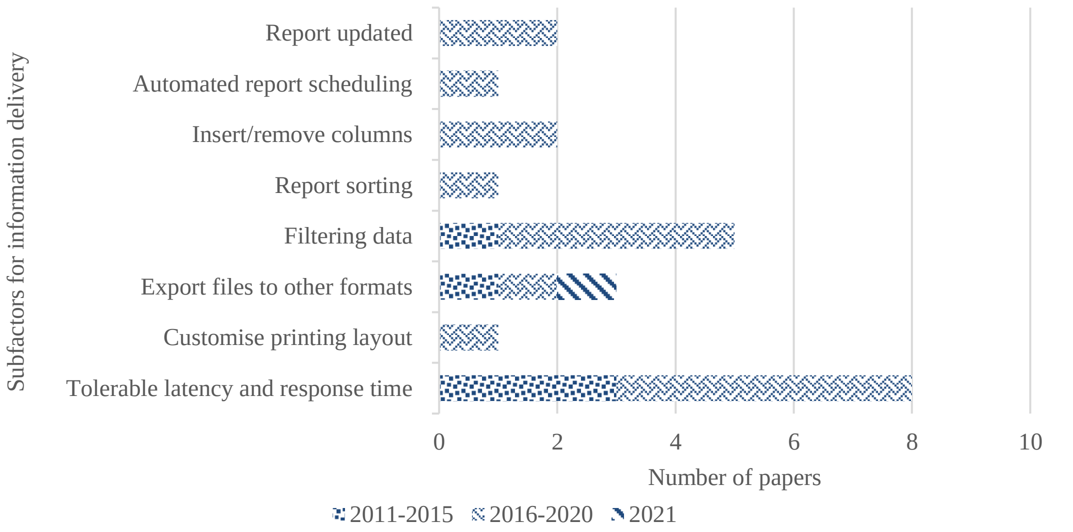

Figure 6. Research trends related to the subfactors for information delivery by year

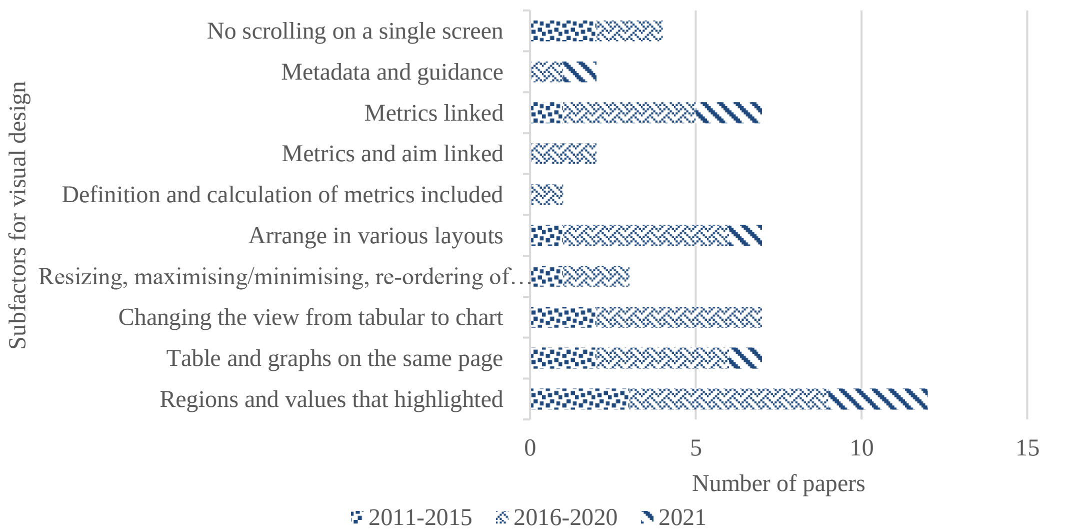

Figure 7. Research trends for subfactors of visual design by year

4.7. Research trends based on the alerting factor in 2011–2021

Figure 8 shows the research trend for alerting factor by year. There are ten subfactors. This is also divided into five years, except the last phase is only for one year. From this chart, it can be seen clearly that the alert defined are discussed for each phase, in the first phase [14], [17], second phase [4], [16], [18], [23] and last year [25]. Alert delivered through a pager, email, and dashboard website has the least paper where only one paper discussed it [16]. Alert notifications and contextualization also be subfactors that were discussed last year.

4.8. Research trends based on the system connectivity and integration factor in 2011–2021

Figure 9 shows the year-by-year research trends related to system connectivity and integration factors. There are six subfactors: data and metadata integration with programmatic APIs, recovery from an internal or external crash, application integration, portals integrating various operating systems supported and data sources connectivity. This also had three phases divided into five years, except the last phase is only for one year. From this chart, it can be seen clearly that various operating system supported by the dashboard has two papers for each phase except for last year. Portals integrating have one paper for each phase except for last year. This chart also stated that no researcher discussed it last year.

