Array 8 (2020) 100037

Contents lists available at ScienceDirect

Array

journal homepage: www.elsevier.com/journals/array/2590-0056/open-access-journal

Incorporating stakeholder concerns in Land Information Systems for urban flood management

Rathnayake Mudiyanselage Manjula Pradeep [a,*], Nallaperuma Thanthirige Sohan Wijesekera [b]

[a] Department of Information Technology, Faculty of Computing, General Sir John Kothelawala Defence University, Kandawala, Rathmalana, Sri Lanka
[b] Department of Civil Engineering, University of Moratuwa, Katubedda, Moratuwa, Sri Lanka

ARTICLE INFO

Keywords:
GIS Tool
Urban flood
Hydro model automation
Stakeholder satisfaction

ABSTRACT

Urbanization increases urban flood. This urges hydrologically and economically planned land development decisions. When decision making, incorporation of hydrology model with GIS is a common practice due to the requirements of accuracy and efficiency. Nevertheless, GIS and hydrology incorporated tools (HydroGIS) should facilitate stakeholder concerns for practical implementation. But there were no single tool and developing such becomes a hard undertaking due to the absence of proper guidelines. Therefore, the present work is to identify the stakeholder concerns and incorporate those in a HydroGIS tool (Land Information System) for Urban Flood Management. For the purpose, it identified and verified the stakeholder concerns through a literature survey and stakeholder discussions. Then, incorporated those into the tool and evaluated the achievement. Present work identified and incorporated the stakeholder requirements; such as the requirement of an automated tool, User friendliness using novel GIS-GUI development guidelines, development of the software using a novel approach of development, security through novel security mechanism and, integrating the hydrology-GIS model using a suitable base software. The systematic incorporation of such requirements into the tool shows the growth in user satisfaction from 48% to 92%. The accurate recognition and incorporation of stakeholder requirements lead to the successful HydroGIS tool in urban flood management.

1. Introduction

1.1. Background

Urbanization, which is mainly caused by the migration of people to seek employment opportunities and better services, creates high population densities because of land restrictions in designated areas [1]. The UN report on World Urbanization Prospects - 2018 [2] shows only 43% of world population lived in urban area in 1990. However, it has increased to 55% in 2018 and predicted to be 60% by 2030. This will definitely cause aggravated pressures on urban land development.

Demand for land development exerts pressure on surface runoff drainage systems and also on the available water storage in floodplains. Hellmers et al. [3], study shows the increment in flood inundations areas with the urban growth and existing drainage system. Carver [4] describes the reduction of lag time to collect runoff to drainage as a reason for flood. USGS fact sheet [5] also describes the negative effect of urbanization on streams. Further, whilst attempting to model the urban flood, Xia [6], found that the rainfall excess overwhelming the drainage capacity.

Meantime the guideline developed by Jha et al. [7], highlights the appearance of urban flood fatalities had not reduced in developing countries. The state of art review of Hammond et al. [8], describes the damages by grouping into two areas, tangible (destruction of properties) and intangible (effect on health, economical and etc.). Further Pregnolato et al. [9], describe the floods' negative effect on transportation, and Elmoustafa's [10] study shows all the above as repercussions of floods. Moreover, Xia et al. [6], study figures out devastating damage due to such urban flood. Therefore, flooding is described as a major factor that disrupts the equilibrium of economic activities in urban areas because of the damage to property, crippling of transport and other public utilities and increased pollution of the environment.

At 2011, Gunaruwan [11], found that the estimated damage in Colombo city, Sri Lanka for a 25 year flood is approximately 260,000

* Corresponding author.
E-mail addresses: pradeep@kdu.ac.lk, rayantha@gmail.com (R.M.M. Pradeep), sohanw2@gmail.com (N.T.S. Wijesekera).
URL: http://www.kdu.ac.lk/dit/major-rmm-pradeep (R.M.M. Pradeep), https://uom.lk/staff/Wijesekera.NTS.php (N.T.S. Wijesekera).
https://www.linkedin.com/in/sohan-wijesekera-a7b59a6a/?originalSubdomain=lk (N.T.S. Wijesekera)

https://doi.org/10.1016/j.array.2020.100037
Received 22 October 2019; Received in revised form 14 May 2020; Accepted 24 June 2020
Available online 8 August 2020
2590-0056/© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

$/km^2. According to Huizinga [12], damage due to urban floods varies significantly from Asia to America. Word Bank [13] estimates the global flood loss will be 52 Bn $/year in 2050 which was only 6 Bn $/year in 2005. This points to the importance of achieving sustainable development in urban areas.

Apart from that Jha et al. [7], describe that the existing laws & regulations are poorly controlling land enhancements which obstruct the natural water flow. Further Zhou [14] argues that urban land modifications are only considering the economic factors, then those damage the natural water systems. Therefore, this "Hydrologically unplanned land and infrastructure development" becomes the most contributing factor for the undesirable increase in storm water runoff, shortening of time to respond and finally the flood. Hence, there is an urgent need to support and execute "hydrologically-planned land development" for sustainable urban environments.

Further, core of sustainable urban flood management is the availability of a reliable hydrologic model for runoff estimation from urban land parcels. Then, when developing a system for urban flood management, the hydro model is the most important component. Development of urban hydrologic models spans over 50 years. In 1968, Geological Survey Circular [15] was developed to guide the hydrology for urban land planning. Furthermore, various other researches were carried out, such as, Mcpherson and Schneider [16] attempt to identify urban watershed modelling problems, Chan and Bras [17] analysis on urban flood volume distribution and Jacques et al. [18], model of urban runoff process. Maidment and Parzen [19] pay the attention to urban water use in 1984. Moreover, when Chow et al. writing their book on *Applied Hydrology* [20], a special attention was paid to urban water to manage the flood. Since then, a number of books have been written and researches have been carried out on urban hydrology such as guiding the urban drainage design in the book of Smart and Herbertson [21], chapter on engineering application of urban hydrology by Shaw [22]. Djokic and Maidment [23] analyses the terrain for urban storm water modelling, and Mitchell et al. [24], model the urban water cycle. Apart from these attempts, UNESCO Urban Water Management Program (UWMP) which perform under International Hydrological Program –IHP has contributed to develop and accumulated number of hydro models and share the knowledge and experience on urban water among 36 UNESCO Member States [25].

However, there are inherent problems to be solved when hydrology modelling. Ficchi et al. [26], found that the hydrology models' accuracy depends on the resolutions of the inputs. Even though the resolution increases the accuracy, Ichiba et al. [27], found that high resolution results performance issues. When hydrology models generate outputs, Eger et al. [28], shows the importance of removing communication problem with the non-technical audiences. To solve such problem, Fatichi et al. [29], urge to improve the visualization of the outputs. However, according to Ogden et al. [30], the huge amount of data handling and manipulating capabilities of the GIS provide assistance to hydrology models to generate more accurate results. Thakur et al. [31], review shows that the most of hydrological modeling problems can be solved using GIS. Hence it can consider that the present hydrology models can highly dependent on the capabilities of GIS software.

Identifying the capabilities of the GIS in hydrology, the term "HydroGIS" was introduced in HydroGIS 93 conference, Vienna, April 1993, to describe the common ground between GIS and hydrological applications [32]. Pradeep and Wijesekera [33] have introduced the term "HydroGIS tool" which is a software tool that facilitates to practice the hydrologic models using spatial information management potential of GIS. When considering the HydroGIS tools, Assaf et al. [34], highlight an important requirement which should provide an interactive stakeholder decision making capability. Further Sörensen et al. [35], state that the GIS component of the tool should assist multi-stakeholder approach. Then multi-stockholder approach assists to practically develop and implement sustainable urban flood management options.

1.2. Integration of stakeholder aspirations

Sustainable urban land management in the light of flood management is a spatially distributed task involving a large number of stakeholders. Both Gray et al. [36], and Scott et al. [37], have identified that these stakeholders consist of land owners and developers, land managers and policy makers, urban dwellers, business people, migrant employees, services seekers, technical experts in water and spatial data management systems, management tool developers and operators who are equally important for a thriving urban economy.

However, Han et al. [38], highlight that urban lands have more pressure when considering the effect of urban economy on the international supply chain and commodity trade. Hence, the business-people have more interest on urban lands. Meantime, according to Struyk and Angelici [39], the Russian urban dwellers pay a high interest on rural cottages/villas known as dacha phenomenon, and less interest on urban lands. Then, it can observed that the stakeholder interest on urban land does not have a common behavior. Nevertheless, it is common that the uncompromising nature of floodwater that continues to flow under gravity with no respect for administrative boundaries.

Therefore, these two main factors: stakeholder interests (objectives) and nature of water, need to be considered when managing land for urban flood mitigation. For the purpose, it is necessary to have a GIS for land management that successfully incorporates urban stakeholder aspirations while integrating a spatially distributed hydrologic model to deliver outputs that satisfy both recipient stakeholders and decision makers.

