Can SaniChoice contribute to better urban sanitation planning?

A case study in Changunarayan, Nepal

Master Thesis in Environmental Science and Engineering

submitted by

Basile Weber

supervised by

Dr. Dorothee Spuhler (eawag)
Prof. Dr. Urs von Gunten (EPFL)

September 2, 2022

eawag aquatic research EPFL

Acknowledgments

I wish to show my sincere appreciation to every person who inspired, guided or supported my work in very different way and to extend my special thanks to the following persons who gave a relevant contribution to this work (given in alphabetical order):

Christoph Lüthi
Dorothee Spuhler
Dimitri Weber
Mingma Sherpa
Phurba Moktan
Quentin Pythoud
Siddhartha Shakya
Urs von Gunten

and the entire Sandec team for the precious coffee breaks, laughs and absorbing discussions.

Abstract

To provide access to sustainable, locally appropriate and inclusive sanitation for the entire world population, international research has triggered the development of a large number of sanitation technologies and several sanitation strategic planning frameworks. The selection of a combination of these technologies to create entire sanitation systems is a complex decision-making problem that encompasses multiple criteria, many technical alternatives and different stakeholder preferences. Although it can be facilitated by structured decision-making (SDM) frameworks, the generation of sanitation system options and the lack of information for their performance evaluation still represent a challenge. The situation enhanced in developing urban areas that are characterised by rapid growth, a general lack of infrastructure (water, energy, solid waste), high density, and a lack of human and financial resources.

SaniChoice is an online decision support tool for strategic sanitation planning developed at Eawag [Spuhler et al. 2020]. It allows to systematically select technologies, generate systems and compare them regarding different criteria. The aim is to make sanitation technology and system selection more evidence-based and more transparent to lead to more appropriate and accepted technical alternatives. It comes with its Practitioners' Guide that summarizes the integration procedure of the tool into any strategic sanitation planning framework. This master thesis aims to assess the contribution of SaniChoice and its Practitioners' Guide to the sanitation planning process in Changunarayan, a municipality in the periphery of Kathmandu, Nepal. The main objectives were (1) to assess if SaniChoice allows efficient identification of locally appropriate sanitation solutions considering novel technologies in a systematic way; (2) if it helps to prioritise sanitation systems with high resource recovery potentials; (3) if it helps to come up with more inclusive solutions in line with the Citywide Inclusive Sanitation (CWIS) principles; (4) and if its integration into existing sanitation planning framework contributes to enhance the transparency of the selection process and the ownership of local stakeholders.

SaniChoice does allow to transparently identify locally appropriate sanitation technologies including novel ones thereby contributing to the prioritisation of more inclusive and resource efficient sanitation solutions. In contrast, the Practitioners' Guide suggests meaningful supporting resources and activities that can enhance the ownership of local stakeholders. However, SaniChoice is a new tool that still requires some improvements to be fully applicable and used as a significant support tool for strategic and inclusive sanitation planning. Important needs for improvement is the simplification of criteria and better guidance on what criteria to use when in order to find a good balance between complexity and transparency. The testing of the Practitioner's Guide lead to the development of a new systematic methodology to define zones within a city and different types of settlement. This allows to come up with a mix of different appropriate systems considering the heterogeneity of an urban area. In the case of Changunarayan, the results provide valuable alternative options that triggered interesting discussions among the local decision-makers and the process raised the interest of the local partners who recognized its contribution to develop a more transparent and inclusive citywide sanitation planning.

Résumé

Afin de fournir un accès à un assainissement durable, stratégique, approprié et inclusif à l'ensemble de la population mondiale, la recherche internationale a dévelopé un grand nombre de technologies d'assainissement et plusieurs lignes directrices de planification stratégique de l'assainissement. La sélection d'une combinaison de ces technologies pour créer des systèmes d'assainissement complets et localement appropriés est un problème complexe de prise de décisions qui englobe de multiples critères de durabilité, de nombreuses alternatives techniques et différentes préférences des parties prenantes. Bien qu'elle puisse être facilitée par des cadres décisionnels structurés (SDM), la génération d'options de systèmes d'assainissement et le manque d'informations pour l'évaluation de leurs performances représentent toujours un défi important. La situation est renforcée dans les zones urbaines en développement qui se caractérisent par une croissance rapide, un manque général d'infrastructures (eau, énergie, déchets solides), une forte densité et un manque de ressources humaines et financières.

SaniChoice est un outil d'aide à la prise de décision pour la planification stratégique de l'assainissement développé à l'Eawag [Spuhler et al. 2020]. Il permet de sélectionner systématiquement des technologies, de générer des systèmes et de les comparer en fonction de différents critères. L'objectif est de rendre la sélection des technologies et des systèmes d'assainissement plus transparente et basée sur des preuves afin de conduire à des alternatives techniques plus appropriées et acceptées. Il est accompagné d'un manuel d'utilisation qui résume la procédure d'intégration de l'outil dans n'importe quelle framework de planification d'assainissement. Ce projet de master vise à évaluer la contribution de SaniChoice et de son manuel d'utilisation à la planification d'assainissement à Changunarayan, une municipalité dans la périphérie de Katmandou, au Népal. Les principaux objectifs étaient (1) d'évaluer si SaniChoice permet l'identification efficace de solutions d'assainissement localement appropriées en tenant compte des nouvelles technologies d'une manière systématique ; (2) s'il aide à donner la priorité aux systèmes d'assainissement à fort potentiel de récupération des ressources ; (3) s'il aide à trouver des solutions plus inclusives en conformité avec la *citywide inclusive sanitation (CWIS)* ; (4) et si son intégration dans la planification d'assainissement contribue à améliorer la transparence du processus de sélection et l'appropriation des parties prenantes locales.

SaniChoice permet d'identifier de manière transparente les technologies d'assainissement appropriées au niveau local, y compris les nouvelles, contribuant ainsi à la priorisation de solutions d'assainissement plus inclusives et efficaces en termes de ressources. D'autre part, le manuel d'utilisation constitue un soutien significatif en proposant entre autres des activités intégrant SaniChoice au processus de plannification qui visent à renforcer l'appropriation par les parties prenantes locales. Cependant, SaniChoice est un nouvel outil qui nécessite encore quelques améliorations pour être pleinement applicable et utilisé comme un outil de soutien significatif pour la planification stratégique et inclusive de l'assainissement. Les besoins importants d'amélioration sont la simplification des critères et une meilleure orientation sur quels critères utiliser quand afin de trouver un bon équilibre entre la complexité et la transparence. Le test du manuel d'utilisation a conduit au développement d'une nouvelle méthodologie systématique pour définir différentes zones au sein d'une ville. Cela permet d'obtenir une palette de différents systèmes d'assainissement appropriés en tenant compte de l'hétérogénéité d'une zone urbaine. Dans le cas de Changunarayan, les résultats fournissent de précieuses alternatives qui ont déclenché des discussions intéressantes parmi les décideurs locaux et le processus a suscité l'intérêt des partenaires locaux qui ont reconnu sa contribution au développement d'une planification de l'assainissement plus inclusive et transparente à l'échelle de la ville.

Contents

Glossary

Capex Capital Expenditure.

CWIS Citywide Inclusive Sanitation.

DEWATS Decentralized Wastewater Treatment Systems.

FG Functional Group
Grouping of sanitation technologies that have similar functions. There are five FGs: U: *User Interface*, S: *Collection and Storage*, C: *Conveyance*, T: *Treatment* and D: *Use and/or Disposal*.

FGD Focal Group Discussion.

GIS Geographic Information System.

MoU Memorandum of Understanding.

O&M Operation & Maintenance.

ODF Open Defecation Free.

Opex Operational Expenditure.

SAS System Appropriateness Score.

SDG Sustainable Development Goal.

SDM Structured Decision Making.

ST System Template
It defines a class of sanitation systems with similar conceptual characteristics such as if the system is dry or wet, if it produces biofuel, sludge, biomass or uses urine diversion or considering its level of decentralisation (onsite, decentralized, centralized or hybrid). Each sanitation system can be assigned to one unique template.

SWOT Strength, Weaknesses, Opportunities, Threats..

TAS Technology Appropriateness Score.

WASH Water supply, Sanitation and Hygiene
Interventions to reduce people's exposure to disease by providing a clean environment in which to live, with measures to break the cycle of disease. This involves both behaviours and facilities which work together to form a hygienic environment.

WWTP Wastewater Treatment Plant.

1 Introduction

1.1 Motivation and problem statement

Sanitation refers to the access to and use of facilities and services for the safe management of human excreta [WHO, 2018]. Universal, affordable and sustainable access to sanitation is a key issue for human well-being since it directly affects the human and environmental health and is one of the biggest and most urgent challenges faced by most developing countries [WHO, 2018; WHO and UNICEF, 2021]. Improving sanitation isn't only reducing the risk of disease transmission but also a basic ingredient to enhance the attractiveness of a city in terms of socio-economic development [Hutton and Varughese, 2016; Parkinson et al., 2014]. Access to safe and clean drinking water and sanitation is a human right [UN, 2010]. The Millennium Development Goals concerning sanitation focus mostly on toilet coverage and safe containment, whereas the Sustainable Development Goals (SDGs) underline the importance of sanitation, together with water and hygiene (WASH) along the entire sanitation value chain from the toilet to collection and treatment *SDG6. Ensure availability and sustainable management of water and sanitation for all* [UN, 2018b]. It targets among other to achieve by 2030 access to safe and affordable drinking water (SDG6.1), adequate and equitable sanitation, hygiene and end open defecation (SDG6.2), improve water quality and increase recycling and safe reuse (SDG6.3) [UN, 2015].

Despite these efforts, 46% of the global population didn't have access to safely managed sanitation in 2020 according to Figure 1. Therefore, about half of the population is subject to high risk of faecal contamination, including 20% of very high risks [WHO and UNICEF, 2021]. The unprecedented growth of urban areas of developing countries caused by rural exodus combined with population growth significantly increases the urban sanitation challenge.

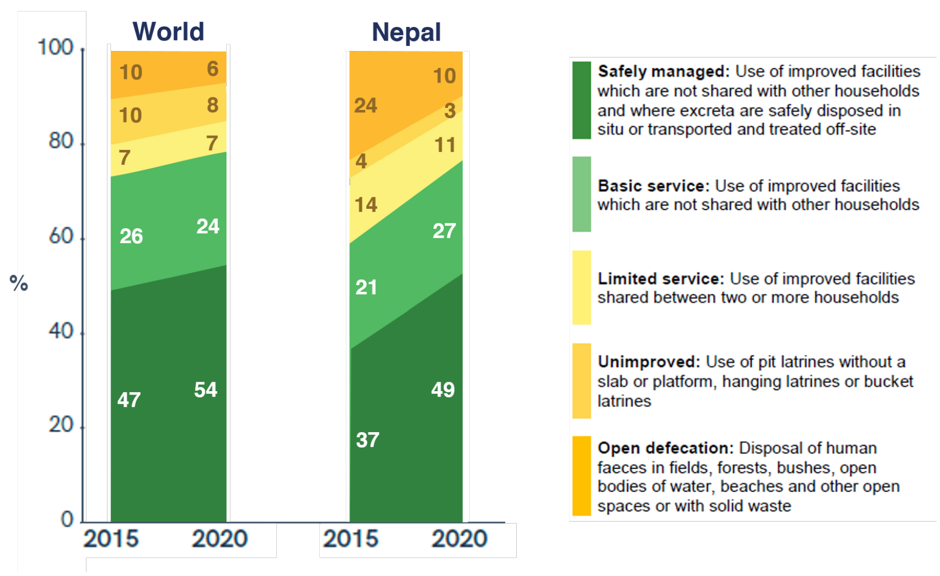


Figure 1: Percentage of sanitation service level worldwide and in Nepal adapted from [WHO and UNICEF, 2021].

While Nepal is one of the most water rich countries in the world [Gurung et al., 2019], WASH is a major issue due to poor technical knowledge, lack of hygiene barrier and safe water barrier, deficient investment, and a lack of monitoring and maintenance. Today, around 90% of Nepal's population has at least access to basic drinking water services, 49% to safely managed sanitation and 62% to basic hygiene services [WHO and UNICEF, 2021]. For sanitation, the Nepal government, helped by international support and NGOs improved between 2015 and 2020, the WASH situation: open defecation decreased by 14% and access to at least basic sanitation increased by 18% (Figure 1). By declaring Nepal an open defecation free (ODF) country in 2019 [MoWS, 2020], the government moved the sanitation challenge from toilet coverage downstream the sanitaiton value chain to total sanitation.

To increase access to WASH in the growing urban areas of Nepal, WASH plans have to be developed and implemented. While the country is doing relatively well in terms of developing these plans, sanitation is often under-prioritized or even left out. To address this issue, the Ministry of Water Supply and the Department of Water Supply and Sewerage Management (DWSSM) with support from WaterAid have started recently to develop specific guidelines for Citywide Inclusive Sanitation (CWIS) Planning. Narayan and Lüthi defined the CWIS as an approach to urban sanitation, where all members of the city have equitable access to adequate and affordable improved sanitation services through appropriate systems of all scales (sewered and non-sewered), without any contamination to the environment along the entire sanitation value chain [A. Narayan and Lüthi, 2020b]. The CWIS approach requires to think differently focusing on service provision and on its appropriateness, rather than on building infrastructure based on the conventional sewerage and wastewater treatment [Gambrill et al., 2020]. To reach the higher levels of services provided by universal coverage of sanitation systems, one has to identify sanitation system planning options that fit the different physical context and stakeholder preferences in a given urban area [Spuhler et al., 2020]. These sets of options consist of a mix of locally appropriate technologies when combined create an entire and valid sanitation system from the user interface to end use or disposal. In line with the definition of Sustainable Sanitation [SuSanA, 2008] and the SDGs, these systems also allow for resource recovery.

When designing a new sanitation system or improving an existing one, five sustainability criteria have been defined by the Sustainable Sanitation Alliance [SuSanA, 2008]. One should consider

1. the protection of human **health and hygiene** which includes the risk of exposure to pathogens and hazardous substances at all points of the considered system

2. the protection of the **environment and natural resources** required for the implementation of the system to avoid any pollution and optimise resource use and recovery

3. a locally **appropriate technology**, considering the local environmental and economical conditions and leading to operation and maintenance of the entire system

4. the **financial and economic viability** including the capacity of the local community to pay for the sanitation system (initial investments and operational and maintenance costs) and benefits from recycled products

5. the socio-cultural and institutional **acceptance** through its compatibility with legislation, authorities and infrastructures but also taking into account gender issues and impacts on human dignity

1.2 Background

1.2.1 Sanitation challenges in the Global South

Planning for the unknown

The rapid urbanization caused by the population growth and rural exodus is a major concern for urban planning: about 70% of the global population will live in cities by 2050 against 54% in 2015 [UN, 2018a]. Although Nepal is one of the least urbanized countries in the world, it is also one with the fastest urban population growth and urbanization rate [Bakrania, 2015]. Indeed its urban population doubled in the last 20 years [UN, 2018a]. This becomes a challenge when designing a system for all to manage huge amounts of human waste in a constantly changing context where spatial disparities are growing day by day.

Complexities of urban sanitation

Urban areas in the Global South are heterogeneous in terms of variation of settlements. They include often a city core with middle and high income settlement, planned urban development areas, informal settlements and a peri-urban interface spreading the city in its surrounding environment. They are characterized by high density rates, low financial power of citizens, inadequate institutional capacity assessment and investments, complex social dynamics and land tenure, poor physical site condition or variable water quality and availability. These attributes can limit significantly the technologies and affect the long-term operation of treatment facilities.

Whether it consists in including the marginalized communities, seeing human waste as a resource or acknowledging the important role of the informal sector, considering the socio-cultural dynamic and acceptance is a key element to ensure sanitation sustainability. Therefore, each step towards the total sanitation coverage becomes a multidisciplinary challenge.

Past approaches failed to meet targets

Conventional wastewater treatment approaches based on centralized systems with conventional sewers have rarely been successful in low and middle income countries [Schertenleib et al., 2021]. Reasons include the continuous and large quantities of water and electrical power required, the high capital investment and high operation and maintenance (O&M) costs, stable institution, and the need for skilled expertise for maintenance [ADB, 2018; Schertenleib, 2005]. Also, they require large planning horizons and advanced management plans which is difficult for weak institutional setting. If such systems exist in developing urban areas, they most often only provide services for privileged settlements which generally consist in very small percentage of the urban population [Schertenleib et al., 2021]. In Nepal, most of these systems have largely failed: of the five WWTPs constructed in Kathmandu, none of them has worked consistently due to technical and manpower problems and still today, almost the entire volume of wastewater generated within the city is discharged directly into the Bagmati river.
Decentralized wastewater systems (DEWATS) are assumed to be more appropriate and suitable to the urban context in the Global South but the proper functioning of DEWATS often decreases when external support and funding stops. Reasons are often unawareness of users of the importance of O&M and thus reluctance to pay for the sanitation services once the problem is not visible anymore [Bright-Davies et al., 2015].

1.2.2 Strategic sanitation planning

1.2.2.1 Structured decision making (SDM)

SDM is a participatory approach that targets at dealing with multidimensional problems and at guiding any process to end up with value-based and transparent choices. It is based on a six steps approach: (1) clarifying the decision context, (2) identifying decision objectives, (3) developing decision options, (4) evaluating decision consequences, (5) discussing trade-offs and selecting preferred options and (6) implementing and monitoring [Gregory et al., 2012]. The SDM steps can be embedded in any existing sanitation planning framework such as the Community-led Urban Environmental Sanitation (CLUES), Sanitation 21 (San21) or City Sanitation Planning (CSP) as a facilitated participatory framework.
Furthermore, *A Sanitation Journey* [Schertenleib et al., 2021] reviews the different frameworks and tools that have been developed to operationalize the different steps of SDM (Shit Flow Diagram, Q&Q of Feacal Sludge, SaniPath, etc.). Nevertheless, most of these tools focus on step 1 of SDM and there is a lack of tools for the identification of the most appropriate options. SaniChoice (see section 1.2.3) could become an useful tool to counteract this lack, especially in step 3 and 4.

1.2.2.2 City-wide Inclusive Sanitation (CWIS)

Based on the Manila Principles on CWIS in the Figure 2, along with safety and sustainability, equity is one major component of this approach by putting inclusion in the center of the planning process. Inclusive means to fit equally everyone's needs, whatever its gender, disability, age, religion, caste or income level, by potentially providing several sanitation systems (e.g sewered and non-sewered) within the same city [A. Narayan and Lüthi, 2020a]. One can imagine centralized systems where economy of scale works (e.g. downtown), decentralized system for areas segregated by topographic, demographic or economic criteria and a system based on faecal sludge management in areas where access is an issue (e.g. slums or peri-urban settlements).

Manila Principles on CWIS

1. Equity
Everyone in an urban area – including communities marginalized by gender, social, and economic reasons – benefit from equitable, affordable, and safe sanitation services.

2. Environmental and public health
Human waste is safely managed along the entire sanitation service chain, starting from containment to reuse and disposal.

3. Mix of technologies
A variety of sewered and non-sewered sanitation solutions coexist in the same city, depending on contextual appropriateness and resource recovery potential.

4. Comprehensive planning
Planning is inclusive and holistic with participation from all stakeholders including users and political actors – with short- and long-term vision and incremental perspective and is synergistic with other urban development goals.

5. Monitoring and accountability
Authorities operate with a clear, inclusive mandate, performance targets, monitoring requirements, human and financial resources, and accountability.

6. Mix of business models
Sanitation services are deployed through a range of business models, funding sources, and financial mechanisms to reach all members equitably.

Figure 2: Manila Principles on CWIS [A. Narayan and Lüthi, 2020b]

To ensure the sustainability of the project, the responsibility of the service authorities to deliver services and their accountability to collect and report data for performance and monitoring is initially clarified.
CWIS in Nepal is an initiative taken by the Ministry of Water Supply (MoWS) to achieve the SDGs related to sanitation. It would help the authorities to align sanitation with the overall municipal development strategy and WASH plan to deliver safely managed sanitation services and achieve consistency in nationwide sanitation approaches. Thus, CWIS targets at moving from the ODF status to adequate "open discharge free" status by removing misconceptions about urban sanitation, creating interdisciplinary team and providing an informed decision-making process to develop ownership of local communities.

1.2.3 SaniChoice

To provide access to sustainable, more strategic, appropriate and inclusive sanitation for the entire world population, international research has triggered the development of a growing number of sanitation technologies and system configuration [Spuhler et al., 2020] regrouped among others in the *Compendium of Sanitation Systems and Technologies* [Ulrich et al., 2014], in the *Guide to Sanitation Resource-Recovery Products & Technologies* [Mcconville et al., 2020] or also in the *Compendium of Sanitation Technologies in Emergencies* [Gensch et al., 2018]. This can be seen as an opportunity to find the most appropriate technologies to a certain context but on the other hand, it might present difficulties in decision making. While strategic sanitation planning is an iterative multi-stakeholder process with many steps, SaniChoice focuses on the steps of identifying sanitation system options and comparing them to support the selection of a preferred option given the different stakeholder preferences.

Santiago Santiago (SANitation sysTem Alternative GeneratOr) is a package of the Julia programming language that allows to generate appropriate sanitation system options.
It is able (1) to find all possible system given a set of sanitation technologies, (2) to assess the appropriateness of a technology in a given context, (3) to assess the overall appropriateness of the sanitation systems previously built, (4) to calculate the massflows of relevant substances for each system and (5) to select a meaningful subset of systems for the given context.

The open-source package including the technology library, examples, R codes for the data analysis as well as a step-by-step guide on how to use the package are available on GitHub[1].

SaniChoice web-tool SaniChoice[2] is an online open-source capacity development and decision support tool currently being developed at Eawag. It is a user-friendly web-application of the Santiago software and technology library. Whereas Santiago is an expert software, SaniChoice is intended to a broader audience including different types of WASH practitioners. The primary target group however are engineering and planning consultants developing sanitation plans for towns and settlements. SaniChoice helps [Spuhler et al., 2021]:

[1]available online at https://github.com/santiago-sanitation-systems
[2]available online at https://www.sanichoice.net/

1. to learn on different technology options and select the locally most appropriate technologies for a specific case or use an advanced filter with geo-physical, technical, socio-cultural, legal, financial as well as criteria concerning capacity and management
2. to learn about and prioritise among different system templates (ST): dry, wet, onsite, decentralized or hybrid sanitation system producing biofuel, urine, blackwater, or biomass
3. to select and compare systems regarding resource recovery or losses, investment requirements, or system complexity
4. to save and share the results with a web link

SaniChoice considers multiple dimensions of sustainability but it focuses on the preselection of appropriate systems and technologies. It doesn't allow to quantify the performance of the system inherent to the real implementation nor designing the technology. SaniChoice only looks at the blackwater, with or without urine separation, but doesn't consider stormwater and greywater. Moreover, SaniChoice is only a tool and doesn't replace facilitation skills of the participatory planning process and thus always required an experienced facilitator to lead the workshops to integer it into the sanitation planning and experts to conduct the plausibility check, to look at non-technical aspects such as service delivery and to design the final selected option. After a SaniChoice application, the sanitation planning process is not completed and still requires the implementation and the monitoring of the selected sanitation system option.

Practitioners Guide The web-tool is complemented with the SaniChoice Practitioner's Guide [Spuhler et al., 2021]. This guide helps to apply SaniChoice as part of any structured decision making process for urban sanitation. It provides guidance on how to gain the required inputs for SaniChoice and what to do with the outputs in a facilitated participatory process (see Table 3 in appendix).

Expected benefits from the SaniChoice web-tool
(1) to systematically include a large range of technology options including innovations
(2) to make performance data available for an informed selection of the most appropriate technologies
(3) to enforce the consideration of entire and valid sanitation systems
(4) to prioritise sanitation systems with resource recovery

Expected benefits from the SaniChoice Practitioners' Guide
(1) to provide guidance to the SaniChoice user on how to integrate it with the planning process
(2) to ensure the participation of different stakeholders and thereby eventually leading to more accepted solutions and ownership for their implementation and long-term operation and maintenance

Moreover, SaniChoice can help to bridge different local priorities with citywide objectives and to find a mix of different sanitation systems appropriate to different conditions within the area. This should eventually lead to more citywide inclusive sanitation planning (CWIS).

1.3 Research objectives

The main aim of this master thesis is to test the SaniChoice web-tool and its Practitioners' Guide as a planning support tool in a real case. The application case is a town in Nepal where Eawag partners are currently carrying out a strategic sanitation process using a CWIS planning guideline for Nepal. SaniChoice will be used for the identification of technical sanitation solutions. The SaniChoice Practitioners' Guide will be used to embed the use of SaniChoice in the participatory multi-stakeholder planning process.
The specific objectives are:

1) To assess if SaniChoice allows efficient identification of locally appropriate sanitation solutions considering novel technologies in a systematic way;
2) To assess if SaniChoice helps to prioritise more appropriate sanitation systems with high resource recovery potentials including novel technology options;

3) To assess if SaniChoice helps to come up with more inclusive solutions by suggesting different solutions for all socio-demographic conditions in line with the CWIS principles;

4) To assess if different stakeholders feel that SaniChoice enhances transparency of the selection process as well as their acceptance and ownership of selected solutions.

These objectives lead to the following main hypothesis:

SaniChoice allows to transparently identify locally appropriate sanitation technologies considering novel technologies thereby contributing to a prioritisation of more inclusive and resource efficient sanitation solutions while enhancing the ownership of local stakeholders.

The main outputs of this thesis will be:

- An assessment of the appropriateness of different sanitation technologies for the given case
- A set of locally appropriate sanitation systems along with data to compare them regarding resource recovery and other dimensions
- An improved design of the SaniChoice Practitioners' Guide
- A better understanding of the contribution of SaniChoice in practice
- A SaniChoice case study

The master thesis started in April 2022 and ended in September 2022. Twice a stay of one month at Eawag in Dübendorf (April and September 2022) was realised. Additionally, research was conducted during a stay of three months (May - July 2022) in Changunarayan, Nepal together with a local private sanitation consulting company (500B Solutions Pvt. Ltd.).

2 Description of the case study

Changunarayan is a municipality located in Bhaktapur district in the province of Bagmati in the center west of Nepal, 20 km east of Kathmandu (see Figure 3). The municipality was formed in 2017 by merging the Village Development Committees of Changunarayan, Chhaling, Duwakot and Jaukhel into nine wards covering an total surface area of 62.98 km^2 [DUDBC, 2020]. It is populated by 64'260 people residing in 16'984 households [CBS, 2022] with a growth rate of 4.4%/yr. The average population density is 1020 cap/km^2 but one has to note that there exists a high-density variation within the municipality. The density can reach 2220 cap/km^2 (Ward 3) in proximity of Bhaktapur and 520 cap/km^2 in more remote and hilly areas (Ward 6, Nagarkot). Some pictures of the municipality are provided in Figures 27 to 29 in appendix B.4.

The annual mean temperature is 17°C with an annual precipitation of 2000 mm (average 1980-2020) mostly concentrated in the monsoon period from June to September [Sharma et al., 2021]. Agriculture is the first source of income of the municipality with a majority of rice paddies and maize culture [DUDBC, 2020]. Recovering slowly from COVID-19 crisis where the restrictions affected the crop planting behavior [Wasti et al., 2022], the agricultural sector in Nepal is now facing an important fertilizer crisis. The prices have risen nearly 30% since the Ukraine's invasion by Russia [Baffes and Chian Koh, 2022].

A road network serves the nine Wards of the municipality with 335 km of roads, mostly with earthen and gravel roads (68%) whereas paved road represents only 20% [DUDBC, 2020]. Although the current road system has been mostly developed during the last decade, the rainy weather during the monsoons period combined with badly managed or absent drainage system might make the earthen road impassable. According to the GIS analysis (Table 2 of Supplementary Information), the truck access in order to process to motorized-emptying of onsite containment is totally absent in about 40% of the residential zone and limited in 45% of the cases.