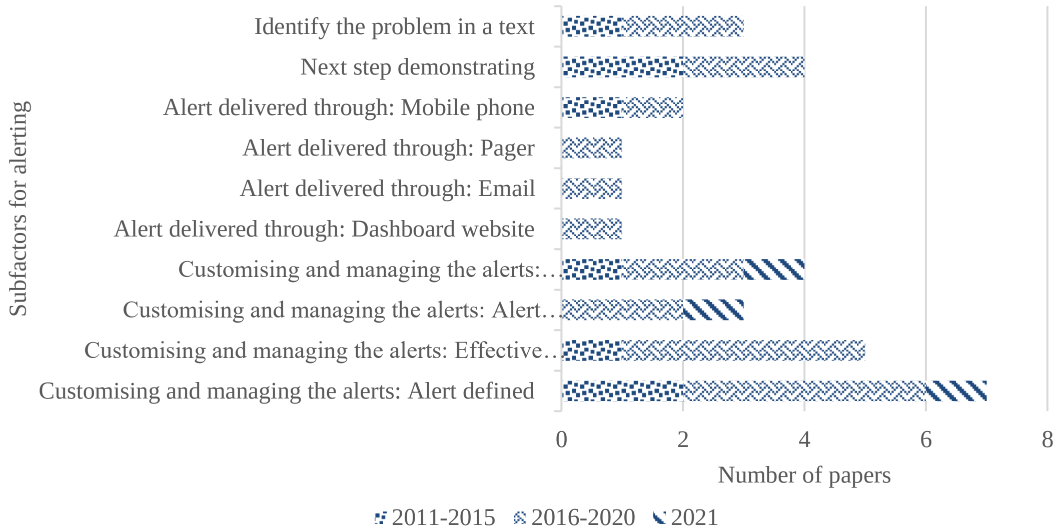

Figure 8. Research trends for subfactors of alerting by year

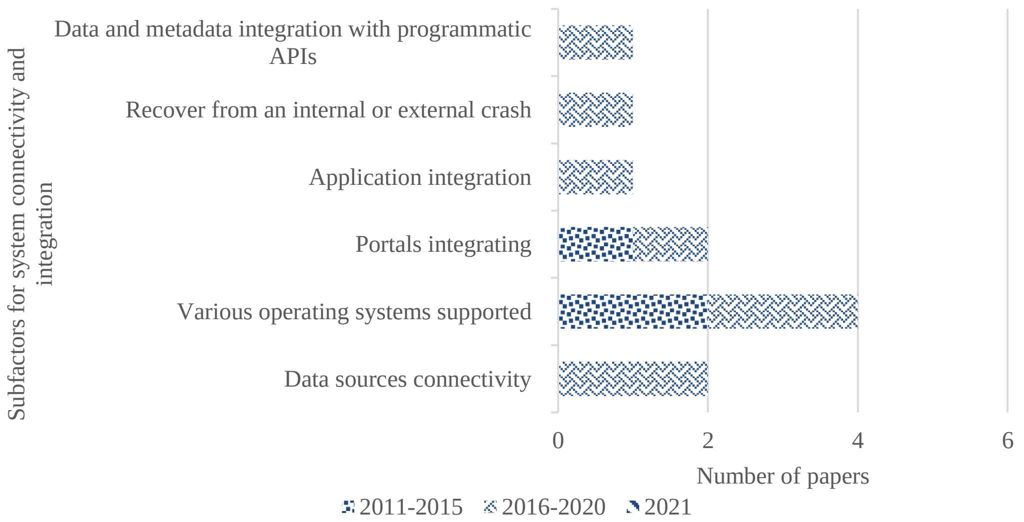

Figure 9. Research trends for subfactors of system connectivity and integration by year

4.9. Research opportunities

Existing literature has shown a lack of studies on integrating effective dashboards for urban water security dashboards. Most research on the dashboard has focused more on the technological dimension, such as user customization, knowledge discovery, security, information delivery, visual design, alerting, and system connectivity and integration factors, leaving many other factors to be explored. Another important finding is that fewer studies focused on the environmental dashboard. The dashboards were relatively less explored and studied within the context of urban water security applications. Finally, based on the review, the analysis suggests that the real applications of effective dashboards for urban water security monitoring and evaluation are almost non-existent, which is an important gap to be filled in this area. Then there is an issue of using a set of factors (or criteria) in these applications; that is, most studies were limited to either the technological dashboard factors or the water security factors (or indicators). It can be argued that these applications should be revisited by considering integrating factors and other important human and socio-technical factors to measure a dashboard's effectiveness. The aforementioned open opportunities and future work to be potentially considered are: i) exploring other dimensions of effective dashboards, ii) considering more research on the environmental dashboard, and iii) investigating the application of dashboards in urban water security. These areas are discussed below in more detail.