In stakholder aspirations evalaution, an important point is highlighted by Scott et al., [37]; accordingly, due to the fact that most of the stakeholders are non-technical, the tool's capability to provide alternative solutions is very important. Further, Bacco et al. [40], identify that such solutions need to be maintainable/sustainable with the assistance of IT, and it is a technical challenge which is to develop a stakeholder agreed practical solution in line with hydrological requirements. Therefore, in other words such spatial tool should provide more non-technical stakeholder assistance.

As an initial activity, the present work carried out an outline review on the different software tools and research works which use in the hydro-land management scenarios against the applicability with non-technical stakeholders.

There are large number of tools that provide only the land information to its non-technical stakeholders such as Micropact's Land Records Management [41] which provides land records to judicial works, Accela's Land Management system [42] that provides online land management viewing platform to land owners and decision makers, LRS [43] provides land information to local authorities for daily administration. General Code's Municity [44] which provides a complete land management solution to local authorities. This type of software tool needs not technical knowledge to operate; however, the decisions made through the tools do not follow proper hydrological assessments.

On the other hand, another set of tools have been utilized land parameters to perform water related information generation and decision making. PIHMgis [45] which integrate land information and other parameters; OpenNSPECT [46] which simulates the soil erosion, water pollution, and overland flow accumulation; Innovyze's InfoWorks ICM Suite [47] which is a sophisticated GIS based real time modeling software tool set; are the tools which perform watershed management activities with hydrological models. Further, there are advanced information processing software to perform storm generation and flood management activities such as the Real Time Hydrological Model for Flood Prediction

[48] that provides online flood prediction information to the general public; Worku's application of SWAT model [49] to analysis the water yield against the land modifications; ArcCN-Runoff [50] software which assist to calcualte hydrological parameters; Geo-PUMMA [51] toolbox that assist in urban hydrology modelling and NOAA [52] which allows users to calculate impervious surface area. Furthermore, there are other tools that are utilizing land information to arrive spatial decisions in different fields such as SOLARIS [53] for agriculture which manipulates soil and land information. However, users of all these tools should have substantial technical knowledge on either input data preparation/carrying out processes/interpret the outputs.

Then when reviewing all these available software tools, there is a lack of an integrated, user-friendly tool for non-technical stakeholders (both the decision makers and land owners) to arrive at economically acceptable, hydrologically sustainable optimum land development options.

1.3. Deficiency of stakeholder concerns in HydroGIS tools

As there are gaps in the initial review, a systematic literature review has been conducted following the guideline by Kitchenham and Charters [54]. Accordingly, a set of literature that describe the tool/procedure/guideline/framework which use for flood/water management are selected. Then literature is evaluated under two research questions (1) How the literature has identified the stakeholder concerns and (2) How those concerns are incorporated to the HydroGIS tool. Among the surveyed literatures, following are crucial for the overall study.

Criollo et al. [55], developed a tool, AkvaGIS to water management and describe how the stakeholders are interacting with that tool. Xu et al. [56], describe the integration of GIS for hydro modelling for the stakeholders' concern on easy management decisions. However, both have predetermined the requirements of stakeholders without proper requirement gathering. However, Pingale et al. [57], having analyzed more than 35 case studies in integration of GIS and water resources models identify the model developers' concerns but lack of operationalization guideline to incorporate those.

Henriksen et al. [58], discusse how to involve stakeholders in hydro-GIS modelling with only elaborating the management of stakeholders than their concerns. Voinov et al. [59], provide a better guideline to Participatory Modelling (PM) which widely identify stakeholder concerns whilst model development. Leskens et al. [60], present a framework that allows flexible decision making using interactive models which are based on theory of collaborative knowledge construction. The analysis shows that only these three works discuss the stakeholders' concerns to a broader extend.

However, when Jessel and Jacobs [61] discuss the applicability of European Water Framework Directive (WFD) in land use development in watershed management partially identifying the requirements of outputs except the stakeholder concerns on the inputs. The 2D/3D flood visualization workflow of Macchione et al. [62], describes the stakeholder concerns on output visualization whilst Van Ackere et al. [63], identify the 2D and 3D simulations are more user-friendly visualization to stakeholders. Concomitantly, Leskens et al. [64], successfully identify and incorporate the dynamic output requirements of non-technical practitioners; Luke et al. [65], study identify the importance of map output visualization, customized legend and geospatial information to stakeholders. Nevertheless, all these works only consider the stakeholders' output concerns.

Therefore, when reviewing the relevant literature, it has been proved that attention has been paid to stakeholders' concerns on outputs rather than inputs and processes. Apart from that, the importance of the stakeholder incorporation to the water decision making and suggesting different work flows has also been discussed to a greater extent. Nevertheless, specific concerns of stakeholders on the requirement to develop tools have not been identified. On the other hand, urban land management for flood mitigation is a multi-stakeholder activity. Hence it is vital to identify all stakeholders and their requirements for sustainable implementation of mitigating measures [35].

At the same time, in the present theory and practices in software engineering [66, p. 71], the fundamental requirement for a successful system is to achieve the organizational goals (the business need of the system/the stakeholders), which stress to address the needs of stakeholders in a holistic manner. Hence there is an urgent need to contribute towards stakeholder receptive tool development guidelines by adequately considering stakeholder concerns and demonstrating the development of a HydroGIS for urban flood management.

1.4. Objective

The objective of the present work is to identify the stakeholder concerns with respect to hydrologically-planned land development and incorporate those into a Land Information Systems (HydroGIS tool) for Urban Flood Management. In this effort, a conceptual HydroGIS tool for urban flood management has systematically been developed on a GIS platform while incorporating the stakeholder requirements identified through literature survey and professional discussions.

2. Materials and methods

2.1. Method of incorporating stakeholder concerns

The present work demonstrates the HydroGIS tool which assists the existing land enhancement approval granting process by providing a new facility to evaluate the modification on hydrological perspective and opting to prevent urban flood. Previous works of the authors [67,68] described software development initiatives with rationale behind the selection of hydro & GIS models except the stakeholder concerns.

Then present work developed and analyzed the main approval granting use case to identify and classify the stakeholders. A comprehensive literature survey was carried out to find the different concerns in GIS automating. Then the findings were discussed with the identified stakeholders and those were modified and enhanced. To implement those concerns when developing the tool, it attempted to apply the state of art methods. If there is no proper method, then present work developed novel methods. When the tool was developed, it was evaluated with the potential stakeholders. Later, based on their views, the tool was further modified. This was repetitively done to reach to a substantial satisfaction of stakeholders.

2.2. Outline of HydroGIS tool

The development of HydroGIS tool is aimed at supporting the prevailing land approval procedure of urban development authority in Sri Lanka. This procedure requires a land developer to submit a hardcopy application containing details of a proposed development. At present the approval granting system does not carry out a systematic hydrologic evaluation and its impacts on flood. The Land parcels in Thimbirigasyaya municipal area in Colombo, Sri Lanka were selected as the spatial extent for tool testing.

Then proposed HydroGIS tool compares the pre and post development hydrology of the land allotment to grant approval with or without modifications following the procedure shown in Fig. 1. At the commencement, the tool facilitates the decision maker to perform land modifications (Phase one of Fig. 1). Then it visualizes modification's effect on the runoff generation (Phase 2). Whilst Phase 3, the applicant and the decision maker are facilitated to perform interactive modifications by carrying out consultative modifications to identify the best available alternative for sustainable flood management.