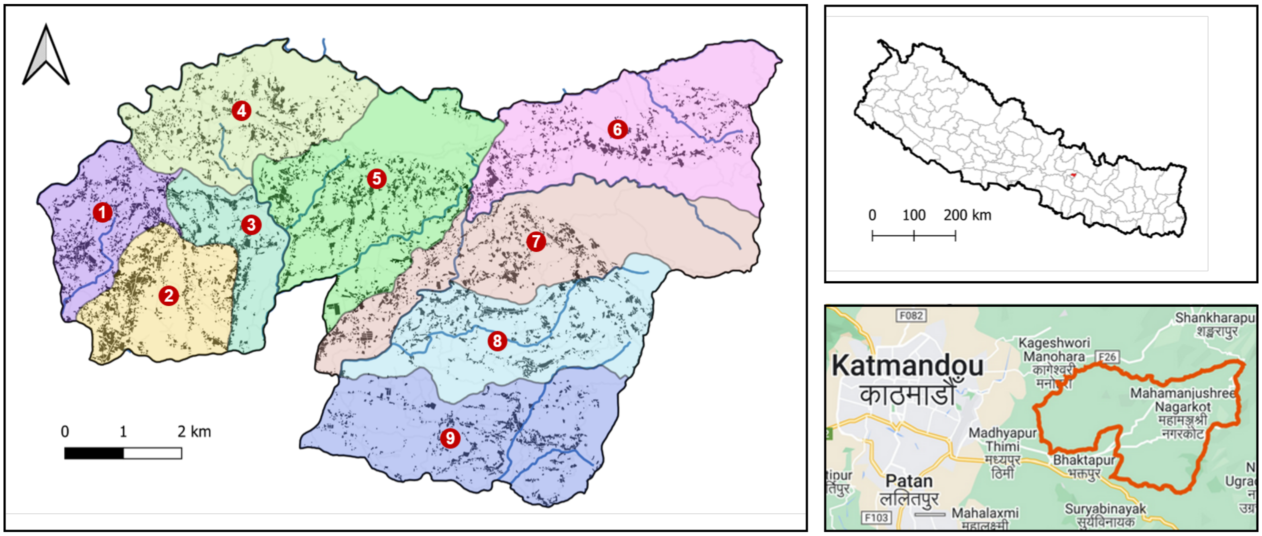


Figure 3: Changunarayan Municipality with the 9 Wards, its location in Nepal and relative to Kathmandu [source: author]

2.1 Water supply

Drinking water mostly comes from groundwater (60%) thanks to protected boreholes extracted from a depth of greater than 10 meters and from springs (40%) in the hilly areas [CWIS Technical Asistance Hub and Environment and Public Health Organization, 2019; WASH Task Force, 2021]. Availability of water is often limited in the dry season where the majority of the sources dry up. Nevertheless rainwater harvesting could make it available throughout the year. Still, 44.2% of households are facing difficulties in obtaining water on a daily basis. While 15% of households get enough drinking water only for drinking purpose and 61% for daily consumption (drinking and cooking), only 24% of households have sufficient water for drinking, cooking, cleaning and washing clothes [Changunarayan Municipality, 2020]. The households survey conducted with 500B Solutions (2022) revealed that 73% of the households have supply directly within the dwelling, 19% is at the yard level (private well or handpump) and 8% depend on public taps and wells reachable within 15 minutes.
In terms of water quality, 24% of the water sources used in the municipality have revealed the presence of coliforms. However, drinking water is purified in 67% of the households at the user interface (mostly ceramic candle filters or boiling) [Changunarayan Municipality, 2020].

2.2 Sanitation

User interface Almost every household (99.4%) has access to private toilets. The rest is shared at the neighborhood level, still under construction or defective due to lack of maintenance. Despite the open-defecation free (ODF) declaration by the municipality in 2013, open defecation is still slightly in practice (0.2%), even if they do have toilet facilities. The user interface mostly consist in pour flush toilets producing blackwater and very few households use pit latrines producing sludge mixed with the anal cleansing water [500B Solutions, 2022; Changunarayan Municipality, 2020].

Containment There is no standard design for the construction of holding tanks in the municipality. While people are aware about the need of septic tanks, people are unaware about the proper construction of septic tanks and its function, leading to misinformation of holding tanks and pits being recognized as proper septic tanks. Nowadays, the onsite containment system consists in holding tanks or pits that are emptied in about 40% of the cases [500B Solutions, 2022]. According to the Shit Flow Diagram (Figure 39 in Appendices), 83% of the faecal sludge is safely contained whereas 15% is not and approximately 2% consists in off-site sanitation and open defecation. Leachate from pits and unsafely managed septic tanks might biologically contaminate the groundwater and springs as demonstrates the presence of coliforms in the drinking water sources [Changunarayan Municipality, 2020].

Table 1: Current faecal sludge infrastructures in Changunarayan [500B Solutions, 2022]. The percentage represents the proportion of households using the considered infrastructure.

Fully lined tank (sealed)	**42%**
connected to a soak pit	1%
connected to an open drain or storm sewer	1%
no outlet or overflow	40%
Lined tank with impermeable walls and open bottom	**36%**
connected to a soak pit	2%
connected to an open drain or storm sewer	7%
no outlet or overflow	27%
Lined pit with semi-permeable walls and open bottom	**12%**
Piped sewer system	**5%**
Unlined pit	**2%**
Containment failed, damaged, collapsed or flooded	**2%**
Open defecation	**<1%**

Conveyance According to the households survey, only 40% of the containment technologies are emptied [500B Solutions, 2022]. Manual emptying (mostly in rural areas) was found to be dominant. Additionally, a service is provided by private tanker using mechanical emptying, unfortunately without using any personal protective equipment. Since there is no standard design of septic tanks, the emptying frequency varies from monthly to more than 10 years practices [CWIS Technical Asistance Hub and Environment and Public Health Organization, 2019].
Misconceptions of sewer systems have led to the connection of pour-flush toilet or holding tanks effluent to the storm water drains built mostly in ward 2 and 3 that nowadays transport about 5.2% of the faecal sludge and discharge it directly into the river [500B Solutions, 2022].

Treatment Today, there is no treatment facilities in the Changunarayan Municipality.
The integrated urban development plan (IUDP) suggests strategic projects for water treatment without going into details such as the implementation of a centralized wastewater treatment plant with biogas reactor, pilot project using constructed wetlands (reed beds) and even a treatment plant at the community level (Chapter 6.3.2 of IUDP [DUDBC, 2020]). Although the desire to implement a treatment system was mentioned, no area has been allocated for it.

Disposal When containment facilities are manually emptied which occurs more likely in rural areas, people mostly bury the faecal sludge in their own field or discharge it in the nearest open drain [500B Solutions, 2022]. Private tanker empties their tanks in various disposal sites in the banks of rivers [CWIS Technical Asistance Hub and Environment and Public Health Organization, 2019]. Furthermore, illegal discharge of faecal sludge to open drains or directly on the roads is a common practice in the municipality during the rainy season to avoid the emptying fees.

2.3 Hygiene

Within the municipality, 78% of households have access to hand washing facilities with soapy water but only 62% of them have developed the habit of washing their hands with soap and water [Changunarayan Municipality, 2020]. At the public level, only 25% of the educational institutions and 50% of the public places provide hand washing stations with soap.
Menstruation hygiene management is quite well achieved at the household level with 94% of the households having sufficient information about menstrual health. It can be improved at the public level where facilities for sanitary pad or tampons disposal is often absent. Furthermore, there still exists a segregation against women

who are not allowed to use toilets during their period in certain public and religious places [Changunarayan Municipality, 2020].

2.4 Solid waste management

The municipality hired Nepsemyak Sewa Pvt. Ltd. for the management of solid waste which consists in waste collection and disposal into legal dumpsites. Nevertheless, only 34% of the households have subscribed to the service, mostly in Ward 1 and 2 [Changunarayan Municipality, 2020]. The service doesn't separate inorganic from organic waste yet but they are considering to implement a transfer station for the organic part. The remaining 66% of waste is illegally dumped in the forest area [DUDBC, 2020].

Organic waste separation is achieved in ¾ of the households and is managed onsite through composting or is directly given to the animals if any [500B Solutions, 2022]. An informal sector takes care of the collection and separation of recyclables and sell them to biggest vendors to be recycled mostly in India. However, these businesses are not registered and their impact cannot be assessed, nor is secondary data available for the municipality.

2.5 Stakeholder analysis

Engagement with different stakeholder group is crucial for the sustainability of the sanitation services and promotion of behaviour change [IZB, 2017; Parkinson et al., 2014]. Some influential stakeholders should be consulted more frequently, some would like to have the opportunity to speak and be listened or others only expect a clear communication. Nevertheless, to know who to involve, when and how, a stakeholder analysis is necessary.

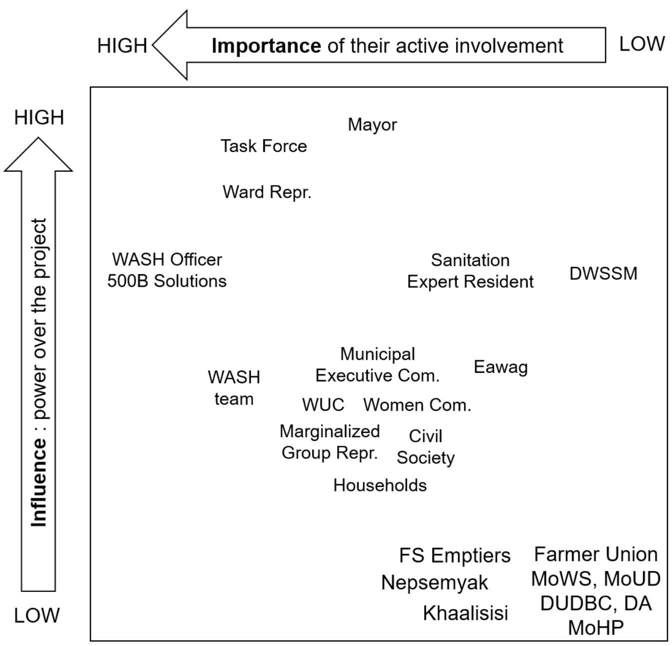


Figure 4: Stakeholder matrix of their relative influence and importance [source: author]

The analysis was done following the Stakeholder Analysis of the Sustainable Sanitation and Water Management (SSWM) Toolbox [Lienert, 2010; ODA, 1995; Rietbergen-McCracken and D. Narayan, 1998]. Figure 4 summarises their relative influence and importance. Special attention must be paid to the stakeholders with low influence and relatively high importance to ensure that their needs are met (e.g. household's ability and will to pay for sanitation services). Furthermore, one has to keep in mind to acknowledge the view of the ones with high influence and low importance to avoid any opposition (e.g. approval of construction facilities by the Department of Water Supply and Sewerage Management (DWSSM)). Characteristics and interest of the stakeholders can be found in appendix B.5.3.

3 Methodology

3.1 Application of SaniChoice

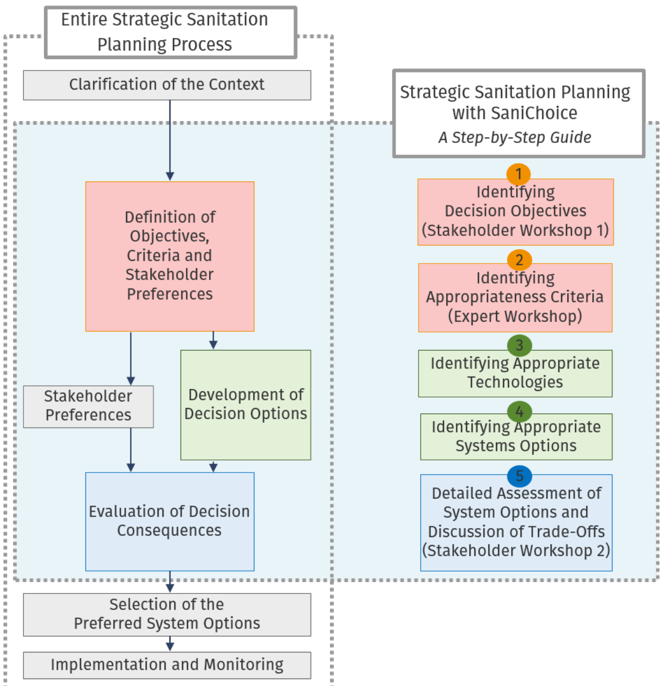


Figure 5: Integration of the 5 steps of the Practitioners' Guide into any strategic sanitation planning framework, adapted from Spuhler et al., 2021

The way to identify sets of locally appropriate sanitation system options is based on a step-by-step application guideline from the SaniChoice Practitioners' Guide [Spuhler et al., 2021]. The five SaniChoice steps that can be embedded in any strategic sanitation planning frameworks (e.g CWIS plan) are presented in Figure 5. An overview of the goals and activities of each of the 5 steps are summarized in Table 3 in the appendix. The Practitioners' Guide provides a theoretical guideline which requires to be adapted to the strategic sanitation planning framework and to the local context. Thus, the following steps are representative of the final methodology used to apply SaniChoice in the Changunarayan case study.
Although the *SaniChoice* term is used throughout the report, the study was done using Santiago and not the web-tool.

3.1.1 Step 0. Definition of application cases

This step is not included in the Practitioners' Guide and was developed especially for the case study.
The study area covers more than 60 km^2 where the topography and the type of settlements might sufficiently vary to consider separating the municipality into different application cases to get the most locally appropriate sanitation systems. The definition of several application cases sufficiently different to end up with more locally appropriate alternative is necessary to overcome this challenge. Figure 6 provides the three main steps to define the application cases.

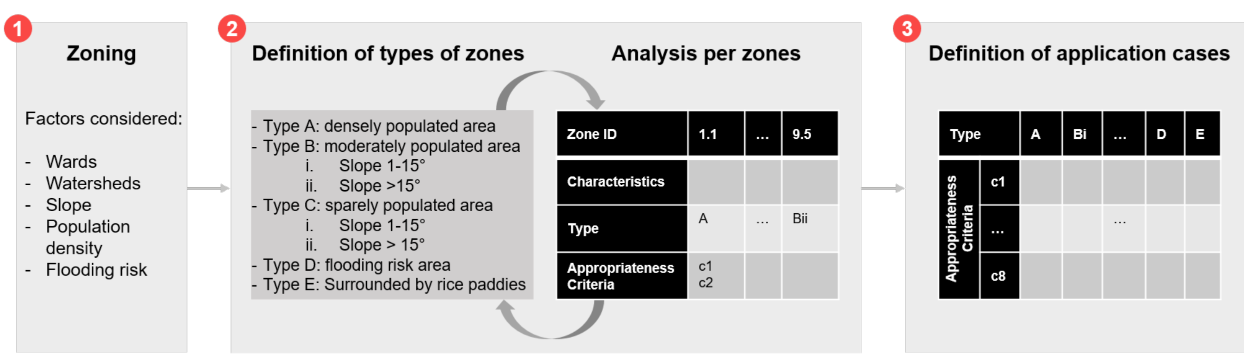


Figure 6: Definition of application cases: from zoning to typology of settlements [source: author]

To define the typology of settlement, one has first to prospect the entire study area and try to demarcate

zones of the main settlements or pocket areas according to several criteria, not necessarily related to the SaniChoice's ones but at least relevant for the sanitation planning. The zoning has been made according to (1) administrative boundaries for implementation, (2) main watersheds, (3) flooding risk affecting containment and storage technologies, (4) slope gradient affecting the type of conveyance technologies and (5) population density affecting mostly the on-site space availability and drinking water exposure.
An analysis of each zone with quantification of SaniChoice Appropriateness Criteria was conducted in order to define the application cases according to the 9 types of zones. This step is an iterative process: a zone first classified as a certain type may turn out into another while analyzing it. Furthermore, the zone analysis may also result with the creation of new type of zone that was not evaluated in the earlier steps.
The last step consists in gathering attributes of similar zones consistently to result with a set of defined criteria for each type.

3.1.2 Step 1. Identifying decision objectives

The decision objectives are defined as desirable outcomes of an intervention in the sanitation sector and thus stipulate the key concerns to ecological, socio-cultural, technical, financial or health considerations [Gregory et al., 2012]. In other words the decision objectives clarify "what matters" and provide a crucial joint vision of the planning process by different actor's perspectives [Spuhler et al., 2021].
Starting with sustainable sanitation criteria [SuSanA, 2008] as highest decision objectives, a draft version of the decision objective has been developed by aligning the outcomes of the Focal Group Discussions (FGDs) (see Figure 40 in appendix) and the municipality's vision on sanitation to the current sanitation problematic. This draft version was then shared, discussed and completed during an experts workshop (W3) based on the *Detailed Agenda for the Expert Consultation Workshop* available in section A.6 of the Supporting Information.

3.1.3 Step 2. Identifying appropriateness criteria

Appropriateness criteria are criteria independent from stakeholder preferences used in SaniChoice for selecting and comparing locally appropriate sanitation options [Spuhler et al., 2022]. The final selection of the criteria results from decision objectives together with the Expert Consultation Workshop (W3). A maximum of 10 to 15 criteria should be used, otherwise the Technology Appropriateness Score (TAS) calculated using a geometric mean may result in all technologies having similar TAS [Spuhler et al., 2021]. They are obviously screened by the data availability. For instance, the *Groundwater Depth* was a criteria that has been decided to consider but since there was no analysis it was discarded. The definitions of appropriateness criteria used in this study are given in appendix B.2.3 and their quantification for each zone is provided in Table 4 in appendix.

3.1.4 Step 3. Identifying appropriate technologies

The data of the application case is compared to the technologies database of SaniChoice. The quantified appropriateness criteria for each type of zone (see Table 4) are assessed one by one for each technology to evaluate how well the latter fits to the local condition. This match of the technology attribute with the application case attribute is the appropriateness score ($AS_{t,c}$) for the technology t and the criterion c. It is given in a range from 0 which means *not appropriate at all* to 1 meaning *fully appropriate*. The approach to quantify the attributes according to the application case profile is illustrated in Figure 7 and equation 1.

$$AS_{t,c} = P(t) = \begin{cases} \int P(t \mid c)\, p(c)\, dc & \text{if } p(c) \text{ is a probability density function} \\ \sum P(t \mid c)\, p(c') & \text{if } p(c) \text{ is a probability distribution function} \end{cases} \quad (1)$$

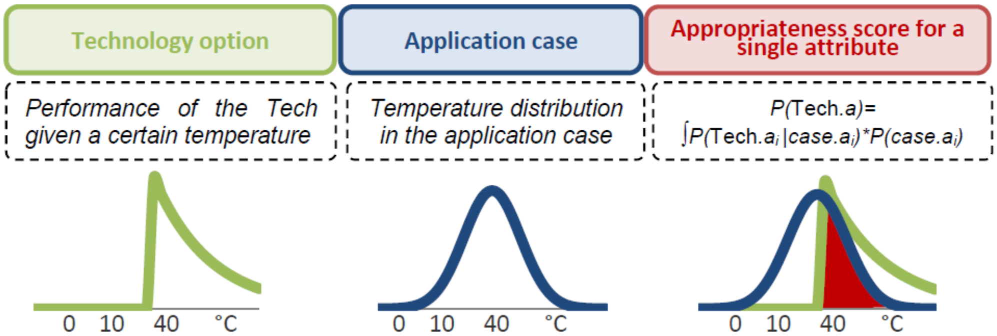


Figure 7: Quantification of appropriateness score $AS_{t,c}$ using the example of the *Temperature* criterion [Spuhler et al., 2018]

Then, the Technology Appropriateness Score TAS can be computed for each technology t of each application case according to equation (2) where $AS_{t,c}$ is the Appropriate Score for the criteria c and the technology t [Spuhler et al., 2018]. The TAS is computed for each technology using a geometric mean of all the criteria considered for this specific technology. A score of zero means a totally inappropriate technology while 1 means fully appropriate. This step is effectuated automatically by Santiago (or SaniChoice).

$$TAS_t = \sqrt[n]{\prod_{c=1}^{n} AS_{t,c}}. \tag{2}$$

Some technologies were initially excluded to speed up and narrow down the generation of entire potential sanitation systems. All technologies related to emergency context (user's interface for controlled open defecation, raised latrine, deep trench latrine, storage trench for controlled open defecation, shallow trench latrine, chemical-based toilets, container-based toilet, hydrated lime treatment, caustic soda treatment, borehole latrine) and technologies for which the technical maturity is still quite low (membrane filtration, microbial fuel cell, lactic acid fermentation, algae cultivation, urea treatment) have been deleted from the technology library.
Using the SaniChoice web-tool and not Santiago, this step can be achieved using the preconditions which limit the number of technologies depending on the considered parameter.

3.1.5 Step 4. Identifying appropriate systems options

Building all possible sanitation systems Given the technology library, Santiago generates several thousands of entire and valid sanitation systems. For this case study, 251'901 sanitation systems have been generated from 71 technologies. A sanitation system is a set of of technologies which combined are able to manage safely sanitation products from the point of generation to a point of reuse or disposal. It contains at least a technology from FG *User's interface* acting as a source and one from FG *Disposal and Reuse* representing the sink. The system is valid if every output product of each technology is connected to another technology that can take this product as its input and if all output product of all technologies are connected to inputs of another technology [Spuhler et al., 2018]. Loops within a sanitation system are possible and considered only within the FGs S and T.

Preselecting a set of locally appropriate sanitation system options

System Appropriate Score (SAS) A SAS is assigned for each sanitation system based on a weighted geometric mean of the TAS according to equation (3) where n_{tech} is the total number of technologies t in a given system S [Spuhler et al., 2018]. The SAS is weighted as a function of the number of technologies: the more technologies involved in the system, the lower the SAS. This allows to rank the systems by selecting the system with the highest SAS.

$$SAS_S = \prod_{i=1}^{n_{tech}} TAS_t^{\frac{1}{0.5(n_{tech}-1)+1}} \quad (3)$$

Screening manually using system templates (ST) and technologies Preselecting the systems based only on SAS is often not sufficient and the set of sanitation system options can be refined by excluding or including some ST or specific technologies. System templates define different categories of systems based on different approaches (dry/wet system, urine diversion, biofuel or sludge production) and on different degrees of centralization (onsite, decentralized, hybrid or centralized) [Spuhler et al., 2022] and therefore allow to prioritize some categories of systems. In contrast, including specific technology could be useful for considering the existing infrastructures or stakeholder preferences and exclusion of other based on external criteria or assumptions not taken into account narrow down the potential options. Furthermore, the maximal number of technologies in the systems has been limited by imposing a threshold at 12 technologies to avoid to complex and long systems. All considerations done regarding this step are summarised in Table 5 in the appendix.

Plausibility Check After having generated and preselected a set of system options per application case, it is strongly recommended to undergo a plausibility check. This closer look to the preselected systems allows to check if the system makes sense and are promising from an engineering point of view. This plausibility check is an iterative process with the previous step and might result with coming back to the technologies and system templates inclusion and exclusion.

Evaluation of preselected sanitation options

Resource recovery potential. The mass flow module quantifies the flows for four substances of interest (nitrogen, phosphorus, water and total solids) for all sanitation system based on simplified transfer coefficients considering the soil, air and water losses ending up with recovery potential [Germann, 2019]. The uncertainties are computed by Monte Carlo error propagation (here using 150 iterations) and expressed as standard deviations [Spuhler et al., 2020]. Resource recovery and loss potentials are relevant in strategic sanitation planning because they are typically negotiable evaluation criteria and can involve trade-offs.

Additional Evaluation criteria. According to the decision objectives, the capital and operation expenditure requirements (Capex and Opex), the land requirements and the frequency of operation and maintenance were the more relevant additional evaluation criteria for the decision-making. All data available in appendix Table 6 and 7 comes from the SaniChoice technology library [Spuhler et al., 2022]

- Capex and Opex are defined qualitatively for each technology considering three required resources: material, labour and land (respectively energy for Opex). This quantities are individually judged and allotted a value 1, 2 or 3 indicating low, medium and high respectively. The sum of each resources represents the final score of the technology. The system score is the average of the score of each of its technology normalized from 0 to 9 (rather than 3 to 9) and the range of the technology requirement is represented by the minimum and maximum expenditure score of individual technology composing the system.

- The frequency of O&M is also given in a qualitative scale from 0 to 9, indicating low and high respectively following the same process than the Capex and Opex. Unlike Opex and Capex, no such assessment has already been done. It can be derived from the technology requirement of the appropriateness criterion *Frequency of O&M* based on the extent of labour (cleaning, repairing or replacing mechanical parts) according to three categories: irregular P_{irr}, regular P_{reg} and continuous P_{cont}. It has been first assume that irregular, regular and continuous frequency represent low, medium and high frequency then the score is allotted according to equation (4).

$$O\&M_t = \begin{cases} 0 & \text{if } P_{irr} = 1 \\ 4.5 \cdot P_{reg} & \text{if } P_{irr} + P_{reg} = 1 \\ 4.5 & \text{if } P_{reg} = 1 \\ 4.5 + 4.5 \cdot P_{cont} & \text{if } P_{reg} + P_{cont} = 1 \\ 9 & \text{if } P_{cont} = 1 \end{cases} \quad (4)$$

- The land requirement considers the sum of all offsite treatment technologies (only from FG Treatment). One has to consider that this number relies on very rough estimations to provide an general idea of the surface area required.

3.1.6 Step 5. Detailed analysis of preselected systems and Discussion of trade-offs

The performance of the preselected sanitation system options are evaluated by gathering all information in a system comparison's plots using R. It is important to note that the assessment done with SaniChoice is not sufficient to make a final decision. Therefore, this step should be completed with a detailed assessment of the preselected system, often including a detailed assessment of the costs, service delivery models and health risk. The collected information is then presented in a stakeholder workshop to discuss the trade-offs agreement on a preferred sanitation system. In Changunarayan, it was done with a presentation of the results to the Task Force. It allowed to raise awareness about different options highlighting the main problematic and limiting factors to the implementation of any technology.

3.2 Integration of SaniChoice to the CWIS Planning for Changunarayan

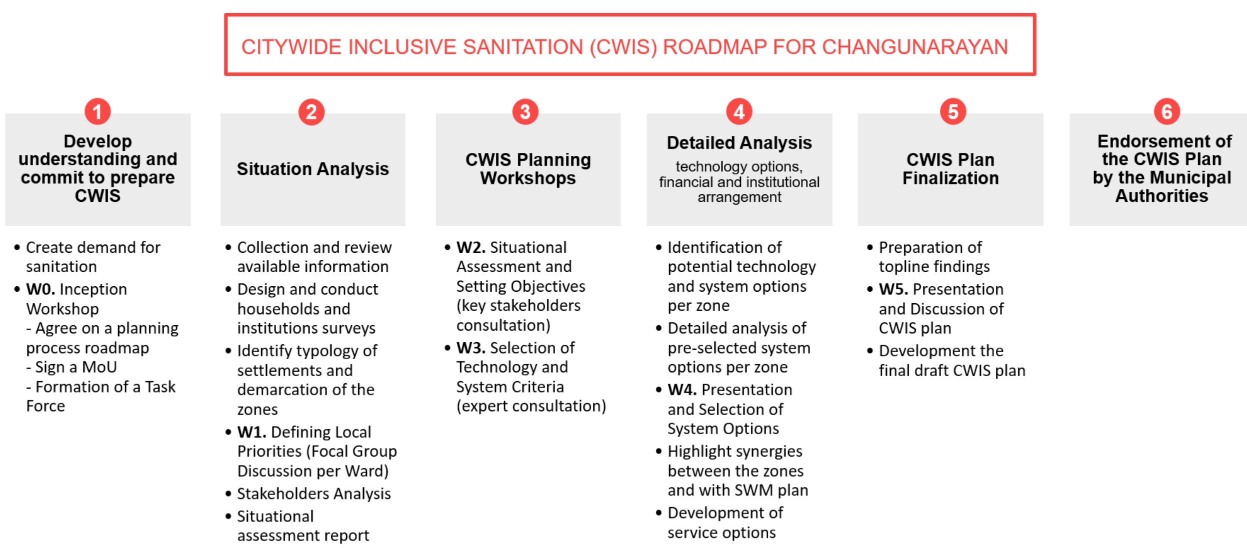


Figure 8: Simplified CWIS roadmap with main activities [source: author]

The simplified CWIS roadmap in Figure 8 shows the 6 stages of the CWIS guideline. So far, stage 1 to 3 were completely done and stage 4 only partially. Although the generalization of this roadmap might be considered, it was developed for this specific case study.
The implementation of SaniChoice in the CWIS plan was mostly applied based on the workshops organized with the municipality and other planning activities (e.g household survey) to get the necessary inputs to apply the tool. A more detailed CWIS Planning Guideline for Changunarayan with the implementation of SaniChoice is provided in Table 9 in the appendix. As demonstrated in Figure 9, SaniChoice embeds its

activities into stage 2, 3 and 4 of the CWIS plan. The demarcation of the zones resulting with the definition of the application cases was done based on the collection and review of available information, the household survey results and field visits. This step can be conducted independently of any workshop and thus in a very early stage of the planning process. The situation analysis also allows to prescope the quantification of appropriateness criteria. Nevertheless, the final selection of the criteria is achieved through the decision objective hierarchy structured in W3 using the W1 and W2 outcomes. SaniChoice can then be applied to assess the appropriate technology and system options. Experience from Changunarayan of stages 1 to 4 of the CWIS plan is shared with more details in section A.1 of Supporting Information.