4.9.1. Exploring other dimensions of effective dashboards

Based on the analysis, little research has been undertaken on an integrated framework that adds other dimensions, expected relations between factors, and relations with other internal and external factors. Existing research has focused more on the technological dimension, such as user customization, knowledge discovery, security, information delivery, visual design, alerting, and system connectivity and integration, leaving many other factors to be explored and used. One research on effective dashboards [16] focused on technological factors. The research lacks other relatable dimensions, such as the socio-technical (human) factor. Further research can explore user behavior, user experience, and so on. This includes visualization and analytic literacy. Thus, it is challenging to develop an interactive and engaging dashboard that is customizable, adaptable, analytical, and flexible [4].

4.9.2. Consider environmental dashboard criteria

There is less research on the environmental dashboard, but one study on the environmental dashboard [59] uses feedback. First is building a dashboard, tracking and showing the real-time data flow, and getting the people to overview the effectiveness. The people's feedback is through an interview. At that point, a pilot study is conducted with the public to see water usage, electricity, and weather. The three mediums of information distribution for the environmental dashboard are use websites, digital signage, and "environmental orbs". The most profound information is available through the dashboard. The digital signage and "environmental orbs" are accessible for different roles of a user. Eventually, this helps raise awareness among the community about the environment and make informed decisions. Another potential research is to consider techno-environmental criteria using techniques such as multi-criteria decision analysis (MCDA) [60] and goal-question-metric [61], [62]. There is existing work on using these techniques to conduct an evaluation.

4.9.3. Investigate the application of dashboards in urban water security

Previous urban water security dashboard research investigates the urban water security indicators [6]. The research is the first urban water security dashboard to apply the pressure-state-impact-response (PSIR) framework. It utilized 56 factors divided into four sections: pressure, state, impact, and resource. The dashboard is a scoring structure that characterizes, compares, and ranks the level of water security of 10 cities. This research gives insight into cause-and-effect urban water that contributes to a specific water security level. However, based on our analysis, a case study that evaluates the effectiveness of dashboards for urban water security monitoring and evaluation is almost non-existent. Then there is an issue of using a set of factors (or criteria) in these applications; that is, most studies were limited to either the technological dashboard factors or the water security factors (or indicators). It can be argued that these applications should be revisited by considering integrating factors and other important human and socio-technical factors to measure a dashboard's effectiveness.

Figure 2 shows the factors investigated to monitor and evaluate the urban water security dashboard. As mentioned, both sides' circles of main factors differ from past studies as the urban water security factor focuses on the SDG target. The factors for urban water security are the additional data that need to be included in the urban water security dashboard because the paper review by [2] highlights the improvement that can be made, such as water quality data [7]. Moreover, seven technological factors will be used to build the dashboard that the past researcher did not address. Additionally, all the factors will be monitored and evaluated so reports show the water security level status. Therefore, this paper expands the past dashboard version into an environmental dashboard in water security.

5. CONCLUSION

The increased data from day to day need an alternative to manage it properly. The dashboard can increase productivity and is vital for better decision-making since now it is a data-driven world. In the meantime, water security is a growing field that produces too much data yet is vital for people to acknowledge. An environmental dashboard can help to monitor and evaluate the factors. Many factors need to be considered for building an environmental dashboard. The review reveals seven factors in total, and the visual design is the focus highlighted by the researchers, followed by user customization. This also can be seen in the research trend throughout the year. This includes the highlighted regions with values, tables, and charts on the same page and arranged in various layouts. Then, the goals for building the dashboard must be clear. At the same time, security is the least focus since people do not see the important feature of protecting the data.

On the other hand, for water security, the water quantity that can be measured by consumption and availability has been mentioned more by existing researchers. This paper has suggested the effective factor that needs to be indicated to monitor and evaluate the dashboard for urban water security. The review reveals three potential research opportunities that can be further evaluated. Existing literature has shown a lack of studies on integrating effective dashboards for urban water security dashboards. Most research on the dashboard has focused more on the technological dimension. Another important finding is that fewer studies focused on the environmental dashboard. The dashboard phases were relatively less explored and studied within the context of urban water security applications. Finally, based on the review, the analysis suggests that the real applications of effective dashboards for urban water security monitoring and evaluation are almost non-existent; most studies were limited to either the technological dashboard factors or the water security factors (or indicators). It can be argued that these applications should be revisited by considering integrating both factors.

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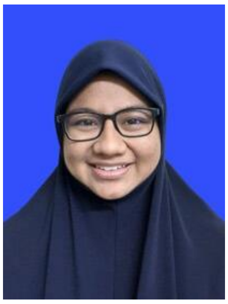

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