The HydroGIS tool development used a cyclic approach to

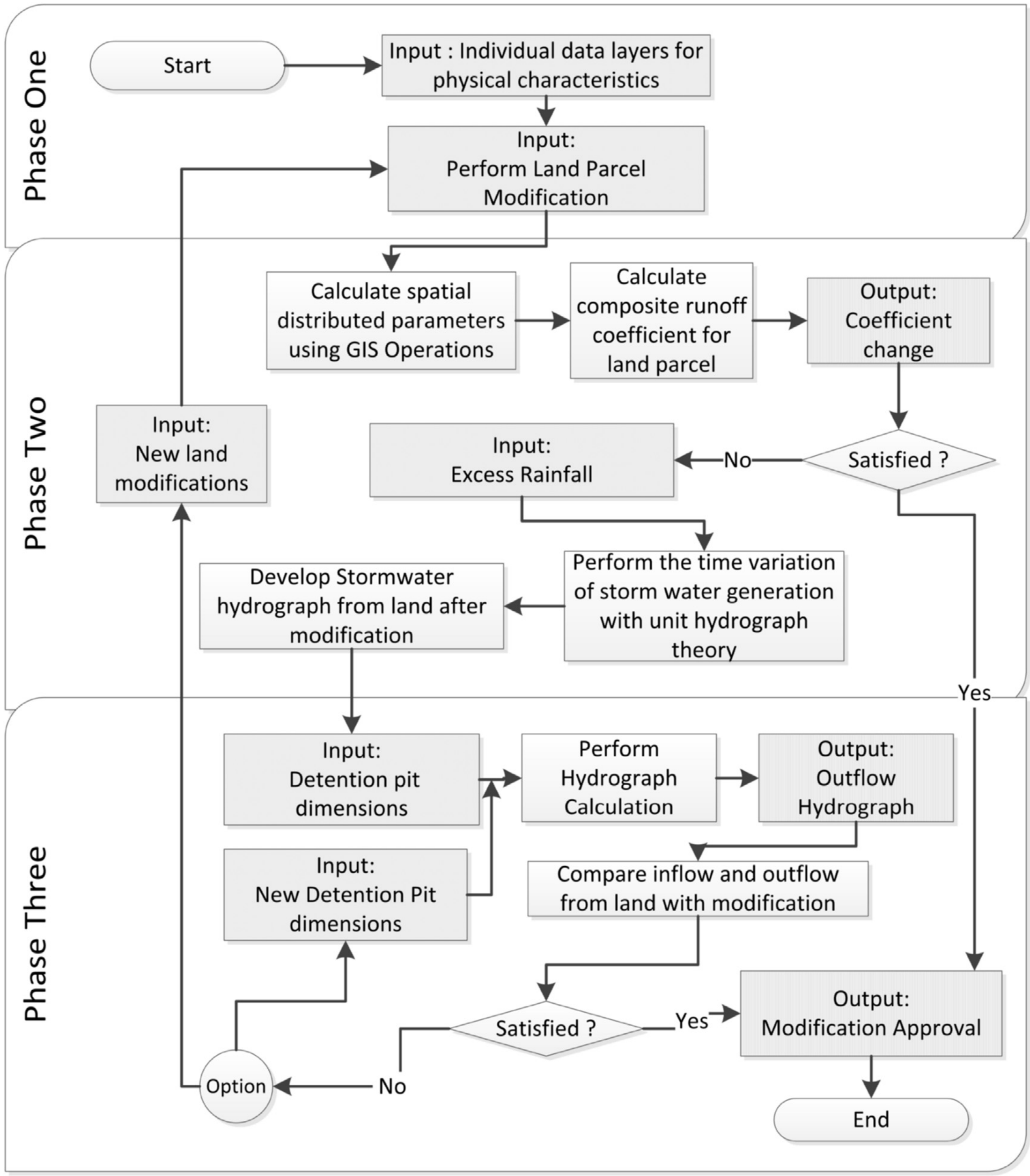


Fig. 1. The process of flood management decision making of the HydroGIS tool.

systematically accomplish the stakeholder aspirations by carrying out repeated evaluation of outputs against the objectives whilst the complex hydrologic calculations automate separately. This specific software development methodology is described in the previous work of the authors [69].

2.3. Stakeholder requirements

2.3.1. Key stakeholders

Key stakeholder groups were identified thorough Critical evaluation of the main use case which is granting the approval for land modifications. It reveals that the stakeholders associated with urban flood management consist of four main groups; Group1 – The recipient stakeholders whose desire is to receive the land development approvals are the individual land owners or real estate/construction agents. Group 2 –The decision making stakeholders are the policymakers and regulators granting approvals and they are mostly non-technical. System operators who perform a mandatory role by transferring information back and forth between the recipient stakeholder, regulators, decision makers, GIS experts, and hydrologic modelers making a variety of decisions are also grouped with decision makers. Group 3 –The expert group consisting of hydrologic and GIS modelers are the technical stakeholders who implement the desires of both recipient and decision maker stakeholders. Group 4 – System and software developers, including computer programmers who strive to deliver a tool of sufficient quality tool facilitate the decision-making process are the software developer stakeholders.

In practice hydro and GIS modelers are expected to deliver verified models to software developers to incorporate codes for automation. Thereafter software developers incorporate the tool requirements to suit the decision makers and recipient stakeholders. In the present setting of land approval, a land owner's application is considered by the decision makers in consultation with the tool operators who transfer the requirements to the software developers. Therefore, in the present development, the key roles considered are those of the decision maker and the software developers.

2.3.2. Documented requirements

Identification of requirements affecting the stakeholders was first carried out by evaluating the state of art and then by performing a consultation of professionals for the confirmation and filling of gaps. Ramachandran [70] has urged to follow the best practices as those can produce high quality software products while securing stakeholder requirements and development costs. The system development methodology is a fundamental best practice. Since 1960s' different methodologies are practiced, but today, the methods which are evolved to satisfy the user requirements are popular [71]. However, Shmueli and Ronen [72] warn the that greater attention on requirement development as it may negatively affect the system development project schedule, quality and cost.

When considering the HydroGIS tool development, Sui and Maggio [73], review that the practice is either incorporation of GIS to hydrology model or vice-versa. However, Shamsi [74], recommends the hydro model to GIS software due to the modeling maturity of hydrology makes the use of technical maturity of GIS platforms.

When considering the information security requirements of the tool, the Department of Community Development of New Berlin city [75] has paid a special attention to security and integrity of spatial land data. It enhances the stakeholders' confidence by protecting the urban land information which are equally worth of urban lands. Further, Bertino et al. [76], who seek the research directions in spatial data security, state that the spatial data standards are important as it provides the interoperability whilst maintaining the privacy.

The design requirements of Decision Support Systems (DSS) are reasonably well documented. The study of Speier and Morris [77]; which is on decision making accuracy, mental workload and time consumption against the different user interfaces; reveals number of interface considerations when addressing problems with increased complexity in dynamic environments. When Liang et al. [78], developed a land management system to Dingzhuang city of China, it has been ideintifed convenient and reversibility in operation, unanimity in interfaces and simple feedback are as the major design principles. Cázares-rodríguez el al. [79], show that the DSS should provide not only the solutions but also technical alternatives to develop stakeholders' confidence.

Assaf et al. [34], whilst attempting to incorporate stakeholders for DSS system, found that the DSS should provide interactive graphical based stakeholder decision making facility. Singh and Kumar's [80] review on the input data scale impacts on output found that the choice of spatial data, data resolution and efficiency of processes are depending on the stakeholders' output requirements.

2.3.3. Professional view

A consultative survey to capture the aspirations of non-technical decision makers and GIS system developers on the development of a HydroGIS tool for urban flood management was carried out with a sample of 31 non-technical decision makers and four GIS system developers.

The non-technical decision makers requested a software tool that can be installed with ease, enables trouble free data entry, capable of data manipulation without migrating to other tools, and facilitates a smooth execution of computations with a simple "Next-Next button click" process. Key requirements of the decision makers also included the need of a tool capable of easy map utilization for data handling, presentation, decision making and output map generation as hard copies. Specific requests were for the maps that enable easy understanding of land modifications, easy on screen map and attribute editing capability. Regarding hydrologic outputs, the stakeholder requirement was to receive easily understandable graphical results that could easily educate land owners. Trial and error capability to carry out a variety of alternative land modifications, and competency to view and analysis extra spatial information by accessing base software whilst the tool is running were also requested by the non-technical decision makers. However, the decision makers as a critical concern cited the assurance of land information data security preventing unauthorized independent access to database and also preventing use of tool for unapproved alterations. System developers were concerned about the difficulty of achieving data security when using an off the shelf GIS platform for HydroGIS tool development.

System developers pointing to the challenge of achieving a user-friendly GIS map based hydro model without having structured guidelines stressed the need to contribute towards better GIS-GUI development guidelines. The other key concern raised was the time constraint for modeler-developer interaction due to urgency for product development by adhering to independent development of the front end and the back end of tools. Developers highlighted the need for intensified stakeholder interactions to achieve.

Finally, the following six requirement classes have been identified from the literature review and stakeholder discussions were used as guidance for HydroGIS tool development. These requirement classes are: (1) Automated tool (2) Platform Selection/Suitable Base Software for the tool (3) Software Development (4) System Security (5) Dynamic Decision Making and (6) User Friendliness.

2.4. Stakeholder requirement integration

2.4.1. Automated tool and Platform Selection/Suitable Base Software for the tool

The present work selected GIS as the base software whilst the hydrology model is embedded using codes due to the technological advancement of GIS software than hydrology modelling software. Then HydroGIS tool was developed as a Dynamic Link Library (DLL) extension to the off-the-shelf GIS software package, due to the flexibility to the users. ESRI's ArcMap was selected as the base GIS software due to the higher popularity among communities. The details of the automation are described in author's previous work [68].

2.4.2. Software development

The present work identified two main works whilst automation. One is the accurate automation of hydrology model with GIS and other is incorporating the user concerns sufficiently. Then a predictive development method was used as the core for the tool development however, whilst an adaptive development methodology with repetitive prototype development was utilized as a hybrid methodology for the present user interface development. In this effort, development works of both the user interface and the hydro & GIS model computational modules were simultaneously started by incorporating a combined modelling effort thus reflecting a development model which oriented a process centric development to achieve a user centric tool. The process is described in the previous work by the authors [69].

2.4.3. System Security

The present work scenario requested two main functions; share the spatial data with other authorities and identify unauthorized alterations; which are partially available with the selected GIS software. Therefore, a security stamp was incorporated to each spatial feature which enabled the recognition of alterations and recognizing the nature of authorization. The security stamp for each spatial feature was generated by a simple mathematical model which combines the spatial and non-spatial data of each spatial feature. In the developed HydroGIS tool, the user authentication layer recognizes the authorized users to update the spatial features. The security stamp concepts and verification work which are beyond the scope of the objectives of the present work are described in authors previous work [81].