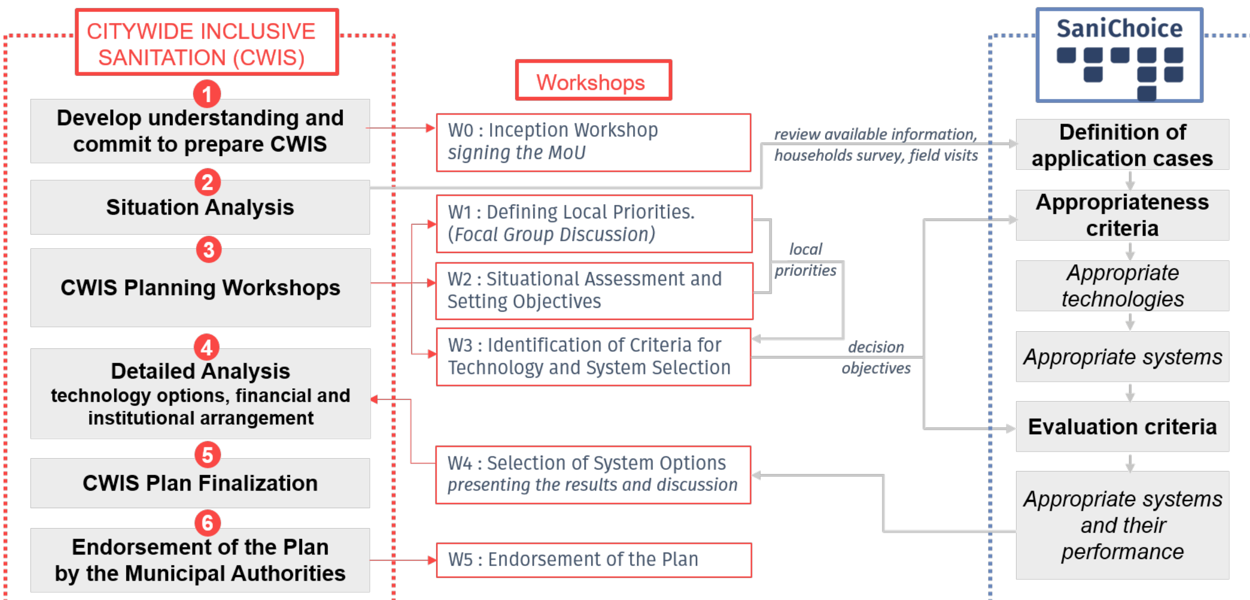


Figure 9: Integration of SaniChoice main activities in the CWIS planning guideline developed for Changunarayan. [source: author]

3.3 Assessment framework for SaniChoice validation

To evaluate the expected benefits from SaniChoice web-tool and Practitioners' Guide (see chapter 1.2.3), an assessment framework was developed prior to the SaniChoice application in the case study. First, a set of hypotheses was developed based on the above benefits. Then a set of questions to assess mostly qualitatively the latter was created for each hypothesis with a precision on the activity in which the question should be embedded.

Despite this preliminary work, the framework was not used because the gap between the theoretical guideline suggested in the Practitioners' Guide and the reality of the field was big enough that the methodology's adaptations no longer made possible its application. Nevertheless, the assessment framework allowed to have this set of questions and considerations in mind during the SaniChoice application. The main ones are listed in the following:

- **Definition of application cases**
  How can the area be separated into different zones? Which attributes, sanitation issues and stakeholders preferences are varying within the municipality?
- **Decision Objectives**
  Do the decision objectives embed all different sanitation issues and stakeholder priorities?
- **Appropriateness criteria**
  How are they limiting the locally appropriate technologies in the different zones? Do the limiting criteria vary among the different functional groups?

- **Preselection of sanitation system options**
  Are the SaniChoice's functions (SAS, system templates, export/include technology) sufficient to refine the pre-selection?
- **Evaluation criteria**
  Are the locally relevant evaluation criteria the same as the ones available with SaniChoice?
- **Stakeholders workshops**
  Are participants a representative group of the stakeholders? Is stakeholder involvement sufficient and do they all participate equitably?

4 Results and Discussion

4.1 Decision Objectives hierarchy

As presented in Figure 10, decision objectives are structured in a hierarchical way. This format helps to communicate better with different stakeholders and to validate the completeness of decision objectives. Indeed, it helped the different partners from 500B Solutions to align their thoughts and visions of the project and provides an understandable support to summarize the decision objectives to the task force and other stakeholders.

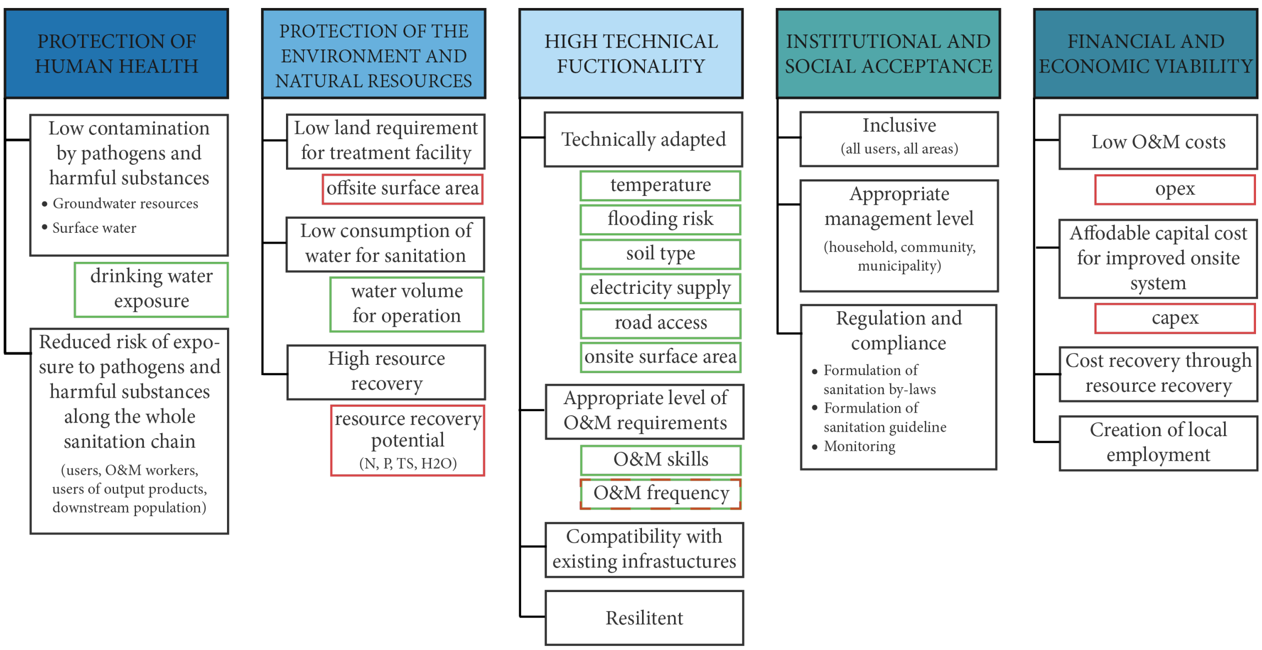


Figure 10: Decision objective hierarchy of CWIS for Changunarayan with sanitation sustainability criteria [SuSanA, 2008] as highest level objectives, lower level objective obtained from local priorities and municipality vision and different indicators used in the SaniChoice application such as appropriateness criteria (in green) and evaluation criteria (in red). [source: author]

4.2 Demarcation of the zones

The major challenge for Changunarayan is probably its periurban character. The municipality consists in a extended area without proper city core nor consistent urban planning resulting with dwellings spread over the entire zone. However the methodology developed in chapter 3.1.1 results with seven different type of zone:

A. **Densely populated area:** characterized with "urban" settlements with population density higher than 2000 cap/km^2. However the main roads are broad, a lot of household don't have the direct road access because several lines of dwellings (up to three) have been built along one road. Even if some fields (rice paddies, maize) are present in some areas, this settlement's type have limited space for onsite sanitation and the human density doesn't allow to use technologies based on soil infiltration. More than half the households already connected their holding tank to the stormwater drain. According to the high population density and the local priorities, centralized and hybrid system are proposed in these zones.

B. **Moderately populated area:** typical periurban settlement with population density of about 1000 to 2000 cap/km^2. Although there is generally more space for onsite sanitation than type A, surface availability still might be limited in some areas. Hybrid and decentralized systems will be prioritized in these zones.

   i. Relatively flat : slope 1-15°

   ii. Hilly: slope steeper than 15°, drinking water source is mostly coming from springs.

C. **Sparsely populated area:** more rural characteristics with population density less than 1000 cap/km^2. The road network is less developed, almost all gravel and earthen narrow roads (less than 2m), making the vehicular access very difficult. Agriculture is omnipresent and surface area onsite should not be a limiting factor. Decentralized and onsite sanitation systems and fertilizer production will be prioritized in these zones.

   i. Relatively flat : slope 1-15°

   ii. Hilly: slope steeper than 15°, drinking water source is mostly coming from springs and water scarcity (at least for sanitation purposes) could be observed during dry season. Dry system will then also be considered.

D. **Flood-prone area:** Monsoon floods might occur in the Manohara river which borders the municipality at East and North during the rainy season. The variations in water levels can lead to easier spread of disease if the onsite technologies are not adapted, it often consists in adaptations of consolidated solutions rather than technologies specifically designed for floodable areas [Borges Pedro et al., 2020]. These zones are characterized with a very limited road access, flat terrain (slope less than 1°) and with a fertile soil with higher sand and gravel contents than the other types. Very few inhabitants are living in this area.

E. **Area surrounded by rice paddies:** Within each of the other type, there are a lot of dwellings that are surrounded by rice paddies and submerged during one month a year.

Figure 11 shows their distribution within the municipality except for type E that shall be considered on a case-by-case basis. Figures 30 to 38 in the appendix B.4 illustrate in picture each type of zones.

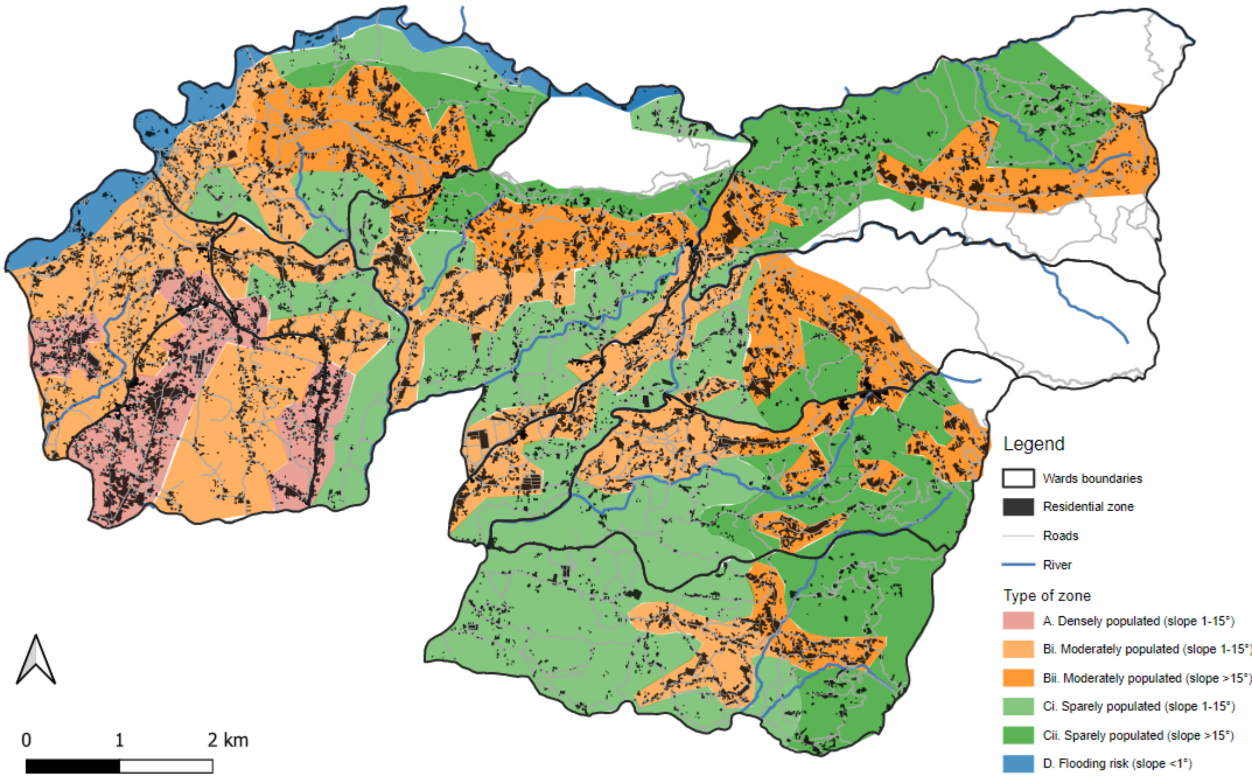


Figure 11: Visualization of the type of zone in the Changunarayan Municipality. Note that type E (Rice paddies) is not represented due to its relative omnipresence within the area, mostly in zone whose slope is less than 15°. The three white spots are uninhabited forest areas. [source: author]

4.3 Appropriateness of technologies and sanitation system in Changunarayan

All criteria used to generate the results are provided in Table 4. Their quantification relies on assumptions available in chapter A.2 in Supporting Information. Technology Appropriateness Score for all technologies and types of zones are provided in Table 8 in appendix B.2.6.

4.3.1 Technology appropriateness

4.3.1.1 Assessment per Functional Group (FG)

FG User interface Existing pour flush toilets narrow down tremendously the opportunity to implement another technology. Nevertheless, four technologies have been taken into account: (1) pour flush which is actually present in almost all the households, (2) the urine diverting pour flush toilet (udpft) for type C and D based on the EOOS NEXTs 'URINE TRAP' design [Beigel, 2020] that presents promising results in a pilot project implemented in a community of farmers in Nepal and dry toilet, (3) dry toilet for the remote hilly areas (type C) which might face water scarcity during the dry season and (4) urinal whenever there is a potential to implement one (public institution, public toilet, restaurant, etc.). Their selection has been done by excluding manually some technologies for certain types of zones (see Table 5 in appendix) and the appropriateness assessment consider only two appropriateness criteria (see Figure 25 in appendix) since it has been decided to ignore the ones acting only on FG U (see appendix A.2). Although analysis of the appropriateness based only on two criteria doesn't make much sens, it informs that technologies managing urine separately (udpft and urinal) require more frequent maintenance, despite its simplicity, than non-separative toilets.
Urine fertilisation is ideal for rural (type C) and peri-urban (type B) areas where agricultural lands are close to the point of urine generation and collection [Mcconville et al., 2020]. Basing a sanitation system on urine diversion or at least including urinal would be logical considering the fertilizer prices volatility. Indeed, since Russia and Belarus produce a significant amount of global fertilizers, the economical sanctions and supply

disruptions due to the war in Ukraine increased the fertilizers' prices by 30% in the first quarter of the year and are projected to rise by almost 70 percent until the end of 2022 [World Bank Group, 2022]. Despite these sad facts encouraging the local resource recovery, the social acceptance of using urine can be the limiting factor here. Indeed, for separating urine and faeces at their point of generation it requires the users to adapt their own interface and be ready to spend time to handle the urine separately. However, such technologies give the opportunity to easily recover nutrients contained in urine which are directly available for plant uptake and in addition, they prevent a rapid filling of the potential onsite containment.

FG Storage and containment The choice of technology of this functional group generally depends on the availability of space, the soil and groundwater characteristics, the availability of technologies for subsequent transport, financial resources and management considerations [Ulrich et al., 2014]. It is shown in Figure 12 by the surface area (onsite), the drinking water exposure, the soil type, the vehicular access and the O&M skills acting as limiting criteria.
The TAS doesn't vary a lot among the different types of zones. Type A restricts the alternatives the most due to its urban character with limited availability of onsite surface area and high risk of drinking water contamination.
One specific consideration should be done according to septic tank for which the attribute appropriateness score of *vehicular access* barely reach 10% for all types of zones. Despite this low score, septic tanks (or holding tanks) are nowadays implemented in Changunarayan. The lack of vehicular access is one of the reasons of the bad management of sludge forcing the population to discharge their tank directly in the environment, especially in hilly areas.

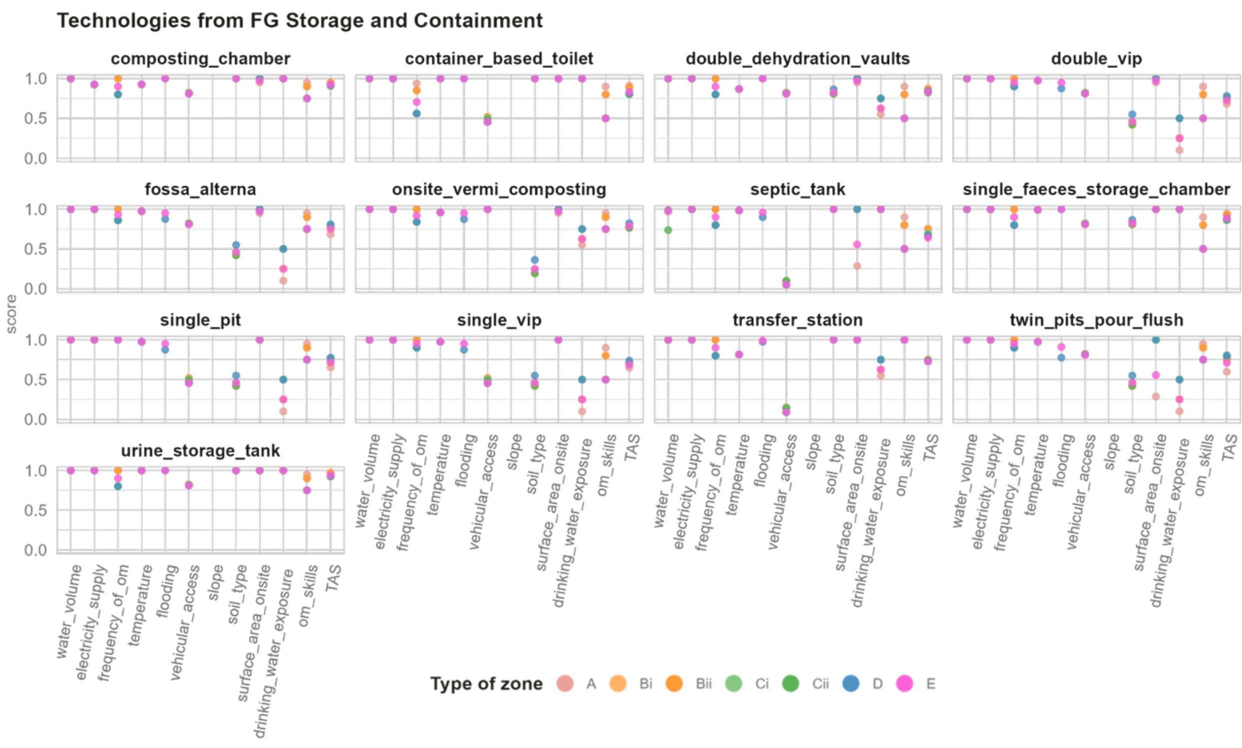


Figure 12: Attribute Appropriateness Scores ($AS_{t,c}$) of each contributing criteria followed by Technology Appropriateness Score (TAS) of technologies from FG *Storage and Containment* for each type of zone. A score of 1 means fully appropriate attribute according to the input data available in Table 4. A criterion is left blank if it is not considered by the technology appropriateness assessment (e.g slope). The color code represents the different application cases. Similar scores for different types of zones might overlap and only the last type will be visible, often type E.

FG Conveyance The water volume, the slope and the O&M skills and frequency are the limiting criteria as it can be seen in Figure 13. The TAS of sewered technologies is decreasing with the density of settlement:

the more "rural" the type of zone, the lower the water volume and O&M skills and thus the lower the TAS. Since pour-flush toilet are widely used, the amount of water per flush might not be sufficient to transport excreta in the pipes. Indeed, the water volume considers the water consumed in the household (including greywater) and might not reflect the actual appropriateness if greywater is treated separately. In contrast, it also shows that the simpler the sewer system, the higher the frequency of operation and maintenance. This might be an issue for C and D concerning the solids-free sewer whose TAS are equal to zero and hence won't appear in a sanitation for those types of zone. However, this assessment presents clearly that the simpler the sewer system, the more locally appropriate. This is an important result that will probably help the decision makers to better understand the misconception they have about the conventional sewered and centralized approach seen as the "best" solution.

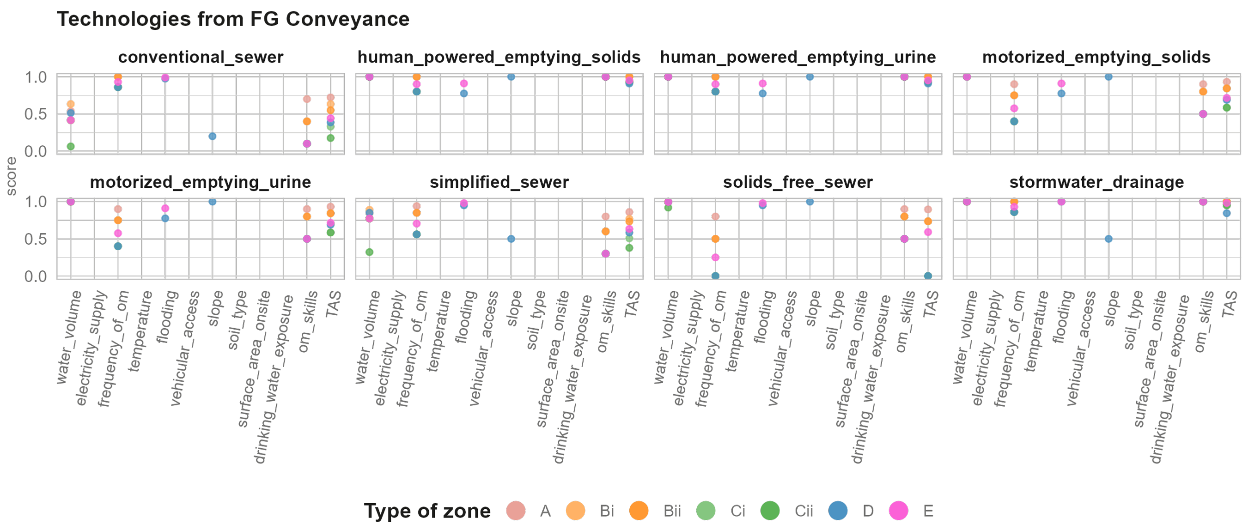


Figure 13: Attribute Appropriateness Scores ($AS_{t,c}$) followed by Technology Appropriateness Score (TAS) of technologies from FG *Conveyance* for each type of zones. A score of 1 means fully appropriate attribute according to the input data available in Table 4

FG Treatment According to Figure 14, the limiting criteria are the electricity supply, the O&M Skills, the frequency of O&M and the temperature for a few technologies. One has to take into account that the land requirement was not considered as a screening criteria but as an evaluation criteria (see system comparison plots in chapter 4.3.2.1) and thus could be a limiting factor for the decision-making. Nevertheless, a manual screening has been done to avoid ending up with locally inappropriate technologies (cf. chapter 4.3.1.2).
Although the anaerobic baffled reactor (ABR) and the anaerobic filter appear here as part of the FG T, they can also be used as a collective containment technology at the neighborhood level. Indeed, the existing holding tanks do not yet safely contained the blackwater and are neither safely managed (see FGD outcomes summarised in Figure 40 in appendix), they require thus to be improved (sealed at least) or another technologies. Furthermore, the road access limits the motorized emptying of the actual containment. A collective containment can improve the situation by providing a storage technology generating less sludge than a septic tank, decreasing the cost related to the emptying services and ensuring the vehicular access with a wise location.
Constructed wetlands seem to be quite appropriate. Of the three constructed wetlands proposed by SaniChoice, a horizontal subsurface flow is probably the most appropriate for Changunarayan. It doesn't require electricity nor pump supply explaining the TAS difference with the vertical one and does not have the mosquito problems of the free-water surface one [Ulrich et al., 2014]. If the offsite surface area for the treatment is such an issue, one can imagine to prioritize the vertical one that uses less than half of the two others. However, offsite vermi-composting has never been tested in Nepal, it is a simple robust and low cost option for human and organic waste treatment that reduces the volume of faecal sludge by 60 to 90% [Mcconville et al., 2020] and its TAS is high for all the types of zones. This technology encompasses all similar technologies,

the vermi-filter is probably a more appropriate technology to treat blackwater. One limiting factor might be the bleach, gasoline or other chemicals that are currently used to clean the toilets and to prevent odors but which are lethal for the worms.

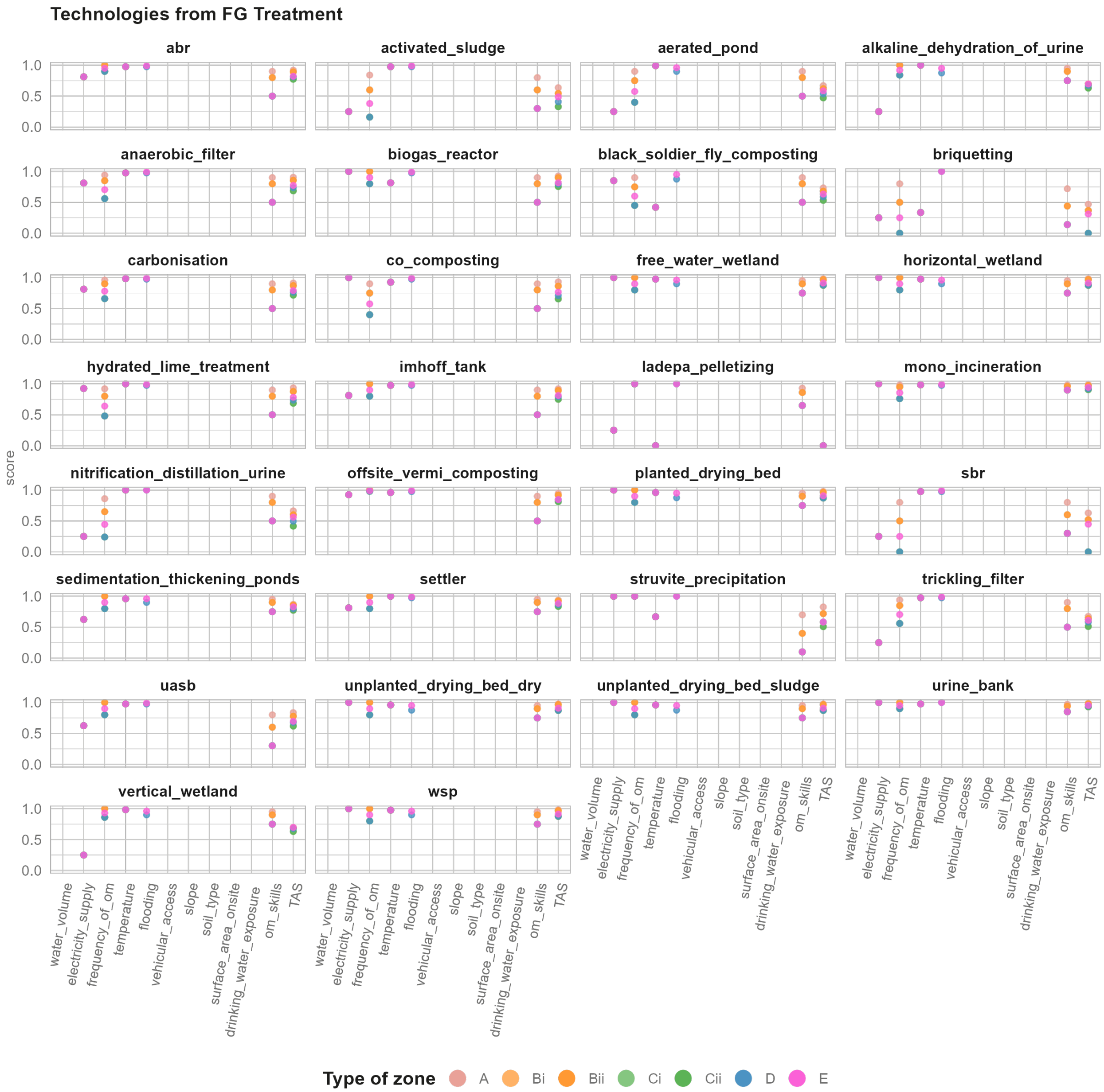


Figure 14: Attribute Appropriateness Scores ($AS_{t,c}$) followed by Technology Appropriateness Score (TAS) of technologies from FG *Treatment* for each type of zones. A score of 1 means fully appropriate attribute according to the input data available in Table 4

FG Disposal and Reuse While examining the technologies of this last functional group, one has first to consider the human health risk and the environment contamination. According to Figure 15, the drinking water exposure and soil type are the major limiting criteria. Again, O&M skills and frequency play also an important role to assess the TAS.
Figure 15 shows that the assumptions on the drinking water exposure criterion have the expected effect by limiting certain technologies (e.g. soak pit). Nonetheless, the effect of this limiting criterion might be obsolete if appropriateness scores of the other criteria are high (e.g. fill and cover). Secondly, it appears that the soil type in Changunarayan has a relative small permeability due to its high clay content and thus bear risk for stagnation and its filtration capacity is quite low (low sand content). Hence, one needs to be aware that technologies relying on soil infiltration are definitely not the most appropriate alternatives.