2.4.4. Dynamic decision making

Because of the dynamic decision making concern can be primarily

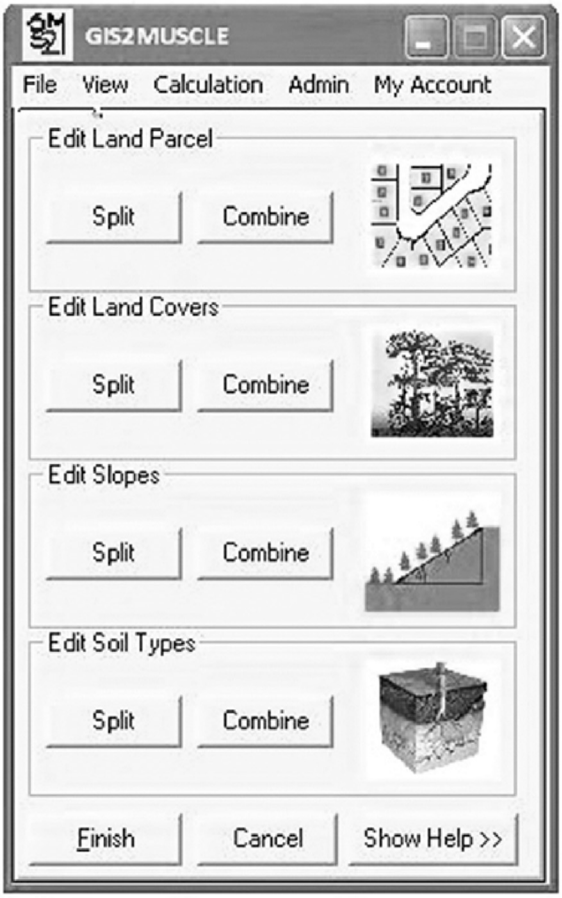


Fig. 2. Main GUI of the Tool, Note: The Figure shows a snapshot of on-screen parcel clipping action. Additionally, it shows three attribute update GUI parts which appear after on-screen map modifications.

satisfied through trial-and-error facility, the tool is developed with enabling the back and forth movement in process. Quick and repeated backward movements with undo facility provide the opportunity for a decision maker to rebound to an identified milestone. Further, the rapid dynamic decision making is always hindered by delays in feeding management inputs. Therefore, the tool functionality presents default values/suggestions that can be edited as necessary. Apart from that, as a measure to reduce incorrect executions either due to data or procedure errors, the tool design embedded a step wise requirement to obtain decision maker confirmation. Simultaneously, output presentations on map and customizable charts also intend to assist quick decision making whilst dynamic decision making is made easy by enabling parallel use of tool and the base software for actions such as customizing and printing maps. This parallel access capability also enables the use of GIS software functions for spatial data manipulation while providing the users a feeling that the tool is a part of the familiar base software.

2.4.5. User friendliness

In the absence of guidelines to achieve user friendliness of GIS-GUI extension, a GIS-GUI development guideline has been developed (see authors' previous work [82]). Then following such, the HydroGIS tool developed to carryout onscreen land modifications, to compare the executed land alterations, to easily add attributes and to perform systematic confirmation of edits. Further, the tool designed to maximize map visualization by reducing the GUI window space. To enhance user confidence the tool has been further developed to display the modifications on a map with customized print facility. To achieve user friendly easy operation, the tool designed to equipped with default data values and backward the processes step by undo facility.

A user manual with descriptions and illustrations of the tool was developed to support user friendliness. Further online assistance which maintaining the styles of the main GIS platform's online assistance was developed. Formative evaluations were carried out for satisfaction of these materials.

2.5. Evaluation with stakeholders

The tool was developed and tested with data of Thimbirigasyaya Ward of Colombo municipal council, Sri Lanka. The initial stakeholder satisfaction evaluation was carried out using a sample of 31 users. After that, the resulted suggestions were appropriately incorporated and subjected to the 1st formative evaluation with 34 users. Similarly, the 2nd and 3rd evaluations and modifications were done with 31 and 34 stakeholder sets. After a comparison of the gradual increase of stakeholder satisfaction in the key areas of concern, the HydroGIS was accepted to submit for practical application.

A structured questionnaire was developed for easy tools testing. The stakeholders after performing the tasks of land approval process using the HydroGIS expressed their satisfaction levels as a percentage. The process took special efforts to facilitate the stakeholders with both without tool and with tool situations for the assessment of the advantages of the tool during the evaluation. Testing was carried out with two sets of potential system operators. One set participated in the first three evaluations and the final evaluation with the other set was considered as tool verification. Finer details of the evaluation process are described in earlier work [82].

3. Results

3.1. The HydroGIS tool

The developed HydroGIS tool was named as "Geographic Information Systems to Manage Urban Storm Water Considering Land Enhancement (GIS2MUSCLE)". Main window of tool (Fig. 2) was designed to maintain the ~0.6 perimetric ratio – aka Golden Ratio, to achieve user-comfort. The major user friendly features of the tool are the on-screen dynamic map and attribute modification capabilities (Fig. 3), clear visualization of the changes to runoff coefficients (Fig. 4) and display of information pertaining to the storm water runoff before and after the land modifications with effect of dynamic detention storage (Fig. 5).

Soil Type Update Window: Shows the attribute update GUI for modify the soil type of the modified layer.

Slope Class Update Window: Shows the attribute update GUI for modify the slope classes of the modified layer.

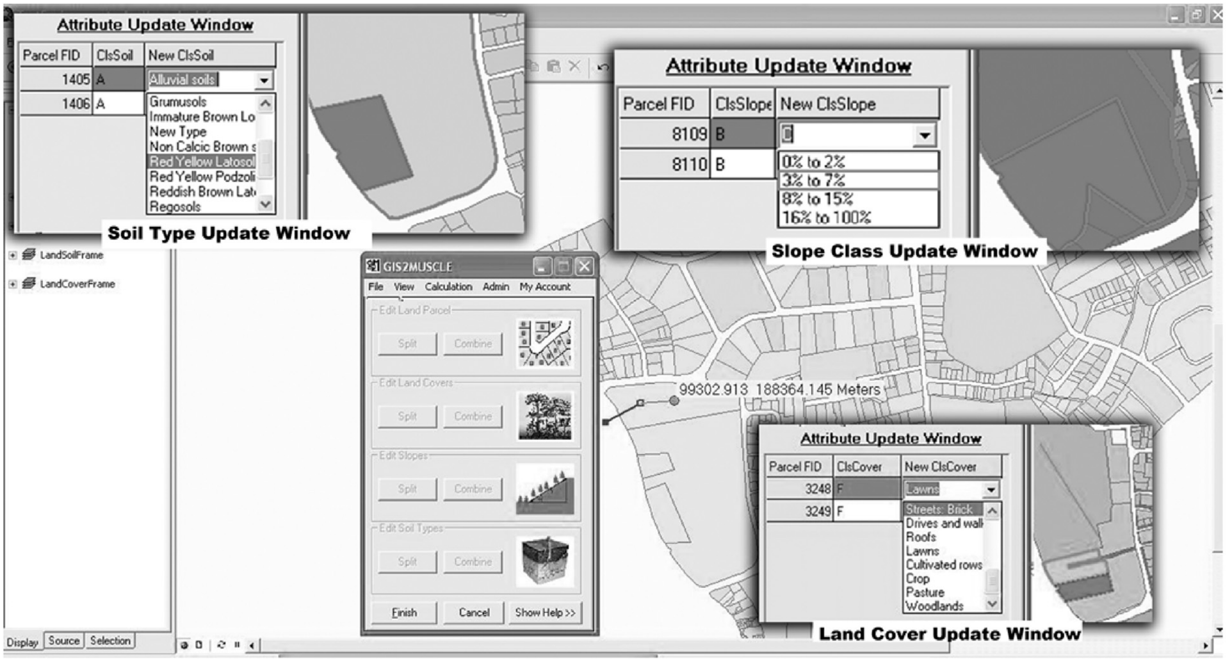
Land Cover Update Window: Shows the attribute update GUI for modify the land cover of the modified layer.

3.2. Evaluation of stakeholders concerns

The step by step evaluation results are shown in the Table 1. Evaluation of software development methodology was not included in the stakeholder evaluation since the performance of the product as per stakeholder requirements and delivered by following guideline methods would reflect the appropriateness of the method used for software development.

3.2.1. Automated tool

The initial evaluations received 72% satisfaction for the process automation. The absence of adequate installation guidance and difficulty to combine two adjacent land parcels and their attributes were the two main suggestions that had to be incorporated. The next evaluation with these additions received a 77% stakeholder satisfaction with a suggestion to customize the attribute update method. This addition increased the satisfaction level to only 78% since the stakeholders made a request to further strengthen the onscreen installation assistance and map feature



Note:

The Figure shows a snapshot of on-screen parcel clipping action. Additionally, it shows three attribute update GUI parts which appear after on-screen map modifications.

Soil Type Update Window: Shows the attribute update GUI for modify the soil type of the modified layer

Slope Class Update Window: Shows the attribute update GUI for modify the slope classes of the modified layer

Land Cover Update Window: Shows the attribute update GUI for modify the land cover of the modified layer

Fig. 3. On-screen dynamic map modification and attribute update GUIs of the Tool.

identification with automatic highlighting facility. Incorporation of these features raised the satisfaction level to 96%.

3.2.2. *User friendliness*

The final tool prior to stakeholder evaluation received a very low satisfaction rating of 46%. This evaluation resulted in requests for standardized GUI sizes, user friendly control and text labels, pop-up help facility, facility to display progress of each GIS operation, feedback messages for modifications, and on screen printing capability. Incorporation of these capabilities increased the tool satisfaction up to 65%. Stakeholder concerns were to incorporate error messages with recovery information, layer buttons with icons, maintenance of command button and text integrity, and small size GUI with more map layouts. Incorporation of these improved the stakeholder satisfaction only up to 70%. Stakeholders expected the improvement of professional attire in maps, a size change of GUI during hydrograph manipulation, a user manual, visual clarity and enhancement of hydrograph display. Once these were achieved the tool received a 92% satisfaction for user friendliness.

3.2.3. *Incorporation of security*

At the first evaluation, the tool lacked a security option, and hence the stakeholder satisfaction was 0%. The stakeholder sample also lacked suggestions. In the next development stage, many options were attempted to secure the data from unauthorized manipulation. The option of physical access control through a lock and key arrangement in a standalone computer was incorporated. Stakeholders showed non-satisfaction with a 0% satisfaction. The development strategy of the tool was changed by considering that data security is a component solely to be handled by a user authentication method within the Tool. In this effort the greatest obstacle was to embed a method for an approved user to recognize any unauthorized changed to data. The concept which was tested in the next stakeholder evaluation received a 35% satisfaction. In this effort a novel method that can identify both attribute and spatial feature changes was developed. The proposed method which deviated from the conventionally preferred prevention methods, generates a soft key for the authorized user to capture unauthorized changes and revert to a secured authenticated setting. The details are included in authors' previous work [81]. Incorporation of this procedure gained 89% satisfaction.

3.2.4. *Base software selection*

The selection of ArcGIS as the base software received a 65% stakeholder satisfaction at the first evaluation. The tool developed as a button of ArcGIS map window in the second version increased the satisfaction to 72%. The stakeholder requirement for conjunctively use base software functions whilst the tool been active was selectively embedded and facilitation of these functionalities increased the satisfaction to 76%. Subsequent stakeholder requirements to incorporate additional base software functionality such as GIS layer manipulation modelling were included. This capability to add most of the desired functionalities to the HydroGIS for conjunctive use increased the stakeholder satisfaction of base software selection to a value of 93%.

3.2.5. *Dynamic nature*

The most important dynamic nature, which is the capability to easily and rapidly carry out undo and redo tool operations in the first version of

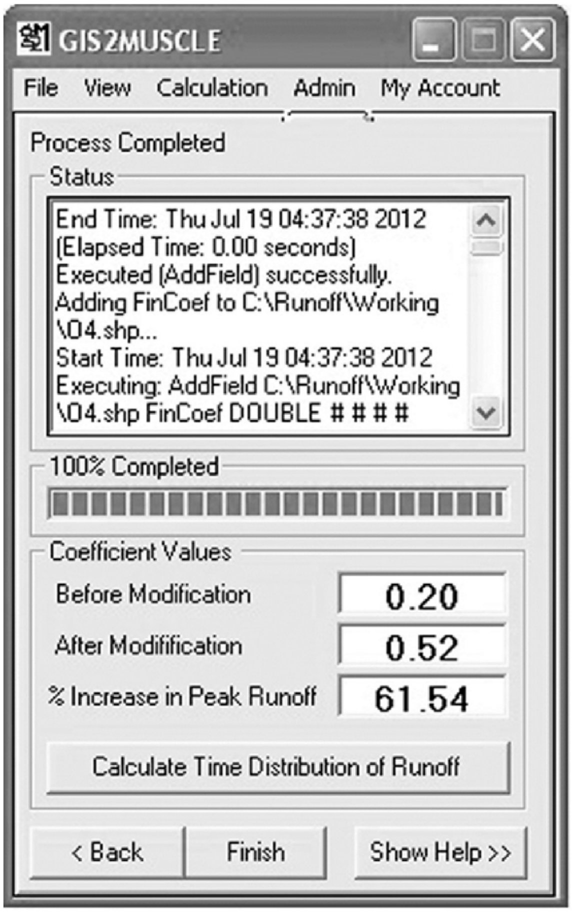


Fig. 4. GUI Showing land modification effect on runoff coefficients.

the tool received a stakeholder satisfaction of 58%. The stakeholders required dynamic map modifications with undo facility and the addition of this to the tool increased the satisfaction to 65%. However, the satisfaction level could be increased to 72% by adding the stakeholder requests to enable on screen dynamic changes to the hydrology parameter changes and manipulation of layer classification schema. At this stage of evaluation, a general request was for dynamic visualization of hydrologic results with the inclusion of a flood detention facility in the land parcel. These modifications enhanced the stakeholder satisfaction of the dynamic nature of the tool up to 93%.

3.2.6. Stakeholder confidence

Stakeholder evaluations with the selected sample indicated an average overall satisfaction level of 92%, which can be considered as a very high achievement under the present setting of tools, methods and guidance material. Stakeholder confidence is always relative to the visibility of present mechanisms and with respect to the time required for reliable outputs. The present HydroGIS demonstrated a vast improvement compared with the prevailing setup and highlighted the confirmation of the success of developed tool using stakeholder based recognition of issues and evaluation of achievements. The present tool removed many decision making barriers to achieve the required services, accuracy and security. The present work demonstrates the need, possibility and method of incorporating the most essential stakeholder role when developing an urban flood mitigation decision tool.

4. Discussion

Sustainable urban land development management is considered as the key to urban flood management. Such sustainability can be achieved through integrating the land development and flood management activities. Then development of such tool must strike a balance between the process automation and the achievement of stakeholder concerns & confidence. Another important consideration is the integration of hydro model and GIS software (HydroGIS) which are the most required components of urban land and flood management.

Among the hydro-GIS integration options, integration of hydro model into the GIS base software was selected since (1) GIS function automation requires complex coding and testing which becomes a laborious and time consuming task, (2) commercial or open source GIS platforms which are specially developed to perform GIS functions accurately and efficiently leads to better user confidence while saving tool development efforts and time and (3) availability of significant developer-community for GIS automation platforms. When considering the easy installation, the present work focused on the best architectural option as development of the HydroGIS tool to a Dynamic Link Library (DLL) extension in off-the-shelf GIS software package, ArcMap.

Bhathal and Singh [83] found that the available security products are insufficient to fulfill the unique stakeholder requirements in new IT paradigm like big-data management In the same way, there is a unique stakeholder concern which is to secure the author's data-dictatorship in HydroGIS paradigm. In present setting, the intended spatial data of land allotments are managed by both local authorities and water management agencies. The possession of valuable urban land allotment boundaries, attributes and their security are not exclusively handled by a single agency, but simultaneously both need the ownership of the data. There are several spatial data security studies such as watermark, hash algorithms [84], GeoXACML [85] and Attribute Based Access Control [86], but those do not provide the required functionalities. Hence, a novel method was incorporated enabling the sharing of the dataset but recognizing any alterations made to data. The security concerns regarding the computations carried out by combining GIS functions also poses a challenge. The stakeholder expectation was to giving security related feedback whilst in the workflows rather than forensic analysis. Therefore, for the automation of processes, the option of developing codes that can be integrated to the security layer was chosen over the readily available Model Builder tool of ArcMap software.

In the absence of guidelines to achieve user friendliness of GIS-GUI, a novel guideline was developed following GNOME guideline of Benson et al. [87], European Union BEST-GIS guideline [88] and visual consistency guideline of Bloch [89]. It found that the fundamental rules of buttons, texts, icons, windows and feedback messages are common to HydroGIS tools too. However, to gain the maximum user friendliness, the HydroGIS tools should provide more attention to user interface of hydrology calculations. Onscreen modification of parameter data, dynamic visual effect such as zoom in and out in hydrograph visualization and real-time result display on maps are few of them. Further, the work proved the successful application of the golden ratio for window sizes according to Gustav Fechner (stated by Stone and Collins) [90]. Even select a popular GIS base software to reduce the learning curves, it developed a user manual with tutorial to increase user friendliness as per Bloch's [89] idea.

Overall, the dynamic nature of the tool gives the flexibility to technical stakeholders to handle the hydrological parameter data such as runoff coefficient and designed rainfall values for local area whilst the non-technical stakeholders to perform calculations for required land parcels and customize flood management options align with hydrological requirements. Then these facilities ensure an active and lively environment for the stakeholders to carry out the desired functionalities with less difficulties.