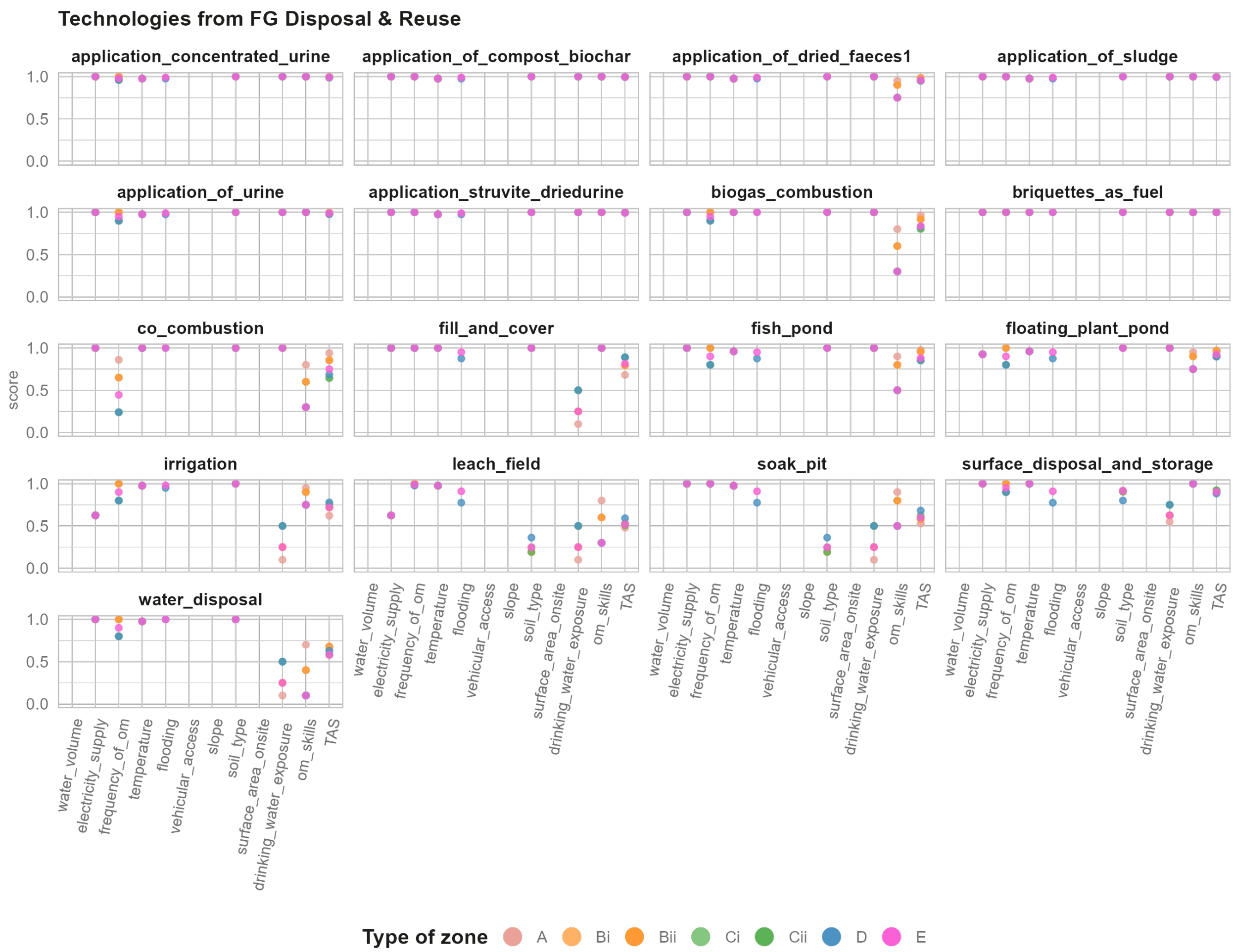


Figure 15: Attribute Appropriateness Scores ($AS_{t,c}$) followed by Technology Appropriateness Score (TAS) of technologies from FG *Disposal and Reuse* for each type of zones. A score of 1 means fully appropriate attribute according to the input data available in Table 4

4.3.1.2 Exclusion of technologies for system selection

At this step, the Practitioners' Guide advices to keep all the technologies except the ones with a very low score. Despite this recommendation, it was decided to exclude some technologies even if their TAS is high because the appropriateness criteria used for this assessment do not represent fully the consideration to make. The land requirement of the sanitation system should be low according to the decision objectives but the criterion *Surface area (offsite)* was not possible to quantify. Thus, waste stabilization ponds (WSP) for wastewater treatment and fish and floating-plant ponds for the discharge are excluded. This exclusion was done based on qualitative judgement without quantification of criteria. Similarly, aerated pond, activated sludge, mono-incineration and sequencing batch reactors (SBR) have also been excluded due to their high complexity and their high energy and cost requirements. All considerations done to generate the system are available in Table 5 in the appendix.

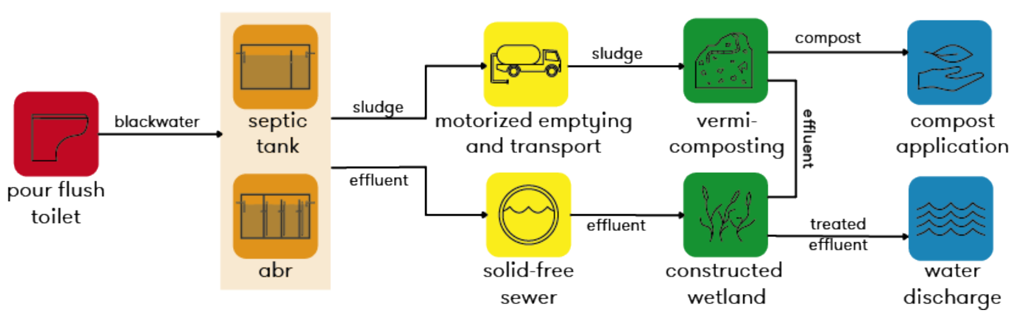
4.3.2 Sanitation system appropriateness

According to the technology appropriateness assessment, the sub-type of zone (i. Relatively flat and ii. Hilly) are not different enough to consider them as two application cases, at least with the set of appropriateness criteria quantified (cf. Table 4 in appendix). Hence, hilly areas were used as a proxy for the considered type of zones because they are the most limiting ones. A similar reasoning results in considering type E (flood-prone areas) and D (rice paddies) as a single type using the data of type E.
Moreover, two urinal systems were generated and assessed for all types of zones. They all include public spaces (market place, religious place, etc.) or institutions (school, municipality office, etc.) in which an urinal based sanitation system can be used additionally to the ones preselected.

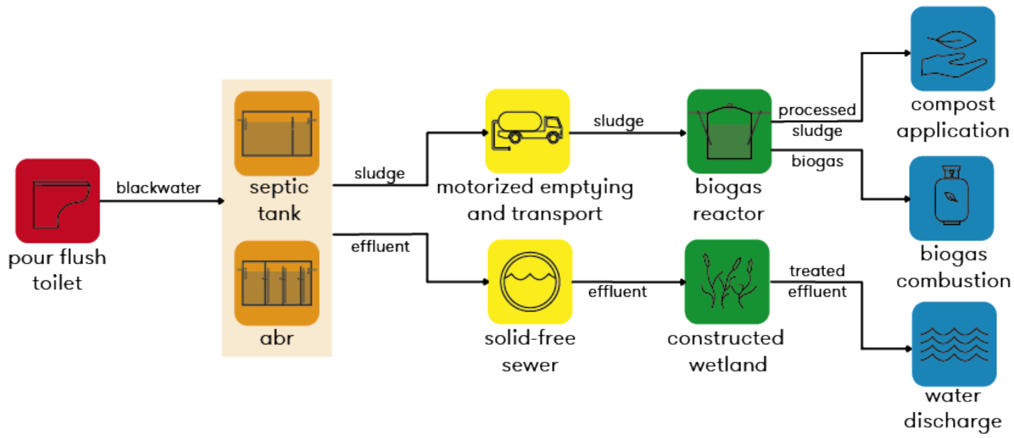
4.3.2.1 Preselected sanitation systems per type of zone

Type A: densely populated areas The existing infrastructures and the urban character of type A forces to consider pour-flush toilets as the only source. Although onsite surface areas might be limited in certain dwellings and the road access for sludge motorized emptying is only present in around 55% of the cases, a hybrid system working with onsite containment (systems A1 and A2) connected to a centralized treatment or a centralized system in which the toilets are directly connected to the treatment facilities through a sewer network (system A3). Effluents of the three systems are treated in a constructed wetland which has been previously constructed also in Nala, a neighbouring small town.

- **System A1. Hybrid blackwater system with compost production**
  As onsite containment, we consider private septic tanks for the households where motorized emptying is possible and collective septic tanks like anaerobic baffled reactors (ABR) for the ones having no road access. Alternatively, a simplified emptying technology that is appropriate for narrow roads (e.g. Vactuc) could be considered. Pumped sludge is brought by trucks to an offsite vermi-composting and their effluents are fed to a constructed wetlands through a solid-free sewer. Vermicomposting's effluent can be connected to the constructed wetland as well.



- **System A2. Hybrid blackwater system with biogas production**
  Similar to system A1 except that the sludge is fed to a biogas reactor instead of the vermicomposting generating biogas and the excess sludge is disposed in the surrounding fields as a soil conditioner. The digestibility of the sludge has to be assessed in detail to evaluate if additional substrate (e.g. animal waste) is required for good performance.



- **System A3. Centralized blackwater system with compost production**
  This is the same system as A1 but this one doesn't include any onsite containment. The pour-flush toilets are directly connected to a simplified sewer that discharges into an offsite vermicomposting. Greywater shouldn't be discharged in the vermicomposting as it can contains chemicals that could harm the worms.

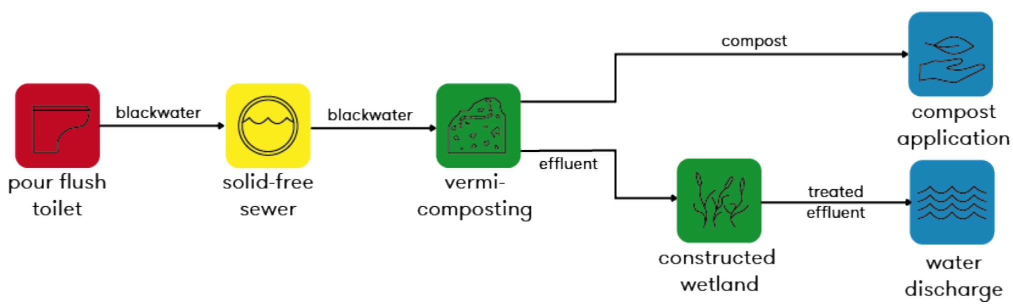


Figure 16 allows to compare the three systems. While their SAS are all similar, all other evaluation criteria indicate that system A3 would be the best one. The resource recovery potential is lower for hybrid systems because the onsite containment technologies already reduces a part of the biochemical oxygen demand (BOD). The capital and operation expenditure requirements (capex & opex) are relatively similar but the opex range is smaller for system A3. Additionally, vermicomposting would allow to use synergies with the solid waste management plans that are currently developed. Nevertheless, the concept must be discussed with the local community to ensure that compost made from human waste is an acceptable product to be used as a soil amendment [Mcconville et al., 2020].
Resource recovery potential uncertainties are quite high relatively to the mean value. Several reasons can explained it since they integrate different aspects: quality of inflow, design and maintenance of technologies, environment conditions, measurement methods or available knowledge that could be limited for novel technologies [Spuhler et al., 2020].

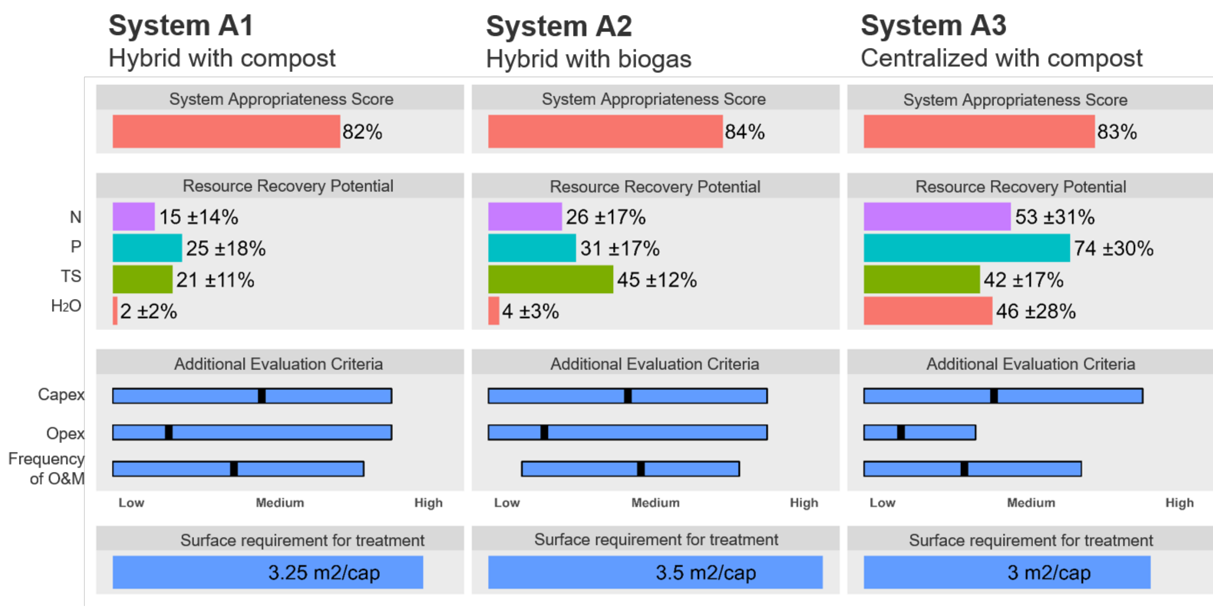
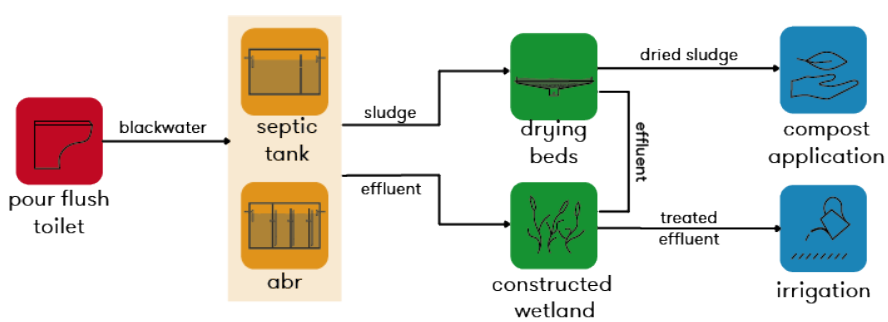


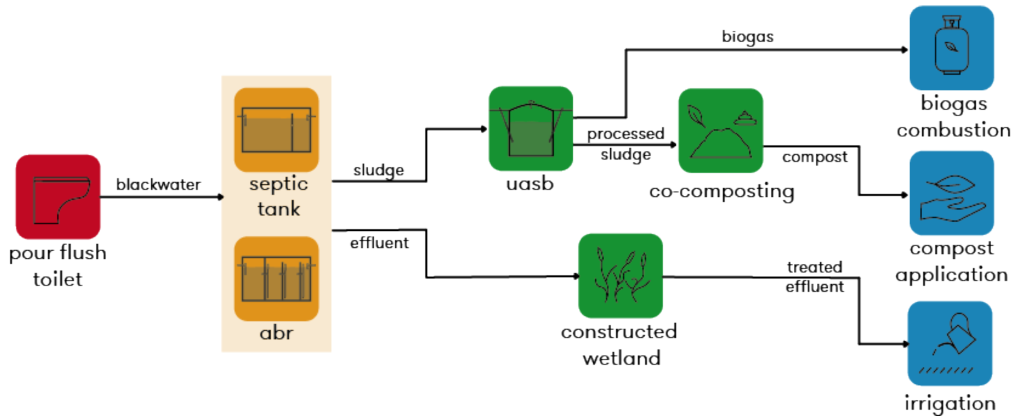
Figure 16: Preselected appropriate systems for type A with their SAS and performance. The mean and its standard deviation are given for the resource recovery potential of each substance (N: nitrogen, P: phosporus, TS: total solids, H2O: water). Additional evaluation criteria are provided with the average of all technologies included in the system (black line) and the blue range is plotted from the minimum to maximum requirement of its technologies.

Type B: moderately populated areas According to the zoning map in Figure 6, type B is represented by pocket areas spread over the entire municipality. Hence, decentralized systems are considered to be appropriate. One has to consider that due to computational limitations, Santiago/SaniChoice doesn't consider the conveyance required to lead from the households to the decentralized treatment. The conveyance has to be added manually. We assumed a motorized-emptying and transport for the sludge and solid-free sewer for the effluent of the containment facilities. Note that these technologies are not considered for the calculation of the local appropriateness nor additional evaluation criteria provided by SaniChoice in Figure 17. A third hybrid system links the settlements with the rest of the municipality considering a centralized treatment facility.

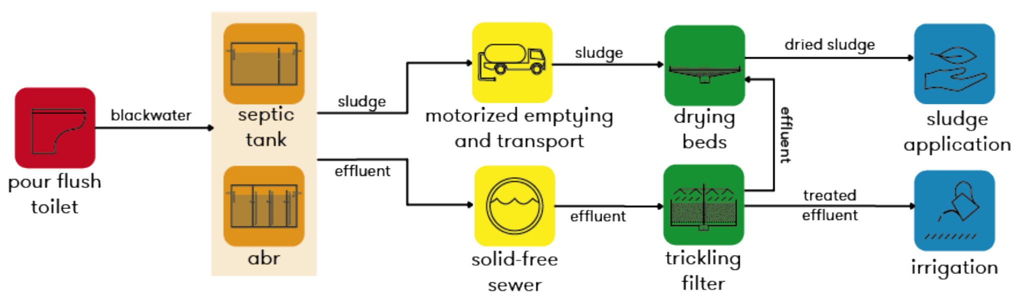
- **System B1. Decentralized blackwater system with sludge production**
  Pour flush toilets are connected to a similar combination onsite containment technologies than systems A1 and A2: septic tanks and anaerobic baffled reactor where vehicular access for truck is limited. From there, sludge is emptyed and transported to a decentralized unplanted drying bed. The effluent feeds to an horizontal constructed wetland. Its effluent can be then used to irrigate the surrounding crops and dried sludge can be applied as soil conditioner. Again, the Santiago/SaniChoice does not include the conveyance for decentralized systems in the appropriateness assessment and evaluation criteria.



- **System B2. Decentralized blackwater system with biogas production**
  Similar system as B1 but with biogas production through an upflow anaerobic sludge blanket bioreactor (UASB). The sludge excess is co-composted with the available organic waste providing again the opportunity to use synergies with solid waste management.



- **System B3. Hybrid blackwater system with sludge production**
  Based on the same combination of onsite containment technologies than the previous ones allowing motorized emptying. The system replies to the limited land by suggesting offsite treatment technologies with lower land requirement. To do so, sludge and effluent are transported to a centralized treatment where a trickling filter treats the effluent and drying beds dewater the sludge coming from onsite technologies. The treated effluent can be used to irrigate the surrounding crops and the dried sludge as a soil amendment.



According to the systems performance's comparison in Figure 17, the SAS of B1 is the highest. The two others are slightly affected by the low TAS of the UASB (*O&M Skills*) and the trickling filter (*Electricity Supply, O&M Skills*). Systems B1 and B2 provide a better resource recovery potential than B3. Although system B1's Opex is slightly lower than the other, overall cost requirements and frequency of operation and maintenance are similar among the three preselected systems. A detailed analysis may serve to widen the gaps. In contrast, the surface requirement difference is big enough to clearly declare that system B3 is the preferred one for an implementation where offsite surface area is very limited thank to the trickling filter, whether the system will be centralized or decentralized.

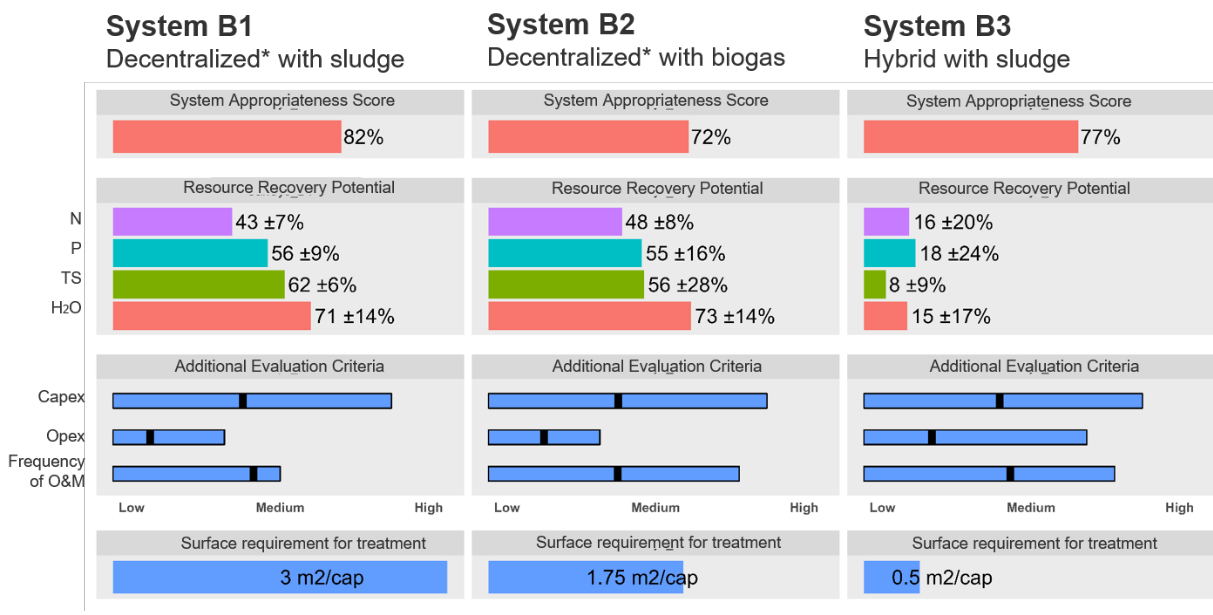
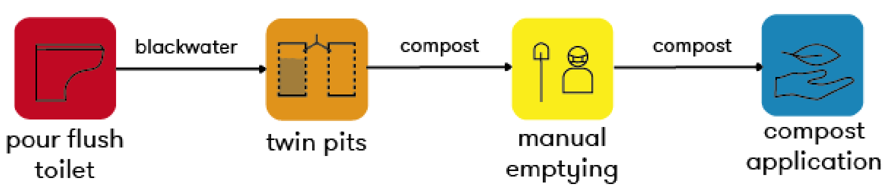


Figure 17: Preselected appropriate systems for type B with their SAS and performance. The mean and its standard deviation are given for the resource recovery potential of each substance (N: nitrogen, P: phosporus, TS: total solids, H2O: water). Additional evaluation criteria are provided with the average of all technologies included in the system (black line) and the blue range is plotted from the minimum to maximum requirement of its technologies.
∗ *no technology of FG Conveyance is considered by the system*

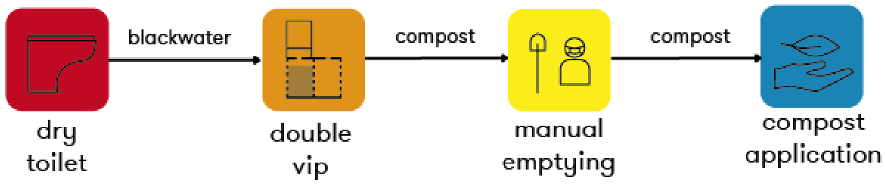
Type C: sparsely populated areas The "rural" areas considered in this type allow more likely to consider onsite systems due to the low density and lack of vehicular access. Secondly some areas are suffering water scarcity for sanitation at least during the dry season. Dry systems could be implemented in these zones. Despite the previous statements, there is still slightly denser areas like in Nagarkot or in the hilly part of ward 9 where decentralized system options at the *tole*[3] level should also be examined, mostly due to the rapid urbanization of the municipality.

- **System C1. Onsite blackwater system with compost production**
  Blackwater is collected onsite in two alternating pits that allow to slowly infiltrate it into the soil. Over time, the accumulated solids are sufficiently dewatered to be manually removed and apply as a soil conditioner. Since leachate can contaminate groundwater, one has to ensure that no drinking water source is close to it.



[3]Tole (Nepali): small settlements whose boundaries are defined by topographic and socio-cultural considerations

- **System C2. Onsite dry system with compost production**
  Based on the same scheme that system C1 except it works without flushwater. The faeces are deposited into two alternating ventilated improved pits (VIP) that provide a safer and easier emptying. This system present less risk of groundwater contamination thanks to the lower amount of leachate infiltrating into the soil. It might be very appropriate in rural hilly areas where water supply is limited during dry season and comes from springs, very sensitive to contamination through leachate infiltration.



- **System C3. Decentralized system with urine diversion and production of biogas and compost**
  Using diverting pour flush toilet, urine is transported to a reactor for struvite crystallisation in order to get a solid phosphorus-rich fertilizer. Brownwater is stored onsite in septic tanks whose effluent is conveys locally to constructed wetlands and the sludge fed a biogas reactor. The processed sludge from the reactor are co-composted with organic waste. All end products are then used onsite and contribute to close the substances' cycles at the local level.

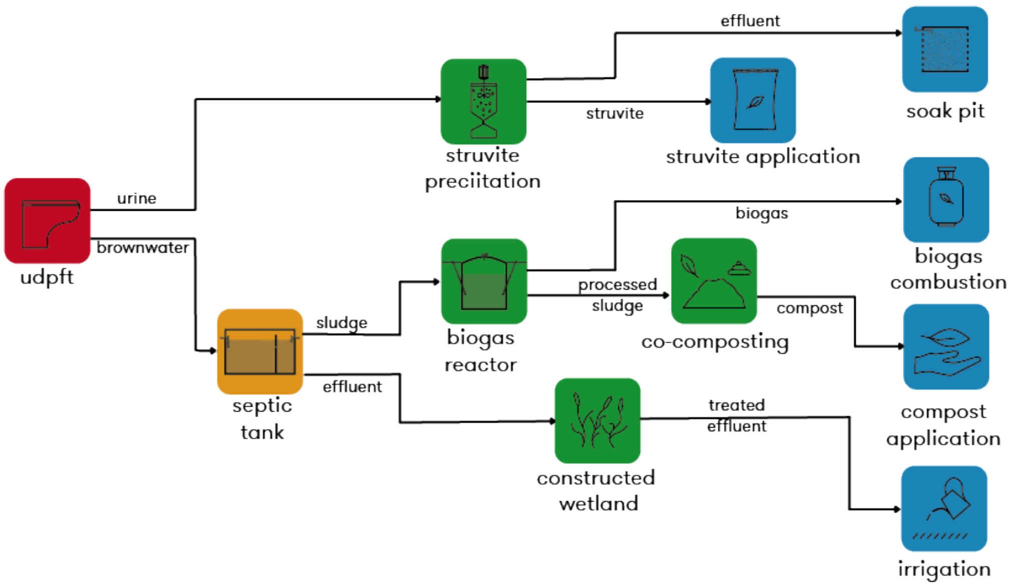


Figure 18 shows that the System Appropriateness Score (SAS) is much higher for systems C1 and C2 than for C3. Despite the medium SAS and the complexity of the latter, it provides a great overview of the broad range of sanitation by-products options. Moreover, it promotes the segregation of sanitation products at its point of generation to maximize the resource recovery potential at the local level. It obviously requires higher initial investment, operation and maintenance and surface area for treatment than the onsite systems.