5. Conclusions

The present study has identified numerous stakeholders through a scientific approach. Among them, there are two main groups as non-technical decision makers and system developers whose concerns are

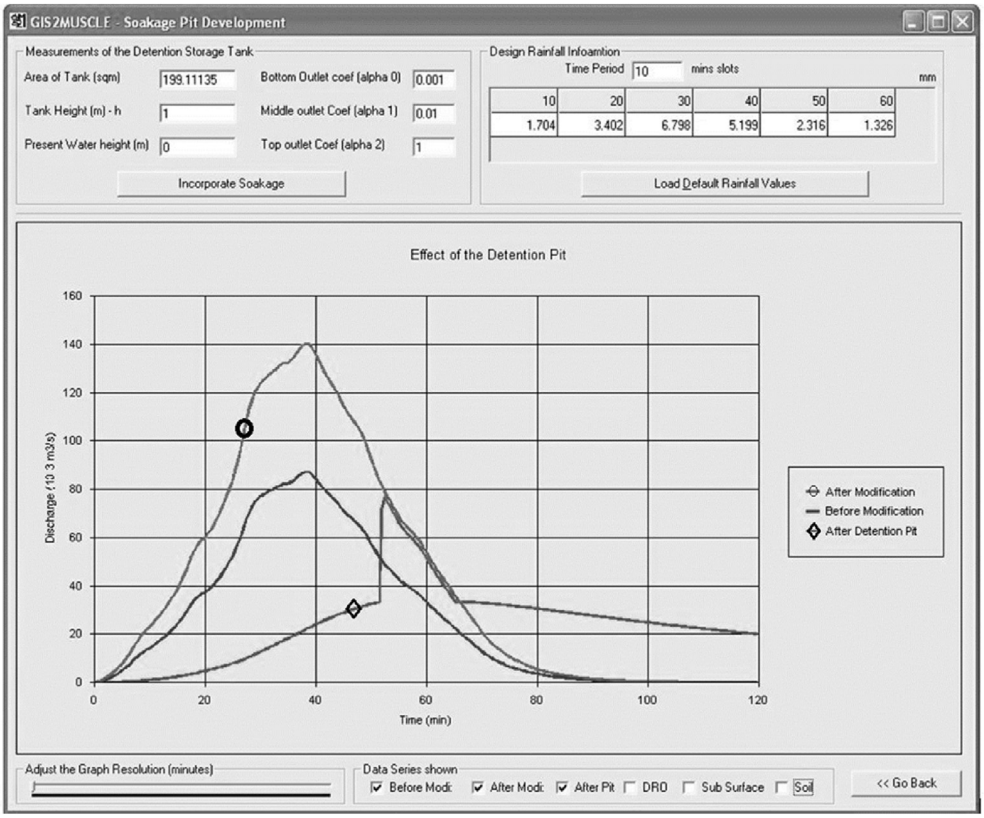


Fig. 5. GUI for visualization of storm water runoff before & after the land modifications and after incorporation of dynamic detention storage.

Table 1
Tool evaluation results.

Requirement	Evaluation cycle			
	1	2	3	4
Development of Automated Tool	72%	77%	78%	96%
Achievement of User-friendliness	46%	65%	70%	92%
SW Development	Did not evaluated through users			
Data and Output Security	0%	0%	35%	89%
Use of Appropriate Base Software	65%	72%	76%	93%
Dynamic Nature of the Tool	58%	65%	72%	93%
Average	48%	56%	66%	92%

the key for successful HydroGIS development. The main stakeholder requirements of the HydroGIS tool were identified as, the development of an automated tool, selection of a suitable software platform, method of software development ensuring the incorporation of stakeholder aspirations, Data and System Security, Dynamic Decision Making capability and User Friendliness. More importantly, it incorporated the easy facilitation of hydrologically as well as a stakeholder/decision maker agreed land development. Then present work could identify in-depth stakeholder concerns and successfully incorporated into the HydroGIS tool with the substantial satisfaction of the potential stakeholders.

The main contribution of the present work is a demonstration of how to identify, evaluate, incorporate and verify the stakeholders and their concerns which is lack of documentations for HydroGIS tool at present. Whilst the other works paying attention to stakeholders concern on output, the present work reveals that input, process and output requirements also to be automated for easy decision making. Those are practically implemented in the developed tool through providing interfaces to technical and non-technical stakeholders to evaluate, adjust, redo/undo and visualize hydro and GIS inputs, processes and outputs. Further, the entire work has carried out a detailed study on; suitable hybrid software development methodology for stakeholder concerns incorporation [69], provide spatial data security for the scenario [81] and GIS-GUI development guideline [82]. Then those proved that the present work has carried out a substantial effort to fill the identified research gap.

Finally, the present work demonstrates the purport and the implementation of a structured development approach and the way to verify the incorporation of urban flood management stakeholders' needs with the scientific hydrology model.

Credit author statement

RMM Pradeep: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Funding acquisition, NTS Wijesekera: Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration.

Declaration of competing interest

No potential conflict of interest was reported by the authors. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Price RK, Vojinovic Z. Urban food disaster management. Urban Water J 2008;5(3): 259–76. https://doi.org/10.1080/15730620802099721.

[2] United Nations. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). Demographic Research 2019. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

[3] Hellmers S, Manojlovic N, Palmaricciotti G, Fröhle P. Modelling decentralised systems for urban drainage and flood mitigation. Journal of Applied Water Engineering and Research 2017;5(1):61–9. https://doi.org/10.1080/23249676.2015.1128368.
[4] Carver S. "Flood management and nature– can rewilding help? ECOS: A Rev Conserv 2016;37(1):32–42. British Association of Nature Conservationists, https://www.ecos.org.uk/wp-content/uploads/2016/05/ECOS-37-1-32-Flood-management-and-nature.pdf.
[5] Konrad CP. Effects of urban development on floods: USGS fact sheet FS-076-03. U.S. Geol. Surv.; 2003. p. 1–4. https://pubs.usgs.gov/fs/fs07603/.
[6] Xia J, Falconer RA, Lin B, Tan G. Modelling flash flood risk in urban areas. Water Manag 2011;164(WM6):267–82. https://doi.org/10.1680/wama.2011.164.6.267.
[7] Jha AK, Bloch R, Lamond J. Cities and flooding: a guide to integrated urban flood risk management for the 21st century. Washington DC: World Bank; 2012. http://hdl.handle.net/10986/2241.
[8] Hammond OMMJ, Chen AS, Djordjević S, D. B.. Urban flood impact assessment: a state-of-the-art. Urban Water J 2013;12(1):14–29. https://doi.org/10.1080/1573062X.2013.857421. http://hdl.handle.net/10871/14066.
[9] Pregnolato M, Ford A, Wilkinson SM, Dawson RJ. The impact of flooding on road transport : a depth-disruption function. Transp. Res. Part 2017;55:67–81. https://doi.org/10.1016/j.trd.2017.06.020. https://www.sciencedirect.com/science/article/pii/S1361920916308367.
[10] Elmoustafa AM. Weighted normalized risk factor for floods risk assessment. Ain Shams Eng. J. 2012;3:327–32. https://doi.org/10.1016/j.asej.2012.04.001. https://www.sciencedirect.com/science/article/pii/S2090447912000251.
[11] Gunaruwan TL. "Economics of flood damage prevention investment in Colombo metro Area : strategic perspectives explored through a viability threshold analysis. In *the 5th international Conference of SLFUE: Sri Lanka economics research conference*. SLERC) Volume V; 2016. p. 250–5. www.semanticscholar.org/paper/Economics-of-Flood-Damage-Prevention-Investment-in-Gunaruwan/b1a7efd873538c61f8fae6f9dfb70f26ab92e4bc.
[12] Huizinga J, De Moel H, Szewczyk W. Global flood depth-damage functions. Methodology and the database with guidelines. EUR 28552. Luxembourg: Publications Office of the European Union; 2017. https://ec.europa.eu/jrc/en/publication/global-flood-depth-damage-functions-methodology-and-database-guidelines.
[13] World Bank. High and dry: climate change, water, and the economy. Washington, DC: International Bank for Reconstruction and Development/The World Bank; 2016. openknowledge.worldbank.org/handle/10986/23665.
[14] Zhou Q. A review of sustainable urban drainage systems considering the climate change and urbanization impacts. Water 2014;6(4):976–92. https://doi.org/10.3390/w6040976. https://www.mdpi.com/2073-4441/6/4/976.
[15] Leopold L. Hydrology for urban land planning - a guidebook on the hydrologic effects of urban land use, vol. 554. Washington, D.C.: U.S. Geological Survey; 1968. https://pubs.er.usgs.gov/publication/cir554.
[16] Mcpherson MB, Schneider WJ. "Problems in modeling urban watershed. Water resour Res 1974;10(3). https://doi.org/10.1029/WR010i003p00434.
[17] O Chan S, Bras RL. Urban storm water management: distribution of flood volumes. Water Resour Res 1979;15(2):371–82. https://doi.org/10.1029/WR015i002p00371.
[18] Jacques WD, Stergios AD, McPherson MB. "Modeling the runoff process in urban areas," *C R C*. Crit Rev Environ Contr 1980;10(1):1–64. https://doi.org/10.1080/10643388009381676.
[19] Maidment DR, Parzen E. Cascade model of monthly municipal water use. Water Resour Res 1984;20(1):15–23. https://doi.org/10.1029/WR020i001p00015.
[20] Te Chow V, Maidment DR, Mays LW. *Applied hydrology*, internatio. McGraw-Hill; 1988. http://ponce.sdsu.edu/Applied_Hydrology_Chow_1988.pdf.
[21] Smart P, Herbertson G. Drainage design. first ed. New York: Springer Science+Business Media; 1992. https://www.springer.com/gp/book/9781475750294.
[22] Shaw EM. Hydrology in practice. third ed. Taylor & Francis e-Library; 1994.
[23] Djokic D, Maidment DR. Terrain analysis for urban stormwater modelling. Hydrol Process 1991;5(1):115–24. https://doi.org/10.1002/hyp.3360050109.
[24] Mitchell VG, Mein RG, McMahon TA. Modelling the urban water cycle. Environ Model Software 2001;16(7):615–29. https://doi.org/10.1016/S1364-8152(01)00029-9. https://www.sciencedirect.com/science/article/abs/pii/S1364815201000299.
[25] Makarigakis AK, Jimenez-Cisneros BE. "UNESCO's contribution to face global water challenges. Water 2019;11(2). https://doi.org/10.3390/w11020388. https://www.mdpi.com/2073-4441/11/2/388/pdf.
[26] Ficchì A, Perrin C, Andréassian V. Impact of temporal resolution of inputs on hydrological model performance: an analysis based on 2400 flood events. J Hydrol 2016:454–70. https://doi.org/10.1016/j.jhydrol.2016.04.016. https://www.sciencedirect.com/science/article/abs/pii/S0022169416301974.
[27] Ichiba A, et al. Scale effect challenges in urban hydrology highlighted with a distributed hydrological model. Hydrol Earth Syst Sci 2018;22:331–50. https://doi.org/10.5194/hess-22-331-2018. https://hess.copernicus.org/articles/22/331/2018/.
[28] Eger CG, Chandler DG, Driscoll CT. Hydrologic processes that govern stormwater infrastructure behaviour. Hydrol Process 2017;31(25):4492–506. https://doi.org/10.1002/hyp.11353.
[29] Fatichi S, et al. An overview of current applications , challenges , and future trends in distributed process-based models in hydrology. J Hydrol 2016;537:45–60. https://doi.org/10.1016/j.jhydrol.2016.03.026. https://www.sciencedirect.com/science/article/abs/pii/S0022169416301317.
[30] Ogden FL, Garbrecht J, Debarry PA, Johnson LE. GIS and distributed watershed models. II: modules, interfaces and models. J Hydrol Eng 2001;6(6):515–23. https://doi.org/10.1061/(ASCE)1084-0699(2001)6:6(515).
[31] Thakur JK, Singh SK, Ekanthalu VS. Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. Appl. Water Sci. 2017;7(4):1595–608. https://doi.org/10.1007/s13201-016-0384-5.
[32] Kovar K, Nachtnebel HP, editors. HydroGIS93: application of geographic information systems in hydrology and water resources management (proceedings of the Vienna conference, April 1993). Vienna: IAHS; 1993.
[33] Pradeep RMM, Wijesekera NTS. Urban flash flood mitigation using a dynamic HydroGIS Tool. In: GeoConf 2014. Colombo: CRD; 2014. https://doi.org/10.13140/RG.2.2.21437.56800.
[34] Assaf H, et al. "Generic simulation models for facilitating stakeholder involvement in water resources planning and Management : a comparison , evaluation , and identification of future needs. In: Jakeman AJ, Voinov AA, Rizzoli AE, Chen SH, editors. In Developments in integrated environmental assessment, elsevier, vol. 3. Elsevier B.V.; 2008. p. 229–46. https://www.sciencedirect.com/science/article/pii/S1574101X08006133.
[35] Sörensen J, et al. Re-thinking urban flood management-time for a regime shift. Water 2016;8(332):1–15. https://doi.org/10.3390/w8080332. https://www.mdpi.com/2073-4441/8/8/332.
[36] Gray S, Paolisso M, Jordan R, Gray S, editors. Environmental modeling with stakeholders: theory, methods, and applications. Springer; 2017. https://www.springer.com/gp/book/9783319250519.
[37] Scott M, Edwards S, Rahall NJI, Nguyen T, Cragle J. GIS story maps: a tool to empower and engage stakeholders in planning sustainable places, vol. 25701. " Newark, DE/Huntington, WV; 2016. http://udspace.udel.edu/handle/19716/21597.
[38] Han MY, Chen GQ, Dunford M. Land use balance for urban economy: a multi-scale and multi-type perspective. Land Use Pol 2019;83(March 2018):323–33. https://doi.org/10.1016/j.landusepol.2019.01.020. https://www.sciencedirect.com/science/article/abs/pii/S0264837718304022.
[39] Struyk RJ, Angelici K. The Russian dacha phenomenon. Hous Stud 1996;11(2):233–50. https://doi.org/10.1080/02673039608720854.
[40] Bacco M, Barsocchi P, Ferro E, Gotta A, Ruggeri M. The digitisation of agriculture: a survey of research activities on Smart Farming. Array 2019;3(4):100009. https://doi.org/10.1016/j.array.2019.100009. https://www.sciencedirect.com/science/article/pii/S2590005619300098.
[41] Micropact Inc.. Land records management solutions. Texas: Court Mana. Tyler Technologies; 2019. https://empower.tylertech.com/rs/015-NUU-525/images/Datasheet_entellitrak_Land-Records-Management_1119.pdf.
[42] Accela. Accela land management. California: Accela Inc; 2016. https://accela.com/images/resources/brochures/accela-land-overview.pdf.
[43] Jain SK, Singh G, Gore MM. "Municipal GIS design and implementation of LRS – a case study. in *Map India Conference*; 2003.
[44] General Code. Municity : parcel management software. 2014. New York.
[45] Bhatt G, Kumar M, Duffy CJ. A tightly coupled GIS and distributed hydrologic modeling framework. Environ Model Software 2014;62:1–15. https://doi.org/10.1016/j.envsoft.2014.08.003. https://www.sciencedirect.com/science/article/abs/pii/S1364815214002266.
[46] Eslinger DL, Carter HJ, Pendleton M, Burkhalter S, Allen M. OpenNSPECT. 2012 [Online]. Available: https://coast.noaa.gov/digitalcoast/tools/opennspect. [Accessed 20 June 2018].
[47] Innovyze Inc.. InfoWorks ICM suite. 2020.
[48] Al-Sabhan W, Mulligan M, Blackburn GA. A real - time hydrological model for flood prediction using GIS and the WWW. Comput Environ Urban Syst 2003;27:9–32. https://doi.org/10.1016/S0198-9715(01)00010-2. https://www.sciencedirect.com/science/article/pii/S0198971501000102.
[49] Worku T, Khare D, Tripathi SK. "Modeling runoff–sediment response to land use/land cover changes using integrated GIS and SWAT model in the Beressa watershed. Environ. Earth Sci. 2017;76:550 1–14. https://doi.org/10.1007/s12665-017-6883-3.
[50] Zhan X, Huang ML. ArcCN-Runoff: an ArcGIS tool for generating curve number and runoff maps. Environ Model Software 2004;19(10):875–9. https://doi.org/10.1016/j.envsoft.2004.03.001. https://pubs.er.usgs.gov/publication/70026763.
[51] Sanzana P, et al. A GIS-based urban and peri-urban landscape representation toolbox for hydrological distributed modeling. Environ Model Software 2017;91(May):168–85. https://doi.org/10.1016/j.envsoft.2017.01.022. https://www.sciencedirect.com/science/article/abs/pii/S1364815216305679.
[52] NOAA Inc.. ISAT : impervious surface analysis tool. NOAA Office for Coastal Management; 2017.
[53] Miah MG, Islam MR. "Use of GIS and RS in agriculture of Bangladesh : present status and prospect. In: Proceedings of international workshop on advanced use of satellite- and geo-information for agricultural and environmental intelligence; 2011.
[54] Kitchenham B, Charters S. Guidelines for performing systematic literature reviews in software engineering. Keele University and Durham University; 2007. https://userpages.uni-koblenz.de/~laemmel/esecourse/slides/slr.pdf.
[55] Criollo R, et al. AkvaGIS: an open source tool for water quantity and quality management. Comput Geosci 2019;127(November 2018):123–32. https://doi.org/10.1016/j.cageo.2018.10.012. https://www.sciencedirect.com/science/article/pii/S0098300417312311.
[56] Xu ZX, Schultz GA IK, Li JY. Integrated hydrologic modeling and gis in water resources management. J Comput Civ Eng 2001;15(3):217–23. https://doi.org/10.1061/(ASCE)0887-3801(2001)15:3(217).