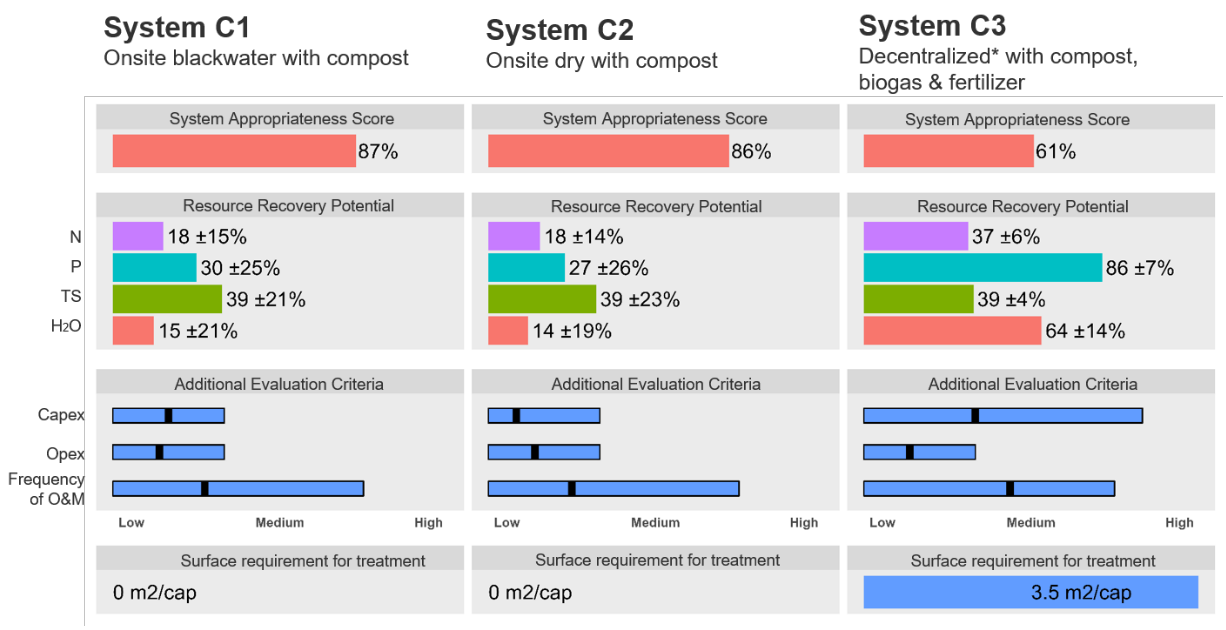


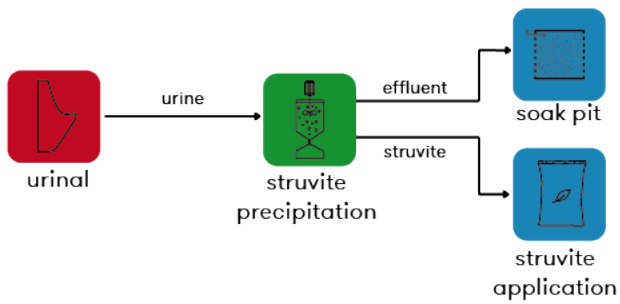
Figure 18: Preselected appropriate systems for type C with their SAS and performance. The mean and its standard deviation are given for the resource recovery potential of each substance (N: nitrogen, P: phosporus, TS: total solids, H2O: water). Additional evaluation criteria are provided with the average of all technologies included in the system (black line) and the blue range is plotted from the minimum to maximum requirement of its technologies.
∗ *no technology of FG Conveyance is considered by the system*

Type D: flood-prone areas The technologies resilient to floods are often an improved version of the existing ones rather than specific technology for flood-prone areas. Thus, the results provided by SaniChoice/Santiago are very similar than for types B and C. This is because the criterion *Flooding Risk*) is not able to influence the TAS sufficiently (see also type D analysis in section A.3 of Supporting Information).
But an improvement of the technologies is possible to increase their resilience to floods. The main adaptation is the elevation of the treatment system above the maximum flood water level to avoid the entrance of external water in the system [Borges Pedro et al., 2020].
Thus, it is reasonable to apply the same system than its surrounding zones by taking precautions to increase the resilience to floods of onsite containment (totally sealed and potentially raised). Since floods are not such a big issue for Changunarayan due to the topography of the municipality, offsite surface area for treatment (decentralized or centralized) can be found outside the mapped flood zones.

Urinal for all types of zone Urinal based sanitation system could be an interesting trade-off to the implementation of urine-diverting toilet requiring new infrastructures. Since urine is a rich-nutrient liquid virtually free of pathogen, it can be used in agriculture to improve the productivity of plants and to reduce the dependence on costly chemical fertilizers [Ulrich et al., 2014]. In contrast, it might increase substantially the operation and maintenance frequency.

- **Urinal 1. Onsite**
  This simple system collects urine onsite in storage tanks appropriately sized to the number of users before its application in the field as a nitrogen rich fertilizer. The urinal considered by SaniChoice could be adapted for public toilets or public institutions (schools, municipality offices, etc.) but it is probably less likely to be implemented at the household level. Nevertheless, it exists a dry urinal where the user directly urinate on straw that, once soaked, can be added to a compost (aka *Uritonnoir*) [Engels, 2017; Gourmand, 2021] or even given to the cattle as a valuable animal product [Rusdy, 2022]. In addition, it can be adapted and used very easily by women. This technology widely known in permaculture practices is still poorly documented but could be adapted for periurban and rural zones if straw is available and composting practices are present.

- **Urinal 2. Decentralized treatment**
  The social acceptance may be low with urine application when collected publicly. Processing the urine to obtain a dry fertilizer would overcome the social constraints. Two technologies allow to get a dry product from urine: alkaline dehydration of urine and struvite precipitation. Whereas the former requires high energy for drying, the latter can operate without electricity [Mcconville et al., 2020] and could be considered for the case study. The technology has been previously tested in Siddhipur in 2008. However, the effluent still contains important amounts of nitrogen and eventual medical residues and therefore should not be directly released in the environment. It is here proposed to infiltrate it through soak pits, but leach field can also be considered.



According to the SAS for each type of zone provided in Figure 19, Urinal 1 performs the best because the appropriateness score of *O&M Skills* for struvite precipitation is quite low (see Figure 14). Since this appropriateness criterion was roughly estimated, one should rather consider it as an evaluation criterion than screening one. Moreover, according to this assessment, urinal systems are less appropriate in rural zones (type C) than urban area (type A).This statement makes sense in terms of urine collection. It is easier to get larger amounts in denser area but is not that consistent in terms of end use: fertilizers are applied in an agricultural context.
Considering the resource recovery potential, it is clear that Urinal 1 would achieve a much more complete recovery than Urinal 2 which only recovers phosphorus as expected. Nevertheless, the end product should also be considered: struvite is a slow-release dry fertilizer without risk of burning the plants whereas stored urine is heavy and difficult to transport but acts as a complete fertilizer. This is reflected also with the frequency of O&M higher for Urinal 1.
Last but not least, Urinal 1 implies lower costs, whether they are capital investment or operation cost. One should note that the cost recovery through resource recovery is not taken into account but could be an important argument for both systems.

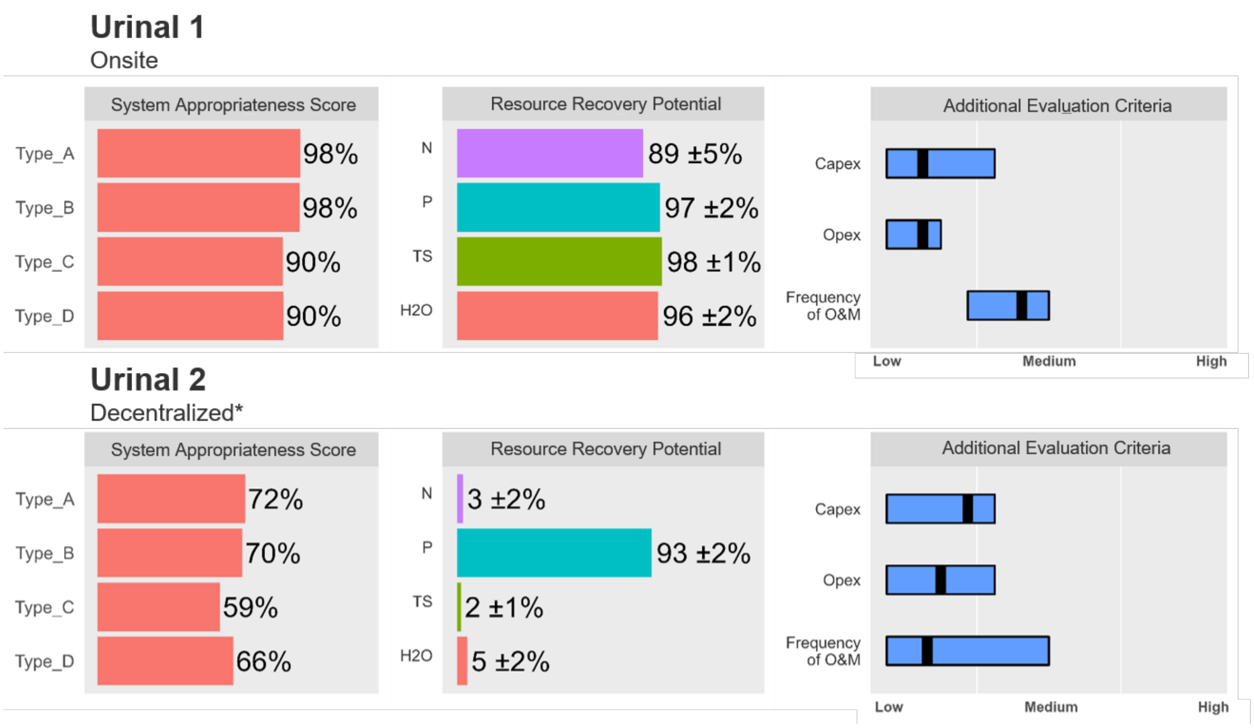


Figure 19: Preselected systems based on urinal for all types of zones with their SAS and performance. The mean and its standard deviation are given for the resource recovery potential of each substance (N: Nitrogen, P: Phosporus, TS: Total Solids, H2O: Water). Additional evaluation criteria are provided with the average of all technologies included in the system (black line) and the blue range is plotted from the minimum to maximum requirement of its technologies. ∗ *no technology of FG Conveyance is considered by the system*

4.3.2.2 Preselected sanitation systems per Ward

After a detailed feasibility assessment looking also at different O&M set-ups, the project partners will discuss them with the different wards. In the scope of this master project, the selection was only presented to the municipality. Hence, the following paragraph presents only the methodology and its discussion and not the results.
The appropriateness assessment was conducted according to the demarcation developed in section 4.2. Figure 20 illustrates how to link the type of zones based on geo-physical aspects to the administrative entities, here the nine Wards. The demarcation of the zones lead to the generation of 14 systems which might be overwhelming. By preselecting two to three systems per Ward according to the types of zones present in the ward, the discussion with local stakeholders and decision-makers at the ward level would probably be facilitated. Besides the appropriateness assessment and the type of zone included in the ward, the selection should also consider the local priorities raised in the Focal Group Discussion (see Figure 40 in the appendix).
An interesting parallel can be drawn with the Swiss regional drainage plan[4] that allows to firstly consider water management at a watershed level and integrate it in a coordinated way at a communal level. According to the methodology developed here, such procedure could be taken into account in a SaniChoice application by first defining the application cases independently of the administrative boundaries and coming back to them in a second step. A third step would be the coordination and the search for synergies between similar sanitation system options in different administrative entities.

[4] *Plan régional de l'évacuation des eaux (PREE)* : developed to guarantee appropriate waters protection in a limited, hydrologically-related area in which waters protection measures of the communes must be coordinated [OFEV, 2021]

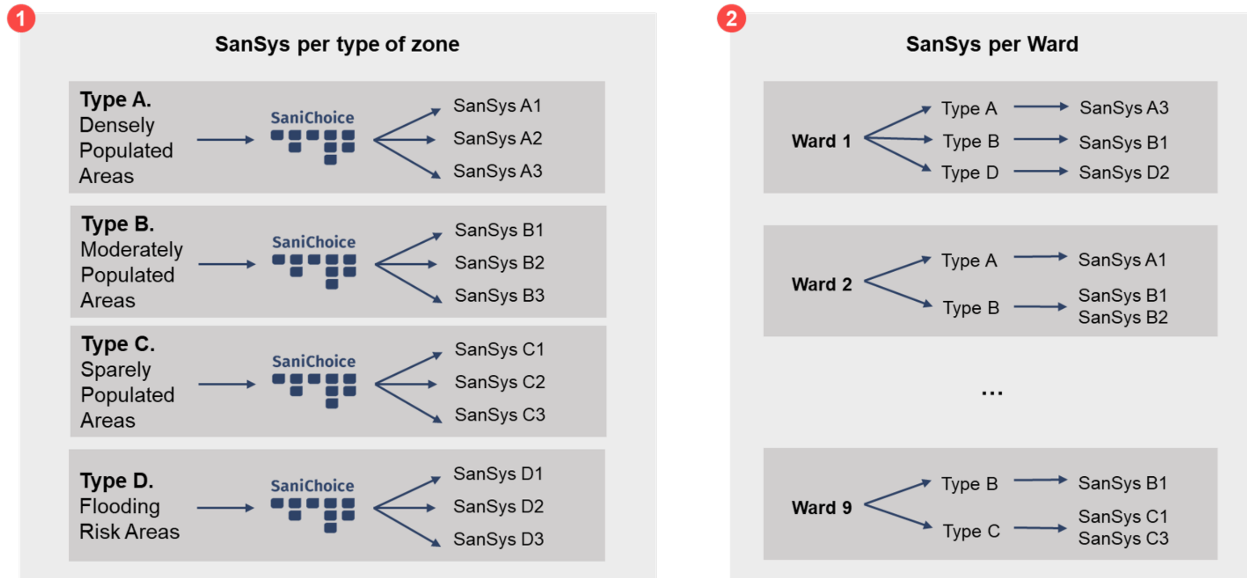


Figure 20: Linking the results obtained per type of zone to the Ward level for further discussion of options and trade-offs.

4.3.3 Additional considerations

The systems generated by SaniChoice are not the final ones. They need yet further and deeper analysis to assess their actual feasibility. One has to consider that one or several technologies can be changed within a preselected sanitation system option to improve its local appropriateness based on external expert points of view. For instance, it could be more reasonable to replace the struvite precipitation of System C3 with a urine bank and apply the end product as liquid fertilizer to recover also nitrogen (N) rather than phosphorus (P) only. Similar reasoning can be applied for a technology encompassing similar types of sub-technologies (e.g vermifilter instead of vermi-composting). Indeed, solid-liquid separation is better achieved by vermifilter that allows to trap the solids at the top of the filter where they are processed by the worms while the liquids infiltrate through the filter.
Urine diverting dry toilet (uddt) has not been considered in this study due to existing infrastructure and failure of the ecosan toilets (lack of maintenance) in different areas of the municipality. However, dry systems with urine diversion are sustainable alternatives for rural settlements (mostly Cii, D): less likely to contaminate the environment, resource recovery, very low water consumption, low land required. Despite these advantages, the social acceptance and the interest of the local population are quite low.

Greywater is not included in the SaniChoice system generation yet. It is though in Santiago by including the additional technologies (U_{add}). Nonetheless, with some creativity and system adaptations, synergies with blackwater can be found. In most of the cases, one could think about simply add it to the treatment chain but it will increases substantially the volume of wastewater to treat since greywater accounts about 65% of the households wastewater [Ulrich et al., 2014]. This blackwater dilution will result with a decrease of the efficiency of treatment and an increase of the treatment land occupation. Hence, an onsite treatment through underground infiltration would probably be a more appropriate solution. This alternative may require a grease trap in certain areas like in the Nagarkot hotel resort (ward 6) to prevent soil clogging (see FGD Summary in Figure 40 in appendix). This pre-treatment technology can be applied at the household level with an under-the-sink grease trap or to bigger infrastructures (hotels, neighborhood) with larger outdoor grease interceptors [Ulrich et al., 2014].

While planning sanitation systems, one has to consider potential synergies between the sanitation value chain and the solid waste management. Some interactions between the two chains represent an added value such as the co-composting technology which consists in adding external organic waste from agriculture or households while composting the sludge to increase the carbon-nitrogen ration (C:N) leading to a higher quality soil amendment. In contrast, other interactions could be problematic resulting with clogging issues in the pipes or contamination of the environment if solid waste (sanitary pads, diapers, etc.) is thrown into the toilet for instance. To avoid such problematic behaviours, awareness raising campaigns for behaviour change should be considered.

According to this study, a lot of areas would be susceptible to implement decentralized wastewater system DEWATS at the tole [5] level. As developed in chapter 1.2.1, the issues with DEWATS are often the lack of operation and maintenance. The CWIS principles target at filling this gap by ensuring and defining accountable persons to manage the operation of the sanitation facilities. Adequate training of those persons and population awareness raising campaigns have to be achieved to ensure the sustainability of the project. Independently of the kind of sanitation ST, the implementation should be done step-by-step. At a short term, by-laws can be developed to establish the vision of the sanitation for Changunarayan. Then, at short/medium term the focus should be on technologies from FG Storage and Containment: sealing the actual holding tanks and constructing the collective ones to ensure a motorized emptying. In parallel, a faecal sludge treatment chain should be constructed to provide a service as soon as possible in order to get rid of its discharge into water bodies without treatment. Then the effluent flowing out of the containment technologies can be connected to the treatment chain through solids-free sewers. Any construction can be done involving local communities and future users, to the extent of their competences, to enhance their ownership on the project.

5 Overall assessment

There is no optimal sanitation system, they are all a result of environmental or socio-cultural constraints and trade-offs which have excluded or included some technologies along the planning phases. A silver bullet doesn't exist, especially for flood-prone zones for which some references have been summarized by [Borges Pedro et al., 2020]. Once a decision on one or several preferred systems is taken resulting from stakeholder and decision-makers consultation workshops, the SaniChoice application is completed but not the sanitation planning.
In this section results of its application are not discussed but the SaniChoice web-tool as well as the Practitioner's Guide.

5.1 SaniChoice contribution to sanitation planning

The contribution of SaniChoice to the sanitation planning is summarized in the following SWOT analysis. Used to develop strategic planning, a SWOT analysis assesses internal and current factors (strengths, weaknesses) as well as external and future factors (opportunities, threats).

5.1.1 SaniChoice web-tool

A detailed analysis is provided in the section A.4.1 of Supporting Information.

[5] Tole (Nepali): small settlements whose boundaries are defined by topographic and socio-cultural considerations

STRENGTHS	WEAKNESSES
- Applicable at an early stage of planning process and with uncertain data - Inclusive approach by considering the uncertainty and trade-offs - Opportunity to think outside the box - Informed selection of sanitation options - Freely available online - Interactive and simple to use with a rapid achievement of outcomes - Technology library versatile allowing improvements and future innovations - Sharing possibilities through a simple weblink	- Novel tool that still requires improvements - Preconditions are too restrictive. - Requires the Practitioners' Guide to be applied - Difficulties to understand some criteria - Visualization of sanitation systems too complex - Impossibility to build the systems manually - Doesn't allow to export the results nor data - Greywater not taken into account
OPPORTUNITIES	**THREATS**
- Promotion and support of the tool - Interest from local partners to use the tool - Use as an educational training tool - User's feedback to update and improve the tool	- Lack of interest for the tool - Low acceptance by practitioners - Discouraging wrong application - Tool provided only in English

Santiago

Although the term "SaniChoice" is used in this report, the appropriateness assessment and system generation was done using the Santiago[6] expert software from which the SaniChoice web-tool is derived. This section aims to compare the use of SaniChoice web-tool to the expert software. Advantages (+) and disadvantages (-) using Santiago rather than SaniChoice web-tool are provided in the following list.

+ Input data availability: Technology library, application cases and R code for data analysis available on GitHub.
+ Output data allow to plot anything, especially how much each criterion is affecting the TAS
+ Flexibility: it allows to directly update the techs library by changing and/or adding technologies and their attributes (e.g. udpft as new FG U technology)
+ Better sanitation system visualization using Graphviz[7] than the one provided by SaniChoice
+ GitHub as a community-based space to find and contribute answers to technical issues and improves the techs library
+ Massflow calculation possible at the technology level (not only for the entire system)
+ Allows to consider greywater
+ No need for an internet connection

- Expert software requiring programming skills
- Time consuming activities to generate the systems and to compute the massflows
- Requires an additional data analysis
- Does not include the preconditions filter (application and management level, development phase, Opex & Capex restrictions, etc.) available in SaniChoice.

[6] SANitation sysTem Alternative GeneratOr
[7] Graphviz is an open source graph visualization software

5.1.2 SaniChoice Practitioner's Guide

Although only a few activities were embedded in the CWIS planning in Changunarayan, the Practitioners' Guide was used as the main reference to apply SaniChoice following 4 of the 5 steps it suggests. The fifth one was not completed due to time restrictions in the case study and impossibility to conduct the last workshop. However, all steps are discussed in the section.
A detailed analysis is provided in the section A.4.2 of Supporting Information.

STRENGTHS

- Easy integration in any strategic planning
- Helps structuring the sanitation planning process
- Aligns different stakeholder's perspectives through decision objectives
- Involves local stakeholders

WEAKNESSES

- Necessary reference to apply SaniChoice
- Issues to get decision objectives from stakeholders
- Difficulties to get criteria from decision objectives without the master list

OPPORTUNITIES

- Foster local momentum
- Facilitates the promotion

THREATS

- Wording might be too demanding
- Decision making of final systems by unqualified stakeholders

5.2 Recommendations for the future

The recommendations are given as a bullet point list. Each point is discussed in details in the section A.5 of Supporting Information.

SaniChoice web-tool

- Shorter videos
- Add step-by-step SaniChoice application in the main page
- Improve the precondition filter or turn it into additional evaluation criteria
- Add an option to export the results (CSV file, graphs, system visualization)
- Include precision on greywater
- Include the criteria appropriate score in the technology appropriateness assessment (e.g. Figure 12)
- Possibility to use appropriateness criteria as evaluation criteria if the available data doesn't allow to quantify them (e.g. surface area (offsite), frequency of O&M)
- Research option in the SaniChoice glossary

The web-tool is now not intuitive enough to be used without external explanation (Practitioners' Guide, training, etc.). The videos that could offer this explanation by providing a guided tour of the website are long and people often skip them. Proposing shorter videos of around 4 minutes might increase the number of views without discouraging the user to watch them. In parallel, a step-by-step figure informing roughly on the procedure to follow while applying SaniChoice would help structuring the website and thus help new users to taking control of the tool. This suggestion can also be completed by short and clearer instruction along the SaniChoice application such as ”1. Select your appropriateness criteria”.

Appropriateness criteria cannot be all quantified because information is not available. It could be due to the early stage of the planning process still having a lot of uncertainties (offsite surface area) or to simply data not being available (groundwater depth). However, certain of these criteria difficult to quantify might be relevant for the appropriateness assessment. Rather than neglecting them, the data from the existing SaniChoice library can be used as evaluation criteria as it was done for the frequency of O&M and offsite surface area in this study.

Technology library

- Add technologies: biogas reactor (household level), urine-diverting pour flush toilet (udpft) and dry urinal on straw
- Change or delete the effect of the *Vehicular Access* criterion on the technology *Tranfer station*

Practitioners' Guide

- Add *Step 0. Definition of application cases* to the guide
- Prescoping the appropriateness criteria in earlier phase of the planning process, during *Clarification of the context*
- Advice on using a criterion without available data to quantify it as a limiting one (e.g. drinking water exposure)
- Warning about the exclusive character of Preconditions (if kept as a filter)
- Specify more clearly what are the types of system templates

The methodology developed to demarcate the zones and thus define the SaniChoice application case could be added to the Practitioners' Guide as a preliminary step. When it comes to the quantification of the criteria, it may result on a lot of missing information that could require data collection activities. Such activities are forming part of phase 1 of SDM (Clarification of the Context). Prescoping the appropriateness criteria and preconditions in earlier stages represents a consequent gain of time since it can be embedded in other activities by the planning framework, such as household survey.

Appropriateness criteria

The effect of a limiting criterion is often dissolved with higher attribute scores from other criteria while computing the TAS. That shouldn't happen with a few criteria only, that's why it is recommended to use 10 criteria max. It is a necessity to know how each appropriateness criteria used actually affect the TAS. Unfortunately, SaniChoice doesn't provide this information. So far, the latter is available only with a Santiago application combined with a data analysis.

Missing data can lead to important simplifications or to neglect limiting criteria (groundwater depth), however the appropriateness assessment can be done with uncertain data or using assumptions to anyway consider locally relevant criteria. Using accurate data is better but actually not that important considering that the appropriateness scores are calculated using probabiliy functions. This acutally allows to consider an uncertain criterion as a limiting one and prospect how it affects the technologies as it was done with the criterion *Drinking water exposure*. Again, this assessment is possible only if the attributes appropriateness scores are plotted.

In this case study, quantifying the appropriateness identified as relevant for the local context posed problems. Some thoughts on and proposition for improvement are given for the most problematic criteria:

- **Electricity Supply** is probably too simplified with its three categories (continuous/intermittent/no supply). There is no distinction between onsite and offsite electricity supply. Indeed, the supply could be limited at the household level but continuous offsite, for centralized WWTP for instance that use another distribution network who ensure a continuous supply. Splitting this criterion in two categories as done for the *Surface Area* might allow a more complete assessment.
- **Surface Area (offsite)** is difficult to quantify, mostly in case studies presenting different typologies of settlement inducing different degrees of centralization. Using m^2/cap as unit, it requires well delimited boundaries to know the number of inhabitant connected to the treatment facility as well as an allocatable land. Since these two components were unknown for Changunarayan, it was decided to use this criterion as rough estimation to compare the preselected systems.

- **O&M Skills** takes into account the locally available workforce skills looking at the proportion of the three categories (unskilled, skilled, professional). Considering its distribution over the local population will end up having a very low proportion of professionals relative to the other categories and thus the TAS will then be highly affected. It makes more sense to quantify this criterion as it was done for this study, which means taking the availability of skills of the team responsible of the sanitation system. However, this data is often uncertain since the sanitation workforce is not created at such an early stage of the planning. Moreover, one has to know that this criterion applies to all functional groups and thus might affect all TAS. Despite those limitations, it remains a good indicator getting the decision makers aware of the relative skills requirements among the different technologies.

- **O&M Frequency** can be delicate to quantify and is probably easier to consider as an additional evaluation criteria at the system level. Indeed, planning for the unknown and at an early point of the planning process induces a lot of uncertainties, mostly when it deals with human focused consideration. For instance, the solid-free sewer has a TAS equal to zero for the types C and D due to this criterion. This technology is thus excluded while it might be appropriate for the hilly areas to connect the onsite containment effluent to a decentralized treatment.

5.3 Discussion of Research Questions (RQ)

RQ#1 Does SaniChoice allow efficient identification of locally appropriate sanitation solutions?

A large range of technologies is initially and systematically included by SaniChoice allowing the user to think out of the box. The appropriateness assessment screens the technologies in a transparent way with the TAS. Nevertheless, the appropriateness assessment and the system generation are sensitive to the selected appropriateness criteria used for the assessment and evaluation attributes. For more transparency, the attribute appropriateness score $AS_{t,c}$ should be made accessible to allow the user to better include or exclude technologies manually with a more informed assessment.
SaniChoice is supposed to consider entire and valid systems. Since the system building works with outputs generated by the technologies, it might result with non-sense such as an urinal-based system producing sludge (see Figure 26 in appendix). Despite some invalid systems that are excluded with a plausibility check, the algorithm is working. Indeed, the fact that similar application cases result with similar sanitation systems (cf. system B1 and D1) proves that the approach is systematic. Since the system building looks at each functional group, it enforces obviously the consideration of entire systems. SaniChoice generates a diverse set of sanitation system options based on different system templates and "selects" as many appropriate systems as the user wants. By allotting a number of systems equal to the number of system templates generated allows to consider the entire diversity for presenting them to the stakeholders. Hence, the answer to this question is positive but the user has to be aware of the assumptions he/she took to get the results and should examine them critically. Also a plausibility check and manual fine-tuning is required before handing the options over to the planning process.

RQ#2 Does SaniChoice help to prioritise more appropriate sanitation systems with high resource recovery potential including novel technologies?

The mass flows computation offers meaningful information on resource recovery potentials of the generated systems. Having this information ex-ante relatively rapidly allows to compare systematically the systems and to select the system in a informed way. One has to remember that the recovery ratio potentials remain *expected* results.
Since novels technologies are included in the initial technology library, the generated systems can obviously include such technologies. Moreover, the additional evaluation criterion *Technical Maturity* informs the practitioner on how well-established the technology is to be aware and critical on the information on its performance and on its practical implementation.
SaniChoice does help to prioritise systems with high resource recovery.

RQ#3 Does SaniChoice help to come up with more inclusive solution by suggesting different solutions for all socio-demographic conditions in line with the CWIS principles?

A SaniChoice application does actually suggest different solutions for a single case. Integrating the step of demarcation of zones and defining types of settlements (as done in this study) allows to provide solutions for different geographical and demographic situation. In the establisehment of zones and types, one could also include more social criteria such as for instance income levels. In any case, the demarcation of the zones is a key activity. However, the practitioner should be aware that if the appropriateness criteria used for the cases result in similar scores, then also similar systems will be suggested by SaniCHoice. This was the case in this study for the differentiation between flat and hilly areas.
Others CWIS principles are still not addressed such as the synergies with other sectors (e.g. solid waste management) nor aspects related to business and service models. Nevertheless, these aspects are considered in further stages of the CWIS guideline (see Table 9 in appendix).

RQ#4 Does SaniChoice enhance transparency of the selection process as well as their acceptance and ownership of selected solutions?

The transparency of the selection is ensured by different aspects: (i) the performance data of technologies is available on the website and allows an informed selection; (ii) the decision objective hierarchy developed for and with the local stakeholder provides the basis of the way the sanitation should take; (iii) the SaniChoice application is detailed in its Practitioners' Guide; (iv) evaluation criteria could be sufficient to highlight or preselect some systems but they still require to be completed by a deeper analysis to process to the final selection. Additionally, the transparency could be enhanced by providing not only technology scores but also the scores for each attribute ($AS_{t,c}$).
In the context of development cooperation, ownership refers to how people identify with an initiative that affects them directly and to the individual responsibility they are able and motivated to assume [IZB, 2017]. Since the ownership of local stakeholder is often key for ensuring the sustainability of the project , it requires special attention to the relevance of the project, the quality of the collaboration between the project and local stakeholders and the social acceptance [IZB, 2017].
Since no final choice was taken with the application of SaniChoice in this case study, the acceptance of the selection process is difficultly to assess. However, the Focal Group Discussions (FGD) (workshop 1) definitively triggered the local stakeholder interest and represents a first step of their inclusion. Special attention was given to ensure the equitable involvement and participation of different groups of stakeholders. Overall, the SaniChoice Practitioners' Guide provides a structured guideline including activities involving local stakeholders that provides powerful insights to strengthen the ownership consideration.

6 Conclusions

The application of SaniChoice following the Practitioners' Guide recommendations is promising but some improvements are required regarding the web-tool. SaniChoice provides an evidence-based and informed appropriateness assessment ex-ante. This is a important contribution to the strategic planning but by far not enough to implement the planning process. An advantage is that it provides an assessment of the potential technologies and entire systems in an early stage of the process thereby eliminating inappropriate technologies early and encouraging to think out of the box. Nonetheless, SaniChoice provides the *expected* appropriateness and resource recovery. It does not replace in-situ performance measurements and therefore should be complemented with additional indicators in a detailed feasibility study.

The SaniChoice web-tool is targeting a broader audience than Santiago by being a user-friendly version of the latter. However, this leads to trade-offs between the simplification taken for its popularization and the loss of information resulting from these simplifications. Currently, SaniChoice is more an awareness raising and training tool than a professional tool. Its application allows to explore interactively the diversity of sanitation alternatives for a better understanding of their performance and limits and triggers discussion on sanitation system options based on the available evaluation criteria. In contrast, Santiago is an expert tool that allows to do in-depth analysis and provide the possibility to modify and add or remove criteria or technologies. The users targeted by SaniChoice are firstly engineering consultants and urban planners. Although they don't have necessarily programming skills, they are able to analyze more complex graphs and data than the one provided by SaniChoice. Hence, the balance between simplification and loss of information should be revised.

Furthermore, the fact that there is no option to manually select the system can be frustrating in some cases. Indeed, the plausibility check conducted while preselecting the systems often ended up with similar conclusions: the system would be locally more appropriate by changing one single technology. For a more complete ex-ante assessment and modelling of sanitation systems, the preselected ones generated by SaniChoice could be implemented and complemented by another existing modelling software, such as SAmpSONS2 or SIMBA# which allow to simulate and visualize material flows in sanitation systems [Schütze et al., 2019]. Also the system builder developed for the Emergency Compendium [German WASH Network and Eawag, 2020] could be integrated in SaniChoice: it allows to add technologies in a basket and assemble them manually in a dashboard.

The application of the SaniChoice Practitioners' Guide as part of the local CWIS leads to a better understanding regarding the steps required and the methods to be used to integrate the approach with the planning process, particularly the data collection and workshops. An additional important contribution of this study is the development of a systematic methodology to define zones within a city and different types of settlement. This allows to come up with a mix of different appropriate systems considering the heterogeneity of an urban area.

This study, including implementation, results and discussion, is based on the experience of the Changunarayan case study. Nonetheless, the SaniChoice application is not limited to peri-urban areas in Nepal nor necessarily embedded into a CWIS planning framework. The methodology developed here is fully generic. The attributes used to define the application cases and the criteria used for the appropriateness assessment and to compare systems can vary according to the local context. The use of Santiago provides even more flexibility by providing all the generated data for further analysis and by permitting the user to adapt and change directly the technology library. The stages of the Structured Decision Making (SDM) used by the Practitioners' Guide can be applied to any sanitation planning and therefore allows to integrate SaniChoice into any existing strategic framework.
The required time to apply SaniChoice doesn't imply additional work. The necessary inputs are often automatically provided by the sanitation planning and the results are generated quickly. Moreover, uncertain data can be used to quantify the appropriateness criteria to prevent the time-consuming activities to obtain accurate information.

In the case of Changunarayan, the results provide valuable alternative options that triggered interesting discussions among the local decision-makers and the process raised the interest of the local partners who recognized its contribution to develop a more inclusive citywide sanitation planning. The SaniChoice application contributed to enhance a coherent and common vision of the planning by the project team. It also allowed to raise awareness of persons with less sanitation planning experience on the limits and possibilities of the broad range of sanitation technologies. Moreover, it helped structuring the CWIS planning process allowing a higher independency of the team from experimented sanitation consultant in the first four stages of the CWIS planning framework. Replicating this procedure for the current other sanitation planning projects that 500B Solutions Pvt. Ltd. is conducting in parallel using the this case study as template could bring an important added-value and would strengthen the outcomes on the SaniChoice relevance.

To conclude, all previous research that initiated SaniChoice and its Practitioners' Guide are well worth it. SaniChoice does allow to transparently identify locally appropriate sanitation technologies considering novel ones thereby contributing to the prioritisation of more inclusive and resource efficient sanitation solutions. In contrast, the Practitioners' Guide summarizes the integration procedure of the tool in a structured step-by-step way into any existing frameworks including meaningful supporting resources and activities that target at enhancing the ownership of local stakeholders. However, SaniChoice is a novel tool that still requires some improvements to be fully applicable and used as a significant support tool for strategic and inclusive sanitation planning.

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A Supporting Information

A.1 Precision on the SaniChoice integration to the CWIS Planning for Changunarayan

This section provides additional information on the section 3.2.

Stage 1: Develop understanding and commit to prepare CWIS.

After the selection of the municipality and some visits to the municipality office to ensure the demand for sanitation was still present, an inception workshop (W0) was conducted on June 17th to explain the CWIS principles, agree on a planning process roadmap with the municipal authorities by signing the Memorandum of Understanding (MoU). This agreement finally allowed to launch the planning process and go forward with the plan. Due to time restrictions, it was decided to prescope the vision of the municipality authorities on sanitation during this inception workshop. In other words, it consisted in mixing partially W2 with W0. The outcomes of this rapid assessment based on the agenda for W2 Stakeholder Workshop (R1.1) provided by the Practitioners' Guide [Spuhler et al., 2021] were used to define the decision objectives.

Stage 2: Situation Analysis

Thanks to the existing data collection (WASH report [Changunarayan Municipality, 2020], Shit-Flow Diagram [CWIS Technical Asistance Hub and Environment and Public Health Organization, 2019], GIS data [Rajdevi Engineering Consultant, 2020]) and field visits, the situation analysis could be started although the MoU was not signed. It allowed to achieve the demarcation of the zone and thus the SaniChoice application cases to quantify preliminarily the appropriateness criteria. A draft stakeholder analysis was also done in that stage and continuously completed along the different sanitation planning steps.
Once the MoU was signed by the municipality and 500B Solutions on June 23rd, a series of Focal Group Discussions (FGDs) was organized. The aim was to bring people from local communities together, inform them about the CWIS Planning approach and to define together the local priorities. The FGDs were based on the current sanitation situation to ensure that the solutions developed and proposed in stage 4 met the people's needs and expectations. The definition of the decision objective relies mostly on these local priorities. In parallel, households and institution surveys were launched to update and complete the existing sanitation data. Some questions specific to the SaniChoice appropriateness criteria were added to the questionnaire. The enumerators (local people) received a training in an orientation workshop where they learned to use KoBo (suite of tools for field data collection) and how to answer to the questionnaire. The surveys were conducted in 531 households representative of every different zone of the municipality. The results of these surveys target at validating the data collected so far.
Last but not least, the stakeholder analysis is completed during this phase based on the methodology suggested by the SSWM Toolbox [Lienert, 2010; ODA, 1995; Rietbergen-McCracken and D. Narayan, 1998]. The FGDs played an important role for this assessment.

Stage 3: CWIS Planning Workshops

Due to time and budget restriction, the workshop 2 *Situational Assessement and Setting Objectives* could not take place. Instead, it was split in two part: the first one on "setting objectives" during the inception workshop (W0) and the presentation of the situational assessment as an introduction of workshop 4 before the presentation of results of the SaniChoice application.
The Expert Consultation Workshop (W3) took place on July 11th resulting with the final Decision Objectives Hierarchy and the selection Appropriateness and Evaluation Criteria as outcomes.

Stage 4: Detailed Analysis

According to the outcomes of the expert workshop (W3) and to the application cases defined during the Situation Analysis, it was finally possible to run SaniChoice in order to identify the potential appropriate

technologies and system options per zone. The results were then presented to the Task Force at the municipality office during the workshop 4 (W4) on July 17th.
Further activities and steps won't be developed here since SaniChoice application is no longer dependent on them.

A.2 Assumptions per type of zone

The input data rely on the following hypothesis:

- **System templates (ST)** Since the project was at an early phase of the planning, many components were unknown, such as the location and surface area allocatable for treatment facilities. It was therefore impossible to take into account the appropriateness criteria *"Surface area (offsite)"* which considers the number of inhabitants connected to the treatment facility and its total surface. As the surface area is an important limiting factor, ST have been set for each type of zones to prioritize the level of centralization.
  Additionally, the production of fertilizer from urine is more realistic in places where agriculture is still widely present (zone B, C, D and E). Last but not least, some dry system templates have been considered in hilly rural and remote areas where water for sanitation can be an issue.

- **User's interface (FG U)** Only four technologies of the FG U have been considered (pour flush toilet, urine diverting pour flush toilet (udpft), dry toilet and urinal). *Water Supply* and *Cleansing Method* which act only on the technologies of FG U have therefore not been taken into account. The udpft was added to the library manually. It has been assumed that its inflows (water volume) are the same as the existing pour flush toilet and its attributes come from the urine-diverting flush toilet.

- **Water Volume** This criterion has been quantified mostly from the households survey (see Figure 21) that shows a slightly weaker consumption in hilly areas (type Bii and Cii) and urban zones (type A). Since these numbers were estimated by local people, the two following papers were used to validate and adapt the collected data. All numbers are given in liter per capita per day (lpcd).

  - mean water consumption is 162 lpcd and median 80 lpcd for Bhaktapur District during dry season [Shrestha et al., 2016].
  - mean water consumption is 71 lpcd (resp. 85 lpcd) and median 41 lpcd (resp. 48 lpcd) for Kathmandu during rainy season (resp. rainy season) [Raina, 2017].

  In the trapezoidal function, minimum refers to the dry season and maximum to rainy season.

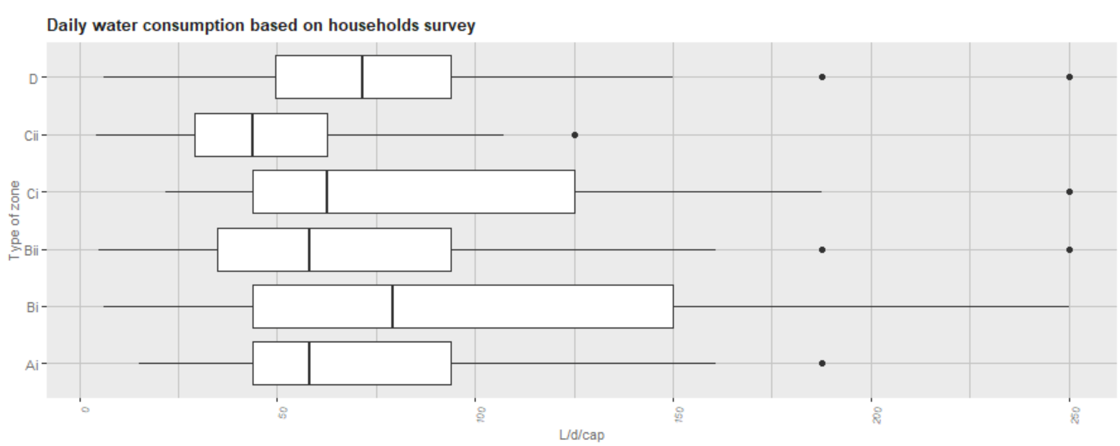


Figure 21: Boxplots of household water consumption per type of zone in liter per capita per day (lpcd) [source: author]

- **Electricity Supply** Although that the average electricity supply at the national level can be limited up to 8 hours per day (16 hours during dry-season) since Nepal is dependant on hydropower [Energypedia, 2020], the situation is not alarming in Changunarayan. Power shortage occurs frequently due to storm during rainy season or electrical overload during winter caused by electric heaters among others, but they do not last. Even if the household survey results with 50% *full supply* and 50% *intermittent supply* [500B Solutions, 2022], it has been assumed that *full supply* occurs only 25% of the cases in order to limit quite efficiently the technologies requiring electricity without excluding them completely (TAS=0).

- **Vehicular Access** Mostly based on the GIS analysis (see Table 2 here under) and the household analysis had validated this data by ensuring that the GIS analysis is probably overestimating the access. Nevertheless, according to field visits and discussion with experts, it has been decided to prioritize the GIS results which are more representative. *Full access* has been defined for the residential area at less than 25m from a road whose width is broader than 7m, *Difficult access* stands for the dwellings located at less than 25m from a 2-5m width road and *No access* represents the remaining residential zones. The results can be visually appreciated in Figure 24 in appendix.

		Ward number									
		1	2	3	4	5	6	7	8	9	**Total**
GIS Analysis	**Full access**	11%	15%	24%	12%	13%	18%	13%	22%	13%	**15%**
	Difficult access	50%	43%	44%	44%	47%	36%	46%	44%	51%	**45%**
	No access	39%	42%	32%	43%	39%	46%	40%	35%	37%	**40%**
HH survey	**Full access**	10%	1%	4%	6%	12%	16%	0%	0%	0%	**5%**
	Difficult access	42%	46%	35%	45%	37%	33%	42%	35%	30%	**39%**
	No access	49%	53%	61%	49%	51%	51%	59%	65%	70%	**56%**

Table 2: Proportion of residential area with vehicular access for motorized emptying of onsite containment [source: author]

- **Other supply criteria** The study area is located at the doors of Kathmandu and it is supposed that any types of supply (fuel, pipes, pumps, concrete or spare parts) are considered to be available anytime. Therefore, these criteria have not been used for the appropriateness scores computation.

- **Surface Area (onsite)** Based on visual estimation of about 30 zones of each types by computing the area available in the direct surrounding of dwellings. The trapezoidal function was used as a triangle where the typical minimum is equal to the typical maximum.

- **Flooding** Floods are occurring during the monsoons, which represents approximately four months a year and they are assumed to only happen along the Manohara river in the flooding risk area (see Figure 11).
  Rice paddies are present in the entire municipality and in many cases surround dwellings. It was therefore assumed that irrigation can lead to similar issues than floods and was taken into account in type E for 10% of the year (one harvest lasting around 1-1.5 month).

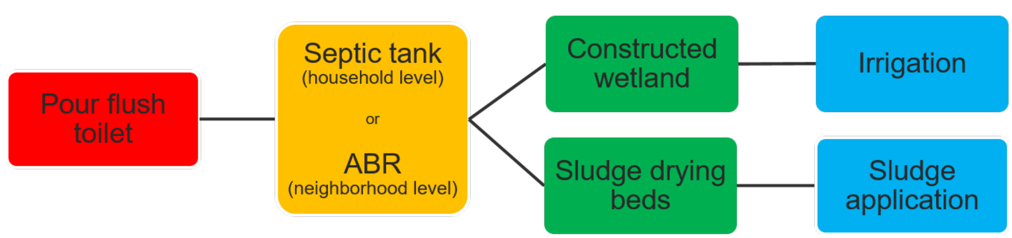
- **Soil Type** It has been assumed that there is only two main types of soil in the study area: clay loam and silty clay [Neeru and Khet, 2020; Rajdevi Engineering Consultant, 2020] which is supported by the fact that the municipality hosts several bricks factories. Average values have then been attributed to these soils from the soil texture triangle. Based on visual appreciation and for simplification, it has been assumed that no rock is present and gravel is present in dispositional alluvial zones [Rajdevi Engineering Consultant, 2020] and absent in other area based on the soil investigations in Duwakot and Bagoshwari [Neeru and Khet, 2020]. It then lead to three soil types according to the proximity with alluvial zones whose properties can be appreciated in the table below. Finally, a visual estimation using weighted average according to the proportion of the soil types in the type of zone has been used.

	Type of zone	Clay	Silt	Sand	Gravel	Rock
Clay loam in alluvial I	type D	28	28	24	20	0
Clay loam in alluvial II	1/2 type Bii and Cii, 1/3 type A, Bi, Ci and E	31	31	28	10	0
Silty clay	1/2 type Bii and Cii, 2/3 type A, Bi, Ci and E	50	40	10	0	0

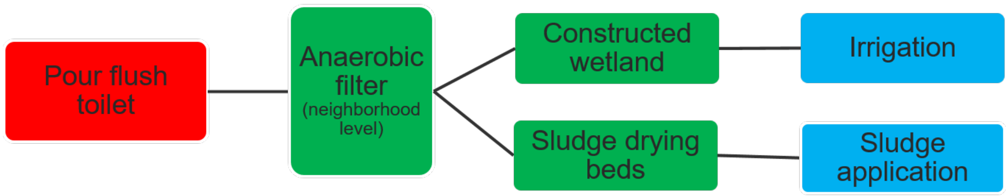
- **Temperature** Due to climate change, we can expect a shift to warmer temperature. Nonetheless, sanitation technologies are rather sensitive to cold climate. Thus it is based on actual monthly mean temperature [Sharma et al., 2021].
- **Slope** Only considered in zone's type D Flooding Risk, otherwise the municipality has slope higher than 1° (see Figure 23 in appendix).
- **Drinking Water Exposure** Since no data is available considering the groundwater table neither the location of the drinking water sources relative to containment or disposal practices, it was assumed that the denser the area, the more likely the drinking water contamination. Therefore, this criterion was considered in the appropriateness assessment based on estimations to avoid technologies based on infiltration (e.g soak pit) in such type of zone.
- **Frequency of O&M** The assumption here relies on the degree of centralization: the more centralized, the more frequent and continuous operation and maintenance requirements.
- **O&M Skills** Although the professional and skilled labour could be quite low relative to the overall population living in the municipality, the proportion is assumed to be relative to the person responsible of the sanitation system. It therefore varies among the zone according to the level of centralization, the more centralized the higher the proportion of professional. On the other hand, onsite sanitation system induces a higher proportion of unskilled labourers.

A.3 Type D: flood-prone areas

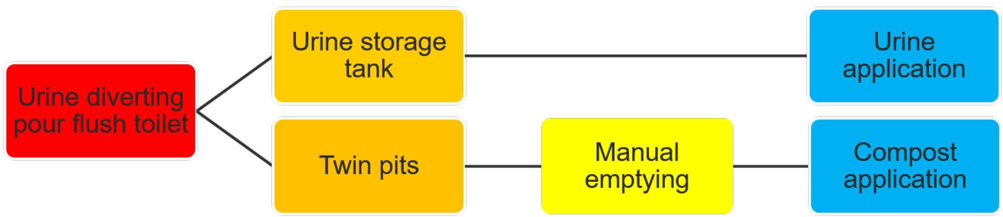
- **System D1. Decentralized blackwater with sludge production**
  This is the exact same system than B1. The only difference lies in its slightly lower SAS due to the additional criteria *Flooding risk*. Septic tanks were identified as solutions for floodable areas by raising the technology above the maximum flood water level [Borges Pedro et al., 2020].



- **System D2. Decentralized blackwater with sludge production**
  Again the system is very similar but this one includes an anaerobic filter instead of ABR. The higher SAS can be explained by the criterion *Vehicular Access* that is not taken into account for technologies from FG Treatment.



- **System D3. Onsite blackwater system with urine diversion and sludge production**
  It represents an alternative of system C1 by including urine diverting toilet to reuse this precious resource onsite (see Urinal 1 here under). However, it was not preselected for type C, it could be appropriate for those zones. Although pits are included in this system and can be considered as a solution to mitigate the effects of flood [Borges Pedro et al., 2020], they remain susceptible to failure or overflowing during flood [Ulrich et al., 2014].



Based on the discussion here above and according to the Figure 22 here under, SAS are more or less the same but systems D1 and D2 seems to be more resilient to flood than D3. However, D3 doesn't include any onsite containment technology: the toilet are directly connected to a close decentralized treatment facility. Hence, it narrows down the possibilities to avoid implementing the treatment facility outside the flood-prone zones.

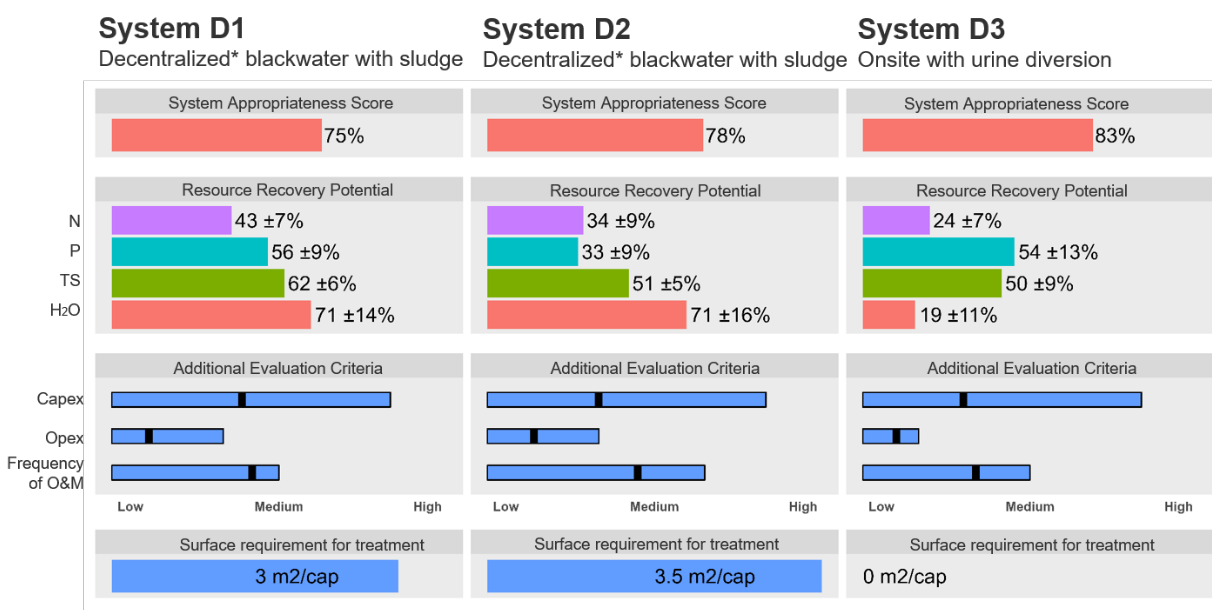


Figure 22: Preselected appropriate systems for type D with their SAS and performance. The mean and its standard deviation are given for the resource recovery potential of each substance. Additional evaluation criteria are provided with the mean of all technologies included in the system (black line) and the blue range is plotted from the minimum to maximum requirement of its technologies.
∗ *no technology of FG Conveyance is considered by the system*

A.4 Detailed SWOT analysis of SaniChoice contribution

This section develops the bullet point appearing in the SWOT matrices of the respective section.

A.4.1 SaniChoice web-tool

Strengths SaniChoice provides now 87 sanitation technologies factsheets including data for preselection and evaluation criteria. This broad spectrum of technological options allows the user to think outside the box by providing an appropriate assessment on each of them. By compiling technologies from different references [Gensch et al., 2018; Mcconville et al., 2020; Ulrich et al., 2014], the online library furnishes the necessary outcomes to draw up an informed selection of sanitation options. The tool provides thus an evidence-based reasoning adding value to the planning process and thus supporting transparently the decision-making process. It does not include or exclude technologies but considers the uncertainty and trade-offs. There is hardly any technology that will be 100% appropriate but some compromises have to be made. By allowing to calculate appropriateness at a system level enables to make this compromises systematically.
As an open-source tool, SaniChoice is freely available online as well as its Practitioners' Guide and its Training Package. The tool is flexible: it is based on a technology library that can easily be updated. The users have the possibility to contact the SaniChoice team to add a new technology or additional data on existing technologies. Moreover, they can also request training for the use of SaniChoice or to get support to apply it for planning.
The website is interactive and easy to use. In a few clicks, results are rapidly generated. They can be obtained by different means depending on the data availability using preconditions, system templates or manual selection to limit the initial number of technologies and criteria to assess quantitatively their appropriateness. Nonetheless, a combination of the latter is recommended. Moreover, SaniChoice can be applied at an early stage of the planning. Indeed, uncertain data can be used since it requires anyway a feasibility study after its application.
The data can be easily saved or shared by generating a web link (URL). The latter allows to use the saved settings and continue working with these defaults. Moreover, the link can also be use to share the results with clients and stakeholders.

Weaknesses SaniChoice is a novel tool which still requires some improvements both in substance and in form. The definition of some appropriateness criteria and how to quantify them is not always straightforward. In some cases, the simplification done for its assessment are too restrictive to represent the reality. Recommendations on the issues experienced while quantifying the criteria for the Changunarayan case study are discussed in section 5.2 and can illustrate this weakness.
When used, some of the additional evaluation criteria (technical maturity, Capex, Opex) from *Preconditions* limit substantially the potential appropriate technologies. Each parameter can be qualitatively characterized as "low", "medium" or "high". Once set, each technology allotted with different attributes is excluded. It may become a too much restrictive criterion. This is not the target of the evaluation criteria which should be discussed with stakeholders rather than an initial exclusion.
Although SaniChoice is intended to be intuitive, its Practitioners' Guide is still a necessary reference to apply the tool. It is not as user-friendly at it should be in term of layout. By asking external people to give their feedback on the web-page, they all encountered some difficulties to start using the web-tool and the majority even didn't notice the "Filter" options which represents the core of the tool and directly dived into the technology library. It is also not intuitive how to get the visualization of the system. Furthermore, the latter is plotted in such a way that the overview of the system doesn't fit entirely in the display. Indeed, it forces the user to scroll horizontally to know how the products are managed throughout the sanitation chain, no matter the length of the system.
SaniChoice does not share any information on the efficiency of treatment. It is assumed that the facilities are perfectly designed and thus requirements for treatment are achieved.
The sanitation systems built with SaniChoice are not always valid and require a plausibility check as suggested in the Practitioners' Guide. The fact that systems are built with products processed and transformed by the technologies, it might result with nonsense. For instance, an urinal-based system can end up managing with sludge after the conversion of urine into effluent and the latter converted into sludge in an anaerobic filter (see fig. 26 in appendix). Moreover, decentralized and onsite systems do not include conveyance technologies even

if such service is always needed, no matter how short is the distance. This dimension consciously neglected in the mentioned systems might cause difficulties to understand them as it was the case with this study while presenting the preselected systems to the local partners.

Opportunities The promotion and the support from scientific and expert communities will now define how relevant the tool is. Despite some improvements still required, the tool present the advantage to be simple to use. Combining it with the Practitioner's Guide and the existing training package, SaniChoice can be easily promoted worldwide. The training and work done in Nepal for this study raised the local partners interest to use SaniChoice, especially to form their new team members with the tool. This interest is a promising result for the future of the web-tool. Although SaniChoice requires internet to its application, internet coverage and computer access are increasing worldwide, thus facilitating the promotion and the use of the tool.
Targeting initially engineering consultant, NGO's or public staff in the WASH sector, SaniChoice can also be used as a training tool (universities, continuing education, etc.). Indeed, it allows to learn about different technology options in an interactive way, understand what matters in term of suitable option and of evaluation criteria and what trade-offs might occur.
The open-source and flexibility character of the tool promotes the users to contribute to its improvement. Thus, SaniChoice has the opportunity to evolve in order to align its services to the user's feedback and contribution.

Threats The lack of interest of the international community would be the worth risk for SaniChoice. Learning a new tool is always time consuming and one could be reluctant to do it especially if the user doesn't see the advantages of it. Despite the efforts to make SaniChoice intuitive and easy to use, it still requires the Practitioners' Guide to apply it properly.
A wrong SaniChoice application can result with locally inappropriate outcomes despite the high appropriateness score. For instance if all the appropriateness criteria used were not limiting criteria, as it was for the temperature criterion used in this study, TAS and obviously SAS would be both high and all systems virtually appropriate. However, such issues are explained in the Practitioners' Guide.
The tool is provided in English that may be a limiting factor in certain areas, mostly to share the results with the local people.

A.4.2 SaniChoice Practitioner's Guide

Strengths The guide fulfills completely its purpose: one can find all necessary information to apply SaniChoice in practice but also additional recommendations for strategic planning. This study partially relies on its application and would not have been very far without it. Indeed, whereas the web-tool can be a bit confusing in a first approach, this guide provides the required insights to start handling with SaniChoice and how to embed it in any strategic planning with a step-by-step application in 5 stages. For each step, inputs, outputs and objectives are clearly stated. If needed, supporting material might help to achieve the goal. One can also find relevant facts that should be paid attention to and definition of the terms to which one will be confronted in the SaniChoice application. These recommendations together with the inputs, outputs and objective are written in such a way that it allows the user to apply the tool by letting him/her some flexibility. Without imposing a way to apply SaniChoice, it structures partially the sanitation planning process and the SaniChoice integration in strategic planning using the structured decision making (SDM) as a common framework.
The decision objectives obtained in step 1 (A1.1 & A1.2) and refined with the expert workshop (A2.1) are highly pertinent because they allow to align everyone's thoughts and vision of the project in a easily communicable way.
Involving local stakeholders is a key factor to ensure the sustainability of the project. The steps suggested in the guide consider that important statement by building up knowledge and understanding among the stakeholders through a series of workshops.

Weaknesses As discussed in the previous section, the Practitioners' Guide is a necessary reference to apply SaniChoice. The support material available on the web-tool is not enough or too confusing to use it properly and embed its application in any strategic sanitation planning.

Despite the relevance of the decision objectives, it is not easy to obtain them. Local stakeholders, as well as sanitation experts, often anchor on particular technologies while asking during stakeholder workshop (A1.1) which characteristics should the proposed system have in order to solve the current sanitation problems. The collected minutes during workshop require a relatively time-consuming analysis to get objectives from problems and solutions raised by the stakeholder during the workshops.
During the expert workshop (A2.1), many difficulties occur while brainstorming the criteria from the decision objectives. Again, all discussion lead to a specific technology and it was laborious to get the criteria hidden behind the technology. When the master list was distributed to each participant in order to align the discussed criteria with the SaniChoice's ones, most of the experts thought that almost all criteria were relevant even if it was specified to tick only 10 to 15 criteria. In other words, the main issue with this workshop is that the experts are confronted with a tool whose complexity cannot be explained in such a restricted time and the simplifications taken to counteract that issue. However, it gives relevant insights after a desk-based analysis by the SaniChoice user to sort all the information.
Once identified, the quantification of the appropriateness criteria (A2.2) is a tedious activity that often requires additional data than the one available. This should be done during the Clarification of the Context (phase 1 of SDM), at the same time of a potential household survey. However, this activity is suggested to overlap phase 2 and 3 according to the Practitioners' Guide.

Opportunities By including local stakeholders in the planning framework, it will more likely foster a local momentum for sanitation and enhance the ownership of the project by the local community. Nevertheless, this is not an inherent attribute of SaniChoice neither of the Practitioners' Guide but rather depend on the person facilitating the sanitation planning. On the other hand, the sanitation framework or guideline will obviously affect it and in that sense, the Practitioners' Guide might play an important role.
This guide is intended to assist users in using SaniChoice as a sanitation planning support tool. The final form of this manual can facilitate the promotion and thus the use of the tool.

Threats The wording used in the Practitioners' Guide can sometimes be likened to scientific jargon. An adaptation of the terms has to be done while dealing with stakeholders or expert to avoid overwhelming them with big words. Using simpler word might result with a loss of its initial meaning but this simplification is necessary in any meeting or workshops with local stakeholders. For instance, "vision" was used instead of "decision objectives" with the municipal authorities.
The third workshop recommended by the guide (A5.2) to discuss the trade-offs and to find an agreement on the preferred options was discussed at length during the SaniChoice Training Workshop. This was conducted by experts at the beginning of the planning process. Sanitation experts were concerned about letting inexpert stakeholders selecting the preferred system options. This concern is understandable if one of the preselected systems is not locally appropriate, thus emphasizing the relevance of the detailed assessment suggested in A5.1. Furthermore, it is probably better to avoid relying on the SaniChoice outcomes to produce the final choice. Its results rather allows to trigger discussions with the decision-makers.

A.5 Detailed recommendations for the future

Recommendations given in section 5.2 are provided in bullet point lists. This section provides a developed version of each of these bullet points.

A.5.1 SaniChoice web-tool

Currently, the web-tool is not intuitive enough to be used without external explanation (Practitioners' Guide, training, etc.). The videos that could offer this explanation by providing a guided tour of the website are long and people often skip them. Offering shorter videos of around 4 minutes might increase the number of views without discouraging the user to watch them. In parallel, a step-by-step figure informing roughly on the procedure to follow while applying SaniChoice would help structure the website and thus help new users to take control of the tool. This suggestion can also be completed by shorter and clearer instructions along the SaniChoice application such as "1. Select your appropriateness criteria".

Preconditions are too restrictive. For more inclusive choice, it should not be possible to include the technologies responding to one rank only, but rather automatically consider the ones that that are not limited by the selected rank. For instance, by allotting *medium* to the Capex evaluation criterion, the filter would include technologies characterized with *low* and *medium* Capex and exclude the ones with *high* Capex. Furthermore, it would be great to provide the possibility to go back to ignore the parameter after having considering it as it is possible with other preconditions parameters (development phase, application and management level).
A more pragmatic and reasonable alternative would be to consider this existing relevant data as additional evaluation criteria and not as a technology filter.

Appropriateness criteria cannot be all quantified because information is not available. It could be due to the early stage of the planning process still having a lot of uncertainties (offsite surface area) or to simply data not being available (groundwater depth). However, certain of these criteria difficult to quantify might be relevant for the appropriateness assessment. Rather than neglecting them, the data from the existing SaniChoice library can be used as evaluation criteria as it was done for the frequency of O&M and offsite surface area in this study.

The web-tool allows to save and share the results but not their export. Exporting the results to access them offline might be interesting added-value. Indeed, it could provide the link between the SaniChoice web-tool and the data analysis possible with Santiago. Moreover, this export option could fill the gap by making available a CSV file of the result as well as more detailed plots such as the ones generated in this report, mostly the technologies appropriateness assessment or better system visualization with Graphviz.

Terms and vocabulary used by SaniChoice can be overwhelming and the glossary provided is thus necessary. However, it is not convenient to scroll down until finding the required definition. A searching option should be added to make the glossary more interactive and user-friendly.

A.5.2 Technology library

According to this case study, some technologies might be added to the SaniChoice library. First, the urine-diverting pour flush toilet (udpft) should be considered. Secondly, the biogas reactor can be implemented at the household level, especially in Nepal through the Biogas Support Program (BSP) from the World Bank and GPOBA [World Bank and GPOBA, 2015]. A specific design for the rural context was developed which often works with the addition of manure. Although this technology might not be that appropriate for Changunarayan considering the actual urbanization rate, it would be relevant to add it in the SaniChoice library to also consider onsite biogas reactor. Last but not least, the dry urinal using straw roughly developed in section 4.3.1.1 could also be added as a new source to promote urine separation also at the household level.

TAS of transfer station affected by vehicular access (see Figure 12). Although this technology targets areas where faecal sludge cannot be easily transported to a treatment facility [Ulrich et al., 2014], its location should be easily accessible and convenient. Thus, a paradox occurs for this criterion. Transfer stations are appropriate for dense and urban zones where vehicular access is severely limited but space and road access can be found in its surrounding. It should be more appropriate not considering the vehicular access or even revert its appropriateness assessment in order that the technology would become appropriate when the access is limited (combined with human-powered emptying and transport).

A.5.3 Practitioners' Guide

The methodology developed to demarcate the zones and thus define the SaniChoice application case could be added to the Practitioners' Guide as a preliminary step. When it comes to the quantification of the criteria, it may result on a lot of missing information that could require data collection activities. Such activities are forming part of phase 1 of SDM (Clarification of the Context). Prescoping the appropriateness criteria and preconditions in earlier stages represents a consequent gain of time since it can be embedded in other activities by the planning framework, such as household survey.

A.6 Detailed agenda for Expert Consultation Workshop

Date	11.07.2022 - 13h30-16h
Objectives	• Agree on a final decision objectives hierarchy • Define the final appropriateness criteria
Inputs	Situation Analysis Demarcation of the zone Stakeholder Analysis Draft decision objectives
Outputs	Structured decision objectives hierarchy Final appropriateness criteria
Participants	5 experts from 500B Solutions and 1 from Ecoconcern
Workshop Material	Slides gathering the inputs FGDs Summary Metacards
References	R1.2 Decision Objective Hierarchy, R1.1 Agenda for Expert Consultation Workshop and R2.2 Master List of SaniChoice criteria from [Spuhler et al., 2021] Chapter 4: Understanding Objective from [Gregory et al., 2012]

The draft decision objectives was created from the local priorities raised during the FGDs (workshop 1) and from the vision of the municipal authorities (workshop 2). To do so, threats and opportunity were listed for each priority and vision, gathered together and categorized according to the SuSanA sanitation sustainability criteria.

Introduction 15'

- Introducing participants and objectives of the workshop
- Presentation of CWIS-Plan (6 steps with key activities and outcomes)
- SaniChoice as a supporting tool to generate locally appropriate systems
- Demarcation of the zones for appropriate system selection

Structuring the decision objective 45'

- Definition of the decision objectives
- **Sharing of the draft decision objective**
  Higher level objectives (SuSanA criteria on metacard) are displayed on the wall and the rest of the metacards containing the opportunity and threats of the local priority are distributed to the participants. Each participant is asked to put his/her card under the right higher decision objective.
- **Discussion of the resulting objective hierarchy**
  Make sure that each card is a fundamental objective (basic outcomes that matters regardless of how they are achieved) and revise the wording if necessary. Let the experts propose additional locally relevant objectives.
- **Check that objectives are fully independent**
  Once everybody agrees on the objective, ensure that they do not overlap and are all fully independent. Compare the resulting decision objective to the generic decision objective hierarchy (R1.2) to make sure that all sustainability dimensions are being considered.

Defining the appropriateness criteria 1h

In this session, participants brainstorm what evaluation criteria can be used to measure the decision objectives. This also involves identifying which criteria are non-negotiable and negotiable to identify potential appropriateness criteria for SaniChoice. Use a color code for separating negotiable from non-negotiable criteria. In smaller groups, ideally with a moderator, participants further develop the appropriateness criteria. Groups might be split according to the highest-level objectives (e.g. health, finance/economic issues, institutional issues and governance, technology, socio-cultural issues, environment).

- **Identifying appropriateness criteria which can be used in SaniChoice**
  In the same groups, test the identified appropriateness criteria for the fulfilment of the basic requirements for screening with SaniChoice:
  (1) -*Neutral*- Non-negotiable: independent from stakeholder preferences and not-involving trade-offs and Objective: given by externally defined circumstances
  (2) -*Measurable*- Data is available at the structuring phase
  (3) -*Generic*- Applicable to a broad range of technologies (although not all appropriateness criteria must apply to all technologies)
  If the non-negotiable criterion written metacard fulfilled the requirements, add a star on it. That might be a criterion that can be used in SaniChoice.

- **Aligning criteria with master list**
  In this session participants are asked to work individually. They receive a copy of the master list (R2.2). Participants are then asked to check the boxes left to all the attributes by ticking column A if relevant for the local context and B if identified previously. Participants can also add additional criteria at the end of the list.

- **Final decision on appropriateness criteria for SaniChoice**
  Share the choice of the appropriateness criteria for each type of zone and ask the two question:
  - Do you agree on that selection?
  - According to your master list, is there any criteria that have not be taken into account with my selection? Why?
  With this final task, which can also be done with a smaller task force after the workshop, a merged list of appropriateness criteria to be supplied to SaniChoice is created. This list should not exceed more than 15 criteria in order to obtain a satisfying result. If too many criteria are selected it will be more difficult to gather data and the appropriateness scores will be less significantly different.

- Further discussion if needed

Closure 30'

- Relevance of setting the decision objective

- Feedback on the workshop

- Open discussion

B Appendices

B.1 Overview of SaniChoice Practitioners' Guide

Step	Goals	Inputs	Activities	Supporting Resources	Outputs
1	Understand what matters to relevant stakeholders Define decision objectives	Study area Stakeholders analysis Situational analysis	A1.1 Workshop 1: Stakeholder consultation A1.2 Defining decision objectives	R1.1 Workshop agenda R1.2 Decision objective hierarchy	O1 Locally relevant decision objectives
2	Validate and complete decision objectives Identify appropriateness criteria	Locally relevant decision objectives	A2.1 Workshop 2: Expert consultation A2.2 Defining appropriateness criteria	R2.1 Workshop agenda R2.2 Master list of appropriateness criteria	O2 Appropriateness criteria for SaniChoice
3	Identify appropriate sanitation technologies	Preconditions Appropriateness criteria Data on application case	A3 Identify appropriate technologies	R3 Technology Appropriateness Filter (SaniChoice)	O3 Technology Appropriateness Scores (TAS)
4	Identify appropriate sanitation systems	Technology Appropriateness Scores (TAS)	A4.1 Pre-selecting appropriate systems A4.2 Plausibility check	R4 System option generation (SaniChoice)	O4.1 Pre-selected locally appropriate sanitation system O4.2 Multi criteria comparison of system performances
5	Evaluate the performance of pre-selected sanitation systems Compile a decision matrix Discuss results with stakeholders and identify a preferred option	Pre-selected sanitation system options with SAS Additional evaluation criteria and data on application cases	A5.1 Detailed assessment of pre-selected systems A5.2 Workshop 3: System evaluation	R5.1 Evaluation and comparison of systems (SaniChoice) R5.2 Workshop agenda R5.3 Links to other evaluation tools than SaniChoice	O5.1 Understanding of consequences and trade-offs (O5.2 Preferred option for different city areas)

Table 3: Summary of the different steps of the Practitioners' Guide Spuhler et al., 2021

B.2 SaniChoice application

B.2.1 Quantified appropriateness criteria for each type of zone

		DENSELY POPULATED	MODERATELY POPULATED		SPARELY POPULATED		FLOOD-PRONE AREAS	RICE PADDIES
		Slope 1-15°	Slope 1-15°	Slope >15°	Slope 1-15°	Slope >15°	Slope <1°	Slope 1-15°
		Type A Ward 1,2,3	Type Bi all Wards	Type Bii Ward 4,5,6,7,8,9	Type Ci Ward 4,5,6,8,9	Type Cii Ward 4,5,6,7,9	Type D Ward 1,4,5	Type E Ward 4,5,6,7,9
Water volume [L/cap/day]	abs min	20	20	20	20	10	20	20
	typ min	60	75	50	50	25	70	50
	typ max	80	100	80	80	50	90	80
	abs max	150	150	125	125	80	125	125
Temperature	very cold <10°C	0%	0%	0%	0%	0%	0%	0%
	cold (-10-10°C)	8%	8%	8%	8%	8%	8%	8%
	temperate (10-20°C)	50%	50%	50%	50%	50%	50%	50%
	warm (20-30°C)	42%	42%	42%	42%	42%	42%	42%
	hot (>30°C)	0%	0%	0%	0%	0%	0%	0%
Slope	flat						100%	
	not flat						0%	
Flooding	no flood						75%	90%
	flood						25%	10%
Vehicular Access	full	10%	10%	10%	10%	10%	5%	5%
	diffult	45%	45%	50%	45%	40%	40%	40%
	no	45%	45%	40%	45%	50%	55%	55%
Electricity Supply	elect.	25%	25%	25%	25%	25%	25%	25%
	interm.	75%	75%	75%	75%	75%	75%	75%
	no elect.	0%	0%	0%	0%	0%	0%	0%
Soil type	clay	45%	45%	45%	45%	45%	30%	45%
	silt	38%	38%	36%	38%	36%	30%	38%
	sand	14.5%	14.5%	9%	14.5%	9%	25%	14.5%
	gravel	2.5%	2.5%	5%	2.5%	5%	15%	2.5%
	rock	0%	0%	5%	0%	5%	0%	0%
Area Onsite [m2/unit]	abs min	1	5	5	10	10	10	1
	typ min	4	10	9	15	15	20	5
	typ max	5	10	9	15	15	20	5
	abs max	7	20	15	20	20	25	10
DW Exposure	close	90%	75%	75%	50%	50%	50%	75%
	not close	10%	25%	25%	50%	50%	50%	25%
Frequency of O&M	irregular	100%	100%	100%	100%	100%	100%	100%
	regular	100%	100%	100%	80%	80%	80%	90%
	continuous	80%	50%	50%	0	0	0	25%
O&M Skills	unskilled	0%	20%	20%	50%	50%	50%	50%
	skilled	50%	40%	40%	50%	50%	40%	40%
	professional	50%	40%	40%	0%	0%	10%	10%

Table 4: Quantified appropriateness criteria for each type of zones

B.2.2 General considerations per type of zone

Type of zone	Appropriateness criteria	System templates to consider	ST to exclude	Techs
A. Densely populated areas	water volume / electricity supply frequency of O&M / temperature vehicular access / soil type drinking water exposure surface area (onsite) / O&M skills	ST16. Centralized blackwater system with sludge ST18. Centralized blackwater system without sludge ST26. Centralized blackwater system with biofuel production ST15. Hybrid blackwater system with sludge ST25. Hybrid blackwater system with biofuel production ST35. Urinal	-Dry systems (ST4,5,6,7,8,21,23,31) -Decentralized systems (ST15, 25, 31, 33) - Onsite systems (ST4,11)	**Exclude** dry_toilet, udpft, wsp, aerated_pond, activated_sludge, mono_incineration, sbr, fish_pond, floating_plant_pond **Include** sewered technology
B. Moderately populated areas	water volume / electricity supply frequency of O&M / temperature vehicular access / soil type drinking water exposure surface area (onsite) / O&M skills	ST16. Centralized blackwater system with sludge ST18. Centralized blackwater system without sludge ST26. Centralized system with urine diversion ST15. Hybrid blackwater system with sludge ST25. Hybrid blackwater system with biofuel production ST33. Hybrid blackwater system with urine diversion ST13. Decentralized blackwater system with sludge ST22. Decentralized blackwater system with biofuel production ST30. Decentralized blackwater system with urine diversion ST35. Urinal	-Dry systems (ST4,5,6,7,8,21,23,31) - Onsite systems (ST4,11)	**Exclude** dry_toilet, wsp, aerated_pond, activated_sludge, mono_incineration, sbr, fish_pond, floating_plant_pond **Include** septic tank (or similar)
C. Sparely populated areas	water volume / electricity supply frequency of O&M / temperature vehicular access / soil type drinking water exposure surface area (onsite) / O&M skills	ST15. Hybrid blackwater system with sludge ST25. Hybrid blackwater system with biofuel production ST33. Hybrid blackwater system with urine diversion ST5. Decentralized dry system without biomass production ST6. Decentralized dry system with biomass production ST21. Decentralized dry system with biofuel production ST13. Decentralized blackwater system with sludge ST22. Decentralized blackwater system with biofuel production ST30. Decentralized blackwater system with urine diversion ST4. Onsite dry system with sludge production ST11. Onsite blackwater system without sludge ST35. Urinal	-Centralized systems (ST16,18,26,34) - Hybrid system (ST7,8,23,31)	**Exclude** wsp, aerated_pond, activated_sludge, mono_incineration, sbr, fish_pond, floating_plant_pond
D. Flood-prone areas	water volume / electricity supply frequency of O&M / flood slope / temperature vehicular access / soil type surface area (onsite) / O&M skills	ST15. Hybrid blackwater system with sludge ST25. Hybrid blackwater system with biofuel production ST33. Hybrid blackwater system with urine diversion ST13. Decentralized blackwater system with sludge ST22. Decentralized blackwater system with biofuel production ST30. Decentralized blackwater system with urine diversion ST11. Onsite blackwater system without sludge ST35. Urinal	-Centralized systems (ST16,18,26,34) - Dry systems (ST4,5,6,7,8,21,23,31)	**Exclude** wsp, aerated_pond, activated_sludge, mono_incineration, sbr,, fish_pond, floating_plant_pond, conventional_sewer

Table 5: Criteria, system templates and technologies to consider per application case

B.2.3 Definition of appropriateness criteria

The defintion of the criteria used in this study and provided below are given by the SaniChoice webtool [Spuhler, Scheidegger, and Eissner, 2022].

- **Water volume**
  Quantitative estimate of the performance of each technology given a certain amount of water volume consumed in a specific case. Only non-drinking, i.e. water for sanitary use is considered (in litres per person per day).
  This criterion accounts for the minimum water volumes which are requisite for several technologies to function (e.g. sewers, septic tank). Additionally, for certain technologies (e.g. pits, composting chamber), too high water volumes entering the technology can disrupt their function and cause failure. This aspect of maximum water volume a technology can handle is also considered as part of this criterion.
  Water requirement in terms of volumes is defined for the collection and storage (FG S) and conveyance technologies (FG C).
  How much water volume is used for sanitary use (non-drinking water) per capita per day in the given case? [Provide the minimum and maximum water volume consumed in litres per capita per day (l/cap/d). If there is no minimum, allot the value 0 l/d/cap. If there is no maximum, the value is assumed to be 999 l/cap/day. Alternatively, four values can be input, namely, the absolute minimum, the likely/typical minimum, the likely/typical maximum, and the absolute maximum water consumed for sanitary use in the case. Note: Here, the water available in the case is assumed to be the water consumed.]

- **Electricity Supply**
  Qualitative estimate of the performance of each technology during normal operation and maintenance (e.g. for pumping, ventilation, aeration), given a certain energy supply in a specific case. It is based on a scale of three categories:

  - Continuous electricity: power cuts are highly unlikely.
  - Intermittent electricity: frequent power cuts are occurring.
  - No electricity.

  Electricity supply is defined for the collection and storage (FG S), treatment (FG T), and reuse or disposal (FG D) technologies. Technologies for conveyance (FG C) such as sewers might need electricity depending on the slope and the pumps required, however, this is covered separately by other criteria ("Slope" and "Pump Supply").
  How is the electricity supply in the case for aeration, ventilation, pumping, or other power-consuming activities? [Allot the proportions (%) of the case area that have a certain electricity availability or the proportion (%) of months in the year where there is a certain electricity availability.]

- **Frequency of O&M**
  Quantitative estimate of the performance of each technology given a certain availability of operation and maintenance (O&M) capacity in a specific case. The criterion is defined based on the extent of labour (type of task and time) required to maintain a certain technology. O&M includes cleaning, repairing and/or replacing mechanical parts. It does NOT include emptying/desludging of the technology. It is based on a scale of three categories:

  - Irregular: is used for technologies that require low maintenance, for operations such as occasional cleaning or eventual repair. No maintenance of odour seals, washing with detergents or monitoring is required.
  - Regular: refers to more time-consuming operations such as regular cleaning, washing with detergents (e.g. the bowl with acid) or checking and replacing odour seals.
  - Continuous: is used for technologies that require permanent staff (full-time job) for maintenance, repair, removing scum, etc.

What is the availability of operation and maintenance (O&M) capacity in the case? [Allot for each category the feasibility (between 0 and 100%) to provide a certain frequency of O&M service Note: This is a ladder function, so if the application case can provide 'continuous' operation and maintenance levels, it can also provide 'regular' and 'irregular' levels (i.e. 100%) . The values allotted to 'irregular' will always be equal to or higher than 'regular' and those allotted to 'regular' will be equal or higher than 'continuous'.

- **Temperature**
  Semi/quantitative estimate of the performance of each technology for different temperature ranges. The criterion accounts for the effect of temperature on biological processes and soil infiltration. It is based on a scale of five categories (referring to daily mean temperatures):
  - Very cold: refers to temperatures less than -10°C.
  - Cold: refers to temperatures between -10 to 10°C.
  - Temperate: refers to temperatures between 10 to 20°C.
  - Warm: refers to temperatures between 20 to 30°C.
  - Hot: refers to temperatures above 30°C.

  Temperature is defined for the collection and storage (FG S), treatment (FG T), and reuse or disposal (FG D) technologies.
  What is the mean daily temperature for the case? [Allot the proportions (%) based on the number of days per year whose mean daily temperature lies in the respective ranges of each category.]

- **Flooding**
  Qualitative estimate of the performance of each technology given a certain risk of flooding in a specific case. It is based on two categories:
  - No flooding: describes conditions where surface flooding is a rare phenomenon.
  - Flooding: describes conditions where intense rainfall and/or rise in levels of a neighbouring water body leads to flooding of surfaces.

  There are three different types of floods.:
  1. Fluvial floods: occur when the water level in a river, lake or stream rises and overflows onto the surroundings. The water level rise could be due to excessive rain or snowmelt.
  2. Pluvial floods: occur when heavy rainfall creates a flood independent of an overflowing water body, either due to an overwhelmed urban drainage system and/or due to a high proportion of sealed surfaces.
  3. Flash floods can severely disrupt sanitation technologies; however, they are "sharp and sudden" i.e. difficult to predict/anticipate for a given region.

  Fluvial and pluvial floods can be anticipated. Therefore the user can allot proportions to the categories 'flooding' and 'no flooding' based on the number of months pluvial or fluvial flooding is to be expected or not expected (e.g. monsoon season). In comparison, flash floods are difficult to predict and thus, are not considered for this criterion (sanitation systems, like other civil engineering projects, are not planned for rare extreme events). Flooding is defined for the onsite collection and storage/treatment (FG S), conveyance (FG C), treatment (FG T), and reuse or disposal (FG D) technologies.

- **Slope**
  Semi-quantitative estimates of the performance of each technology during operation and/or maintenance given a certain slope in a specific case. Slope can be an important aspect for all technologies but here it is considered relevant for conveyance technologies (FG C) only. In FG C, the slope is particularly important for piped technologies such as sewers whose function is greatly affected by flat slopes. Thus, this criterion is based on two categories:
  - Flat: 0-1% gradient.

  - Not flat: this includes everything from rolling to steep slopes (1% gradient).

- **Vehicular Access**
  Semi-quantitative estimates of the performance of each technology during operation and/or maintenance given certain vehicular access in a specific case. This criterion refers to the need to empty onsite facilities by truck in dense areas. It is based on a scale of three categories:

  - No access: vehicles cannot reach the site, because the road widths are less than 2 meters or the terrain is impossible to traverse.
  - Difficult access: road widths are between 2-5 meters or terrain is difficult (no proper roads, hilly, etc.)
  - Full access: road widths are over 5 meters and roads which larger vehicles, such as a pumping truck, can use without any problem.

  Vehicular access is only used for onsite and decentralized collection and storage technologies (FG S). Note: Vehicular access can also be limited due to seasonal conditions (e.g. flooding during monsoon), however, this is not considered here and instead in the criterion "Flooding".
  How accessible by motorized vehicles (e.g. pumping trucks) are the onsite locations for the planned toilets and treatment technologies. [Allot the proportions (%) of the case area that have certain vehicular accessibility.]

- **Soil Type**
  Qualitative estimates of the performance of each technology for construction and operation given a certain soil type in a specific case. Soil type is mainly important for technologies depending on soil absorption during operation.
  Different soil types possess different permeabilities, thereby, some bear more risk for stagnation than others. Additionally, certain soils have better filtration characteristics or in other words a greater cleansing capacity for polluted effluents. It is based on a scale of five categories:

  - Rock: extremely low/ negligible permeability, would certainly lead to stagnation of polluted effluent towards surfaces. Also, the filtration or cleansing capacity is very limited. Here, we refer to a continuous rocky stratum.
  - Clay: very low permeability, has a high risk of stagnation of polluted effluent towards surfaces. Since percolation is low, the filtration or cleansing capacity is also limited. It is assumed here that the clay has no fissures.
  - Silt: low permeability, has a moderate risk of stagnation of polluted effluent towards surfaces. Silty soil offers adequate filtration or cleansing capacity.
  - Sand: moderate permeability, offers good percolation of polluted effluent, along with good soil filtration or cleansing capacity.
  - Gravel: high permeability, is considered best for percolation of polluted effluent. But the cleansing capacity of the soil or filtration power is very limited and likely to be insufficient.

  Although the risk of percolation of polluted effluent and the abilities of different soils to filter it is somewhat considered as part of this criterion, the specific focus of percolation leading to pollution of drinking water sources is additionally looked at in a separate criterion "Drinking Water Exposure". Moreover, some technologies also need a certain soil type for construction, especially when concerning the stability of the technology underground, however, this is not a consideration here.
  Soil type is used for collection and storage (FG S), and reuse and disposal (FG D) technologies.

- **Surface area (onsite)**
  Quantitative estimate of the performance of each technology to be built onsite given a certain space (area or footprint) available in a specific case. The space required is indicated for one typical unit and not per user. The unit could be at the household level or the community level. Surface area (onsite) is defined for the collection and storage technologies (FG S) only.

It must be noted that when multiple technologies from FG S are part of a system, the Santiago algorithm does NOT apply the surface area restrictions to the cumulative sum of all the areas of individual technologies. E.g. if for the case a 5 m2 plot is available, Santiago individually compares the area required by a certain technology against this number. However, if two or more technologies are recommended as part of the system (e.g. urine storage tanks in addition to dehydration vaults), it does NOT compare the sum of their areas against the 5 m2 restriction.
How much surface area (m2) is available in the case onsite per unit of planned technology (e.g. one double pit)? [Provide the minimum and maximum available surface area. Usually, the minimum available surface area equals 0m2. If there is no maximum, the value is assumed to be 999m2. Alternatively, four values can be input, namely, the absolute minimum, the optimal minimum, the optimal maximum, and the absolute maximum, available surface area for the case.]

- **O&M Skills**
  Qualitative estimation of the performance of each technology given a certain operation and maintenance (O&M) skills availability in a specific case. It is based on a scale of three categories:
  - Unskilled: casual/daily labourer such as pit digger, sanitary worker, pit emptier.
  - Skilled: plumber, technician (maintenance, lab, IT), mechanic, electrician, trained mason/artisan/craftsman. Also includes basic administrative and finance skills.
  - Professional: highly qualified collection supervisor, treatment supervisor, chemist, and administrator (including finance).

  What is the availability of different levels of operation and maintenance (O&M) skills in the case? [Allot proportions (%) based on the O&M skill set of the workforce in the case area.]

- **Drinking Water Exposure**
  Quantitative estimation of the performance of the technology given a certain water source proximity. This is important for technologies that rely on soil absorption and might pose a risk to nearby drinking water sources. It is based on two categories:
  - Close: refers to a distance less than 30 meters to the closest drinking water source (e.g. a groundwater well).
  - Not close: refers to a distance of more than 30 meters from the closest drinking water source

  Drinking water exposure is defined for the collection and storage (FG S), and reuse and disposal technologies (FG D). The sites where such technologies are to be implemented are referred to here as 'implementation sites'.
  What proportion of the case is prone to drinking water source pollution (e.g. groundwater wells)? [Allot proportions (%) based on the number of potential implementation sites that are 30m closer or not closer from drinking water sources. Implementation sites could be either at the household or the community level.]

B.2.4 Maps used to quantify appropriateness criteria

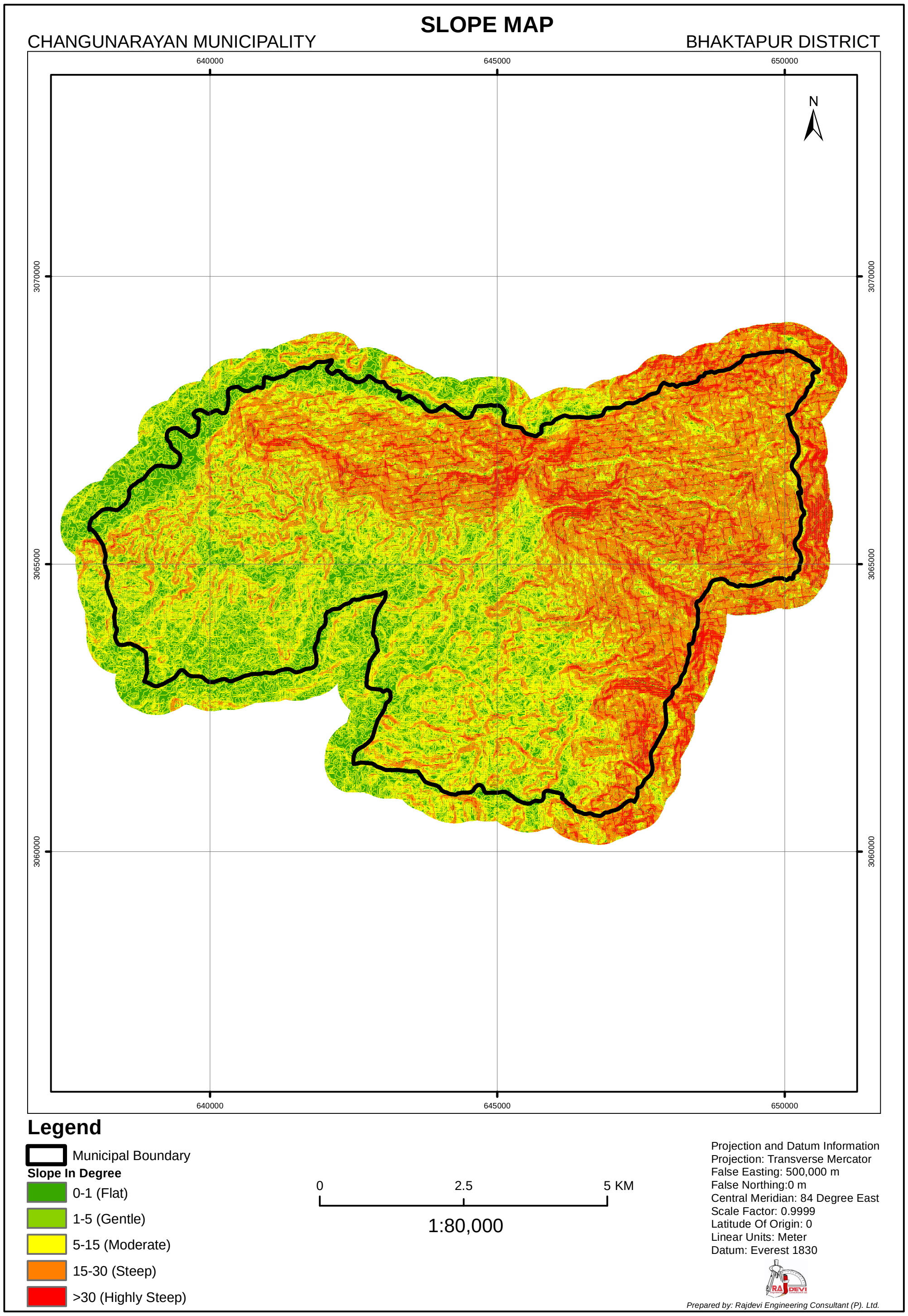


Figure 23: Slope distribution in Changunarayan Municipality Rajdevi Engineering Consultant, 2020

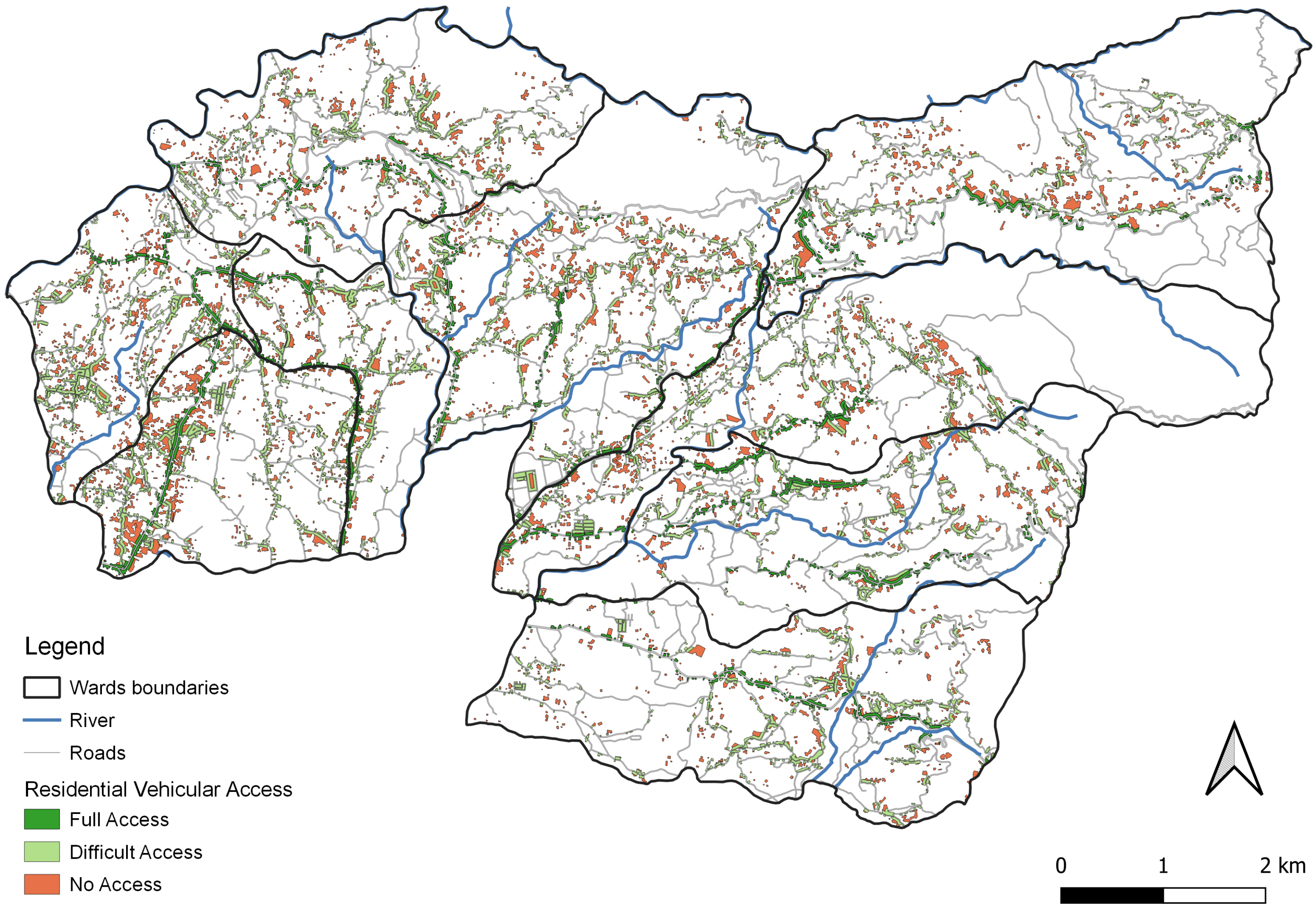


Figure 24: Vehicular access for residential area in Changunarayan [source: author]

B.2.5 Evaluation criteria

	Frequency of O&M				Capex requirements					Opex requirements					Surface area
	irreg.	reg.	cont.	**score**	material	labour	land	total	**score**	material	labour	energy	total	**score**	[m2/cap]
pour_flush	0.8	0.2	0	**0.9**	2	2	1	5	**3**	1	1	1	3	**0**	
dry_toilet	1	0	0	**0**	1	1	1	3	**0**	1	1	1	3	**0**	
udft	0	1	0	**4.5**	3	3	1	7	**6**	1	1	1	3	**0**	
urinal	0	1	0	**4.5**	2	2	1	5	**3**	1	1	1	3	**0**	
urine_storage_tank	0	1	0	**4.5**	1	1	1	3	**0**	1	2	1	4	**1.5**	
double_dehydration_vaults	0	1	0	**4.5**	3	3	2	8	**7.5**	1	1	1	3	**0**	
single_faeces_storage_chamber	0	1	0	**4.5**	1	2	1	4	**1.5**	1	2	1	4	**1.5**	
container_based_toilet	0	0.7	0.3	**5.85**	1	1	1	3	**0**	2	3	1	6	**4.5**	
single_pit	1	0	0	**0**	2	2	1	5	**3**	1	2	1	4	**1.5**	
single_vip	0.5	0.5	0	**2.25**	2	2	1	5	**3**	1	2	1	4	**1.5**	
double_vip	0.5	0.5	0	**2.25**	2	2	2	6	**4.5**	1	1	1	3	**0**	
twin_pits_pour_flush	0.5	0.5	0	**2.25**	3	3	2	8	**7.5**	1	1	1	3	**0**	
composting_chamber	0	1	0	**4.5**	2	2	2	6	**4.5**	1	2	1	4	**1.5**	
fossa_alterna	0.3	0.7	0	**3.15**	1	2	2	5	**3**	1	1	1	3	**0**	
onsite_vermi_composting	0.2	0.8	0	**3.6**	3	2	2	7	**6**	3	3	1	7	**6**	
septic_tank	0	1	0	**4.5**	3	3	2	8	**7.5**	1	1	1	3	**0**	
raised_latrine	0.5	0.5	0	**2.25**	2	2	1	5	**3**	1	2	1	4	**1.5**	
shallow_trench_latrine	0	0.3	0.7	**7.65**	1	3	3	7	**6**	1	2	1	4	**1.5**	
deep_trench_latrine	0	0.6	0.4	**6.3**	1	3	3	7	**6**	1	2	1	4	**1.5**	
chemical_toilet	0	0.2	0.8	**8.1**	2	2	1	5	**3**	2	3	1	6	**4.5**	
s_controlled_od	0	0	1	**9**	1	1	3	5	**3**	1	2	1	4	**1.5**	
transfer_station	0	1	0	**4.5**	2	3	1	6	**4.5**	1	1	1	3	**0**	
motorized_emptying_urine	0	0.5	0.5	**6.75**	3	1	1	5	**3**	2	3	3	8	**7.5**	
human-powered_emptying_urine					1	1	1	3	**0**	1	3	1	5	**3**	
motorized_emptying_solids	0	0.5	0.5	**6.75**	3	1	1	5	**3**	2	3	3	8	**7.5**	
human-powered_emptying_solids					1	1	1	3	**0**	1	3	1	5	**3**	
conventional_sewer	0.3	0.7	0	**3.15**	3	3	2	8	**7.5**	3	3	2	8	**7.5**	
simplified_sewer	0	0.7	0.3	**5.85**	2	3	2	7	**6**	1	2	1	4	**1.5**	
solids-free_sewer	0	1	0	**4.5**	2	3	2	7	**6**	1	2	1	4	**1.5**	
stormwater_drainage	0.3	0.7	0	**3.15**	2	3	2	7	**6**	1	2	1	4	**1.5**	

Table 6: Evaluation criteria for technologies from functional group U, S and C adapted from Spuhler, Scheidegger, Roller, et al., 2022

	Frequency of O&M				Capex requirements					Opex requirements					Surface area
	irreg.	reg.	cont.	score	material	labour	land	total	score	material	labour	energy	total	score	[m2/cap]
urine_bank	0.5	0.5	0	**2.25**	2	1	2	5	**3**	1	2	1	4	**1.5**	**0.1**
struvite_precipitation	1	0	0	**0**	2	2	1	5	**3**	1	3	1	5	**3**	
alkaline_dehydration_of_urine	0.2	0.8	0	**3.6**	2	1	1	4	**1.5**	3	3	1	7	**6**	
unplanted_drying_bed_sludge	0	1	0	**4.5**	1	1	3	5	**3**	1	2	1	4	**1.5**	**0.05**
planted_drying_bed	0	1	0	**4.5**	2	2	3	7	**6**	2	2	1	5	**3**	**0.05**
unplanted_drying_bed_dry	0	1	0	**4.5**	1	1	3	5	**3**	1	2	1	4	**1.5**	**0.05**
sedimentation_thickening_ponds	0	1	0	**4.5**	1	2	3	6	**4.5**	1	1	1	3	**0**	**0.006**
co-composting	0	0.5	0.5	**6.75**	1	1	3	5	**3**	1	3	1	5	**3**	**0.04**
offsite_vermi_composting	0.9	0.1	0	**0.45**	2	2	2	6	**4.5**	2	2	1	5	**3**	**0.04**
black_soldier_fly_composting	0.25	0.25	0.5	**5.625**	2	3	2	7	**6**	2	3	1	6	**4.5**	
ladepa_pelletizing	1	0	0	**0**	2	3	1	6	**4.5**	2	3	2	7	**6**	
briquetting	0	0	1	**9**	2	3	1	6	**4.5**	1	3	3	7	**6**	
settler	0	1	0	**4.5**	2	2	2	6	**4.5**	1	1	1	3	**0**	**0.05**
imhoff_tank	0	1	0	**4.5**	3	2	2	7	**6**	1	1	1	3	**0**	**0.004**
abr	0.5	0.5	0	**2.25**	3	2	1	6	**4.5**	1	1	1	3	**0**	**0.15**
uasb	0	1	0	**4.5**	3	2	1	6	**4.5**	1	2	1	4	**1.5**	**0.03**
biogas_reactor	0	1	0	**4.5**	3	2	1	6	**4.5**	1	2	1	4	**1.5**	**0.4**
anaerobic_filter	0	0.7	0.3	**5.85**	3	2	1	6	**4.5**	1	2	1	4	**1.5**	**0.5**
sbr	0	0	1	**9**	2	2	1	5	**3**	1	3	3	7	**6**	**0.12**
wsp	0	1	0	**4.5**	2	2	3	7	**6**	1	1	1	3	**0**	**10**
free-water_wetland	0	1	0	**4.5**	3	2	3	8	**7.5**	1	1	1	3	**0**	**3**
horizontal_wetland	0	1	0	**4.5**	3	2	3	8	**7.5**	1	1	1	3	**0**	**3**
vertical_wetland	0.3	0.7	0	**3.15**	3	2	3	8	**7.5**	1	1	2	4	**1.5**	**1.2**
aerated_pond	0	0.5	0.5	**6.75**	2	2	3	7	**6**	1	1	2	4	**1.5**	**1.5**
trickling_filter	0	0.7	0.3	**5.85**	3	2	2	7	**6**	2	2	3	7	**6**	**1.15**
activated_sludge	0	0.2	0.8	**8.1**	3	3	2	8	**7.5**	2	2	3	7	**6**	**0.12**
caustic_soda_treatment	0	1	0	**4.5**	2	2	1	5	**3**	3	3	1	7	**6**	
urea_treatment	0	1	0	**4.5**	2	1	1	4	**1.5**	3	3	1	7	**6**	
hydrated_lime_treatment	0	0.6	0.4	**6.3**	2	1	1	4	**1.5**	3	3	1	7	**6**	
microbial_fuel_cell	1	0	0	**0**	3	3	1	7	**6**	3	2	2	7	**6**	
algae_cultivation	0.7	0.2	0.1	**1.8**	2	2	3	7	**6**	2	3	1	6	**4.5**	
membrane_filtration	0.2	0.8	0	**3.6**	3	2	1	6	**4.5**	3	2	2	7	**6**	
carbonisation	0.1	0.7	0.2	**5.4**	2	2	2	6	**4.5**	2	2	1	5	**3**	
mono_incineration	0.2	0.7	0.1	**4.95**	3	2	2	7	**6**	1	2	1	4	**1.5**	
application_of_urine	0.5	0.5	0	**2.25**	1	1	1	3	**0**	1	2	1	4	**1.5**	
application_concentrated_urine	0.8	0.2	0	**0.9**	1	1	1	3	**0**	1	2	1	4	**1.5**	
application_struvite_driedurine	1	0	0	**0**	1	1	1	3	**0**	1	2	1	4	**1.5**	
application_of_dried_faeces	1	0	0	**0**	1	1	1	3	**0**	1	2	1	4	**1.5**	
application_of_compost_biochar	1	0	0	**0**	1	1	1	3	**0**	1	2	1	4	**1.5**	
application_of_sludge	0	1	0	**4.5**	1	1	1	3	**0**	1	2	1	4	**1.5**	
fill_and_cover	1	0	0	**0**	1	1	1	3	**0**	1	2	1	4	**1.5**	
biogas_combustion	0.5	0.5	0	**2.25**	2	1	1	4	**1.5**	3	1	1	5	**3**	
briquettes_as_fuel	1	0	0	**0**	2	1	1	4	**1.5**	3	1	1	5	**3**	
co_combustion	0	0.3	0.7	**7.65**	3	2	1	6	**4.5**	1	2	1	4	**1.5**	
soak_pit	1	0	0	**0**	2	2	1	5	**3**	1	2	1	4	**1.5**	
leach_field	0.9	0.1	0	**0.45**	2	3	1	6	**4.5**	1	1	1	3	**0**	
irrigation	0	1	0	**4.5**	1	1	1	3	**0**	2	2	1	5	**3**	
fish_pond	0	1	0	**4.5**	2	3	2	7	**6**	3	3	1	7	**6**	
floating_plant_pond	0	1	0	**4.5**	2	2	2	6	**4.5**	2	2	1	5	**3**	
water_disposal	0	1	0	**4.5**	1	1	1	3	**0**	1	1	1	3	**0**	
surface_disposal_and_storage	0.5	0.5	0	**2.25**	1	1	3	5	**3**	1	1	1	3	**0**	

Table 7: Evaluation criteria for technologies from functional group T and D adapted from Spuhler, Scheidegger, Roller, et al., 2022

B.2.6 TAS of all technologies for all types of zones

	Type A	Type Bi	Type Bii	Type Ci	Type Cii	Type D	Type E
pour_flush	1.00	1.00	1.00	0.98	0.98	0.98	0.99
dry_toilet	1.00	1.00	1.00	1.00	1.00	1.00	1.00
udpft	0.97	0.95	0.95	0.77	0.77	0.77	0.82
urinal	1.00	1.00	1.00	0.89	0.89	0.89	0.94
urine_storage_tank	0.97	0.97	0.97	0.92	0.92	0.93	0.94
double_dehydration_vaults	0.87	0.87	0.87	0.82	0.82	0.84	0.83
single_faeces_storage_chamber	0.95	0.93	0.93	0.86	0.86	0.88	0.89
container_based_toilet	0.91	0.89	0.89	0.80	0.80	0.81	0.83
single_pit	0.65	0.72	0.71	0.76	0.75	0.78	0.72
single_vip	0.65	0.71	0.70	0.72	0.71	0.74	0.69
double_vip	0.68	0.75	0.74	0.76	0.75	0.78	0.72
twin_pits_pour_flush	0.60	0.76	0.75	0.79	0.79	0.80	0.71
composting_chamber	0.95	0.95	0.95	0.91	0.91	0.92	0.92
fossa_alterna	0.69	0.76	0.75	0.79	0.78	0.81	0.75
onsite_vermi_composting	0.79	0.80	0.78	0.78	0.76	0.82	0.79
septic_tank	0.66	0.75	0.75	0.70	0.67	0.67	0.64
transfer_station	0.74	0.75	0.75	0.75	0.74	0.73	0.73
motorized_emptying_urine	0.93	0.84	0.84	0.58	0.58	0.69	0.72
human-powered_emptying_urine	0.93	1.00	1.00	0.93	0.93	0.91	0.95
motorized_emptying_solids	0.93	0.84	0.84	0.58	0.58	0.69	0.72
human-powered_emptying_solids	1.00	1.00	1.00	0.93	0.93	0.91	0.95
conventional_sewer	0.72	0.63	0.55	0.33	0.18	0.39	0.44
simplified_sewer	0.86	0.77	0.73	0.51	0.38	0.58	0.63
solids-free_sewer	0.90	0.74	0.74	0.00	0.00	0.00	0.59
stormwater_drainage	1.00	1.00	1.00	0.95	0.95	0.84	0.98
urine_bank	0.99	0.98	0.98	0.93	0.93	0.94	0.95
struvite_precipitation	0.83	0.72	0.72	0.51	0.51	0.58	0.58
alkaline_dehydration_of_urine	0.70	0.69	0.69	0.63	0.63	0.67	0.70
nitrification_distillation_urine	0.66	0.60	0.60	0.42	0.42	0.50	0.56
unplanted_drying_bed_sludge	0.98	0.96	0.96	0.87	0.87	0.87	0.91
planted_drying_bed	0.98	0.96	0.96	0.87	0.87	0.87	0.91
unplanted_drying_bed_dry	0.98	0.96	0.96	0.87	0.87	0.87	0.91
sedimentation_thickening_ponds	0.87	0.86	0.86	0.77	0.77	0.80	0.83
co-composting	0.93	0.86	0.86	0.66	0.66	0.71	0.77
offsite_vermi_composting	0.95	0.92	0.92	0.81	0.81	0.84	0.85
black_soldier_fly_composting	0.73	0.68	0.68	0.53	0.53	0.59	0.63
ladepa_pelletizing	0.00	0.00	0.00	0.00	0.00	0.00	0.00
briquetting	0.47	0.37	0.37	0.00	0.00	0.00	0.31
settler	0.94	0.92	0.92	0.84	0.84	0.86	0.89
imhoff_tank	0.92	0.89	0.89	0.75	0.75	0.79	0.81
abr	0.92	0.89	0.89	0.77	0.77	0.81	0.82
uasb	0.84	0.78	0.78	0.62	0.62	0.68	0.70
biogas_reactor	0.93	0.90	0.90	0.69	0.76	0.80	0.82
anaerobic_filter	0.91	0.86	0.86	0.69	0.69	0.74	0.77
sbr	0.63	0.52	0.52	0.00	0.00	0.00	0.45
wsp	0.98	0.97	0.97	0.87	0.87	0.88	0.91
free-water_wetland	0.98	0.97	0.97	0.87	0.87	0.88	0.91
horizontal_wetland	0.98	0.97	0.97	0.87	0.87	0.88	0.91
vertical_wetland	0.70	0.69	0.69	0.63	0.63	0.68	0.70
aerated_pond	0.67	0.62	0.62	0.47	0.60	0.54	0.58
trickling_filter	0.67	0.64	0.64	0.51	0.51	0.58	0.61
activated_sludge	0.64	0.54	0.54	0.33	0.33	0.41	0.49
hydrated_lime_treatment	0.94	0.88	0.88	0.69	0.69	0.74	0.78
carbonisation	0.91	0.87	0.87	0.72	0.72	0.76	0.79
mono_incineration	0.99	0.97	0.97	0.91	0.91	0.92	0.94
application_of_urine	1.00	1.00	1.00	0.98	0.98	0.98	0.99
application_concentrated_urine	1.00	1.00	1.00	0.99	0.99	0.99	0.99
application_struvite_driedurine	1.00	1.00	1.00	1.00	1.00	0.99	1.00
application_of_dried_faeces	0.99	0.98	0.98	0.95	0.95	0.95	0.96
application_of_compost_biochar	1.00	1.00	1.00	1.00	1.00	0.99	1.00
application_of_sludge	1.00	1.00	1.00	1.00	1.00	0.99	1.00
fill_and_cover	0.68	0.79	0.79	0.89	0.89	0.89	0.81
biogas_combustion	0.96	0.92	0.92	0.80	0.47	0.83	0.84
briquettes_as_fuel	1.00	1.00	1.00	1.00	1.00	1.00	1.00
co_combustion	0.94	0.85	0.85	0.64	0.64	0.69	0.75
soak_pit	0.53	0.60	0.58	0.63	0.80	0.68	0.60
leach_field	0.48	0.53	0.51	0.53	0.51	0.59	0.52
irrigation	0.62	0.72	0.72	0.75	0.75	0.78	0.72
fish_pond	0.98	0.96	0.96	0.85	0.85	0.86	0.88
floating_plant_pond	0.97	0.96	0.96	0.90	0.90	0.90	0.92
water_disposal	0.64	0.68	0.68	0.58	0.58	0.63	0.58
surface_disposal_and_storage	0.89	0.91	0.91	0.92	0.92	0.88	0.90

Table 8: TAS of all technologies for all types of zones

B.2.7 Appropriateness Score for technologies from functional group User's interface

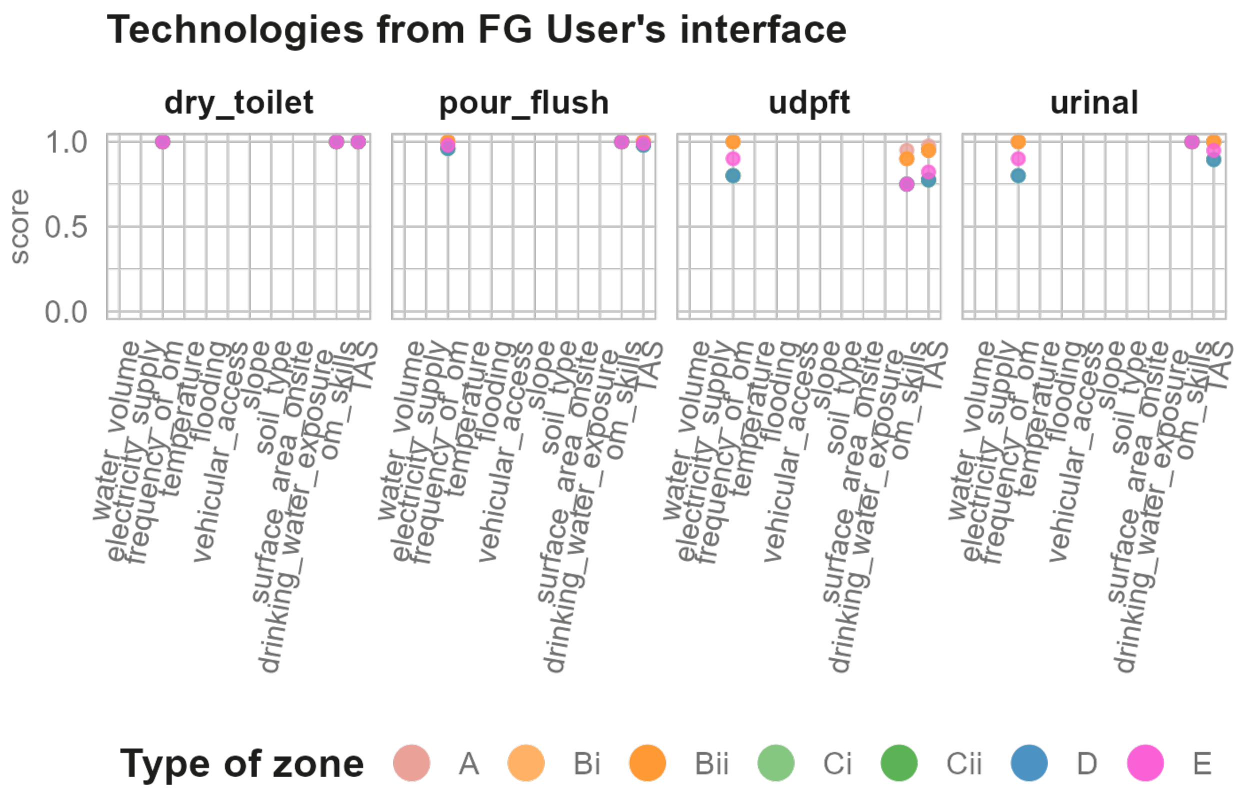


Figure 25: Attribute Appropriateness Scores followed by Technology Appropriateness Score TAS of technologies from FG U [source: author]

B.2.8 Example of invalid system generated with SaniChoice