[57] Pingale S, Jat MK, Khare D. Integration of GIS in environmental modelling and hydrological Analysis : a review of integration technologies. In: National conference on infrastructure development in civil engineeringin civil engineering; 2012.

[58] Henriksen HJ, Refsgaard JC, Hojberg AL, Ferrand N, Gijsbers P, Scholten H. Harmonised principles for public participation in quality assurance of integrated water resources modelling. Water Resour Manag 2009;23(12):2539–54. https://doi.org/10.1007/s11269-008-9395-9.

[59] Voinov A, et al. Modelling with stakeholders - next generation. Environ Model Software 2016;77(January):196–220. https://doi.org/10.1016/j.envsoft.2015.11.016. https://www.sciencedirect.com/science/article/abs/pii/S1364815215301055.

[60] Leskens JG, Brugnach M, Hoekstra A. How do interactive flood simulation models influence decision-making? an observations-based evaluation method. Water; 2019.

[61] Jessel B, Jacobs J. Land use scenario development and stakeholder involvement as tools for watershed management within the Havel River Basin. Limnol. Elsevier 2005;35(3):220–33. https://doi.org/10.1016/j.limno.2005.06.006. https://www.sciencedirect.com/science/article/pii/S0075951105000460.

[62] Macchione F, Costabile P, Costanzo C, De Santis R. Moving to 3-D flood hazard maps for enhancing risk communication. Environ. Model. Softw., no. January 2019: 510–22. https://doi.org/10.1016/j.envsoft.2018.11.005. https://www.sciencedirect.com/science/article/abs/pii/S1364815218300690.

[63] Van Ackere S, Glas H, Beullens J, Deruyter G, De Wulf A, De Maeyer P. Development of a 3D dynamic flood WEB GIS visualisation tool. Int. J. Saf. Secur. Eng. 2016;6(3):560–9. https://doi.org/10.2495/SAFE-V6-N3-560-569. https://www.witpress.com/elibrary/sse-volumes/6/3/1350.

[64] Leskens JG, Kehl Christian, Tutenel Tim, Kol Timothy, Haan Gerwin de, Stelling Guus, et al. An interactive simulation and visualization tool for flood analysis useable for practitioners. Mitig Adapt Strategies Glob Change 2017;22(2): 307–24. https://doi.org/10.1007/s11027-015-9651-2.

[65] Luke A, Sanders BF, Goodrich KA, Feldman DL, Boudreau D, Eguiarte A, et al. Going beyond the flood insurance rate map: insights from flood hazard map co-production. Nat Hazards Earth Syst Sci 2018;18(4):1097–120. https://doi.org/10.5194/nhess-18-1097-2018. https://escholarship.org/uc/item/30z7z36p.

[66] Otero C. Software engineering design: theory and practice. first ed. New York: CRC Press; 2016. https://www.taylorfrancis.com/books/e/9780429100376.

[67] Pradeep RMM, Wijesekera NTS. Development of a GIS tool to capture changing land allotment parameters for urban runoff computation. In: 16th ERU symposium, 2010. Moratuwa: ERU, UoM; 2010. http://dl.lib.mrt.ac.lk/handle/123/8191.

[68] Pradeep RMM, Wijesekera NTS. GIS tool to mitigate urban flash floods through capturing land allotment modifications and incorporating conceptual detention pit. In: ITRU 2012. Moratuwa: ITRU, UoM; 2012. http://dl.lib.mrt.ac.lk/handle/123/9792.

[69] Pradeep RMM, Wijesekera NTS. Predictive cum adaptive systems development methodology for HydroGIS tool development. In: 10th international research conference. Ratmalana: KDU; 2017. http://ir.kdu.ac.lk/handle/345/1682.

[70] Ramachandran M. Guidelines based software engineering for developing software components. J Software Eng Appl 2012;5:1–6. https://doi.org/10.4236/jsea.2012.51001. https://www.scirp.org/pdf/JSEA20120100005_95712632.pdf.

[71] Lei H, Ganjeizadeh F, Jayachandran PK, Ozcan P. A statistical analysis of the effects of Scrum and Kanban on software development projects. Robot Comput Integrated Manuf 2015;43:59–67. https://doi.org/10.1016/j.rcim.2015.12.001. https://www.sciencedirect.com/science/article/abs/pii/S0736584515301599.

[72] Shmueli O, Ronen B. Excessive software development: practices and penalties. Int J Proj Manag 2017;35(1):13–27. https://doi.org/10.1016/j.ijproman.2016.10.002. https://www.sciencedirect.com/science/article/abs/pii/S026378631630182X.

[73] Sui DZ, Maggio RC. Integrating GIS with hydrological modeling: practices, problems, and prospects. Comput Environ Urban Syst 1999;23(1):33–51. https://doi.org/10.1016/S0198-9715(98)00052-0. https://www.sciencedirect.com/science/article/pii/S0198971598000520.

[74] Shamsi UM. GIS and water resources modeling :state-of-the-art. J. Water Manag. Model. 1999. https://doi.org/10.14796/JWMM.R204-05. https://www.chijournal.org/Content/Files/R204-05.pdf.

[75] DCD. Enterprise geographic & land information systems: plans, policies and procedures. City of New Berlin Department of Community Development; 2007. New Berlin, Wisconsin, https://www.newberlin.org/DocumentCenter/View/113/GIS-Policy?bidId=.

[76] Bertino E, Gertz M, Thuraisingham B, Damiani ML. Security and privacy for geospatial Data : concepts and research directions. In: ACM SPRINGLWorkshop. ACM; 2008. p. 6–19. https://doi.org/10.1145/1503402.1503406.

[77] Speier C, Morris MG. The influence of query interface design on decision-making performance. MIS Q 2003;27(3):397–423. https://doi.org/10.2307/30036539. https://www.jstor.org/stable/30036539.

[78] Liang Y, Sun W, Diao H, Li Y. The design and development of the land management system in Dingzhuang town based on spatial data, *comput. Comput. Technol. Agric. IV. CCTA 2010*. IFIP Adv Inf Commun Technol 2010;346:57–65. https://doi.org/10.1007/978-3-642-18354-6_9.

[79] Cázares-rodríguez JE, Vivoni ER, Mascaro G. Comparison of two watershed models for addressing stakeholder flood mitigation Strategies : case study of hurricane alex in monterrey , méxico. J Hydrol Eng 2017;22(9):1–16. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001560.

[80] Singh G, Kumar E. Input data scale impacts on modeling output results : a review. J Spatial Hydrol 2017;13(1). https://www.researchgate.net/profile/Gurdeep_Singh22/publication/321759023_Input_data_scale_impacts_on_modeling_output_results_A_review/links/5a30b748a6fdccbf7ef154da/Input-data-scale-impacts-on-modeling-output-results-A-review.pdf.

[81] Pradeep RMM, Wijesekera NTS. Development of security stamp for desktop spatial data modification in unrestricted access platform. In: In 8th intrernational research conference. Ratmalana: KDU; 2015. http://ir.kdu.ac.lk/handle/345/1057.

[82] Pradeep RMM, Wijesekera NTS. Modification of user friendliness in to a HydroGIS tool. In: 8th intrernational research conference. Ratmalana: KDU; 2015. http://ir.kdu.ac.lk/handle/345/1138.

[83] Bhathal GS, Singh A. Big Data: hadoop framework vulnerabilities, security issues and attacks. Array 2019;1–2:100002. https://doi.org/10.1016/j.array.2019.100002. https://www.sciencedirect.com/science/article/pii/S2590005619300025.

[84] Li A, Lin B, Chen Y, Lü G. Study on copyright authentication of GIS vector data based on zero-watermarking. Int Arch Photogram Rem Sens Spatial Inf Sci 2008; XXXVII(B4):1783–6. https://pdfs.semanticscholar.org/54d3/69f51b837eac9dfc7df65e0aaa4a38084051.pdf.

[85] Le Thi KT, Thi QNT, Dang TK. An enhanced access control model for gis database security. Electr. Electron. Eng. Comput. Inf. Eng. 2014;3(1):40. http://www.aseanengineering.net/aej/issue/2014-v3-1/new/34-45%20AN%20ENHANCE%20ACCESS%20CONTROL%20MODEL%20FOR%20GIS%20DATABASE%20SECURITY(final).pdf.

[86] Hu VC, et al. Guide to attribute based access control (ABAC) definition and considerations. National Institute of Standards and Technology; 2014.

[87] Benson C, Clark B, Nickell S. GNOME human interface guidelines 2.0. Free Software Foundation; 2004. https://developer.gnome.org/hig-book/hig-book-html-3.8.0.tar.gz.

[88] GISIG (Genova). Guidelines for best practice in user interface for GIS. European Commission; 1998.

[89] Bloch J. How to design a good API and why it matters. In: Companion to the 21st ACM SIGPLAN conference on Object-oriented programming systems, languages, and applications - OOPSLA `06. ACM Digital Library; 2006. p. 506–7.

[90] Stone LA, Collins LG. The golden section revisited: a perimetric explanation. Am J Psychol 1965;78(3):503–6. https://doi.org/10.2307/1420591. https://www.jstor.org/stable/1420591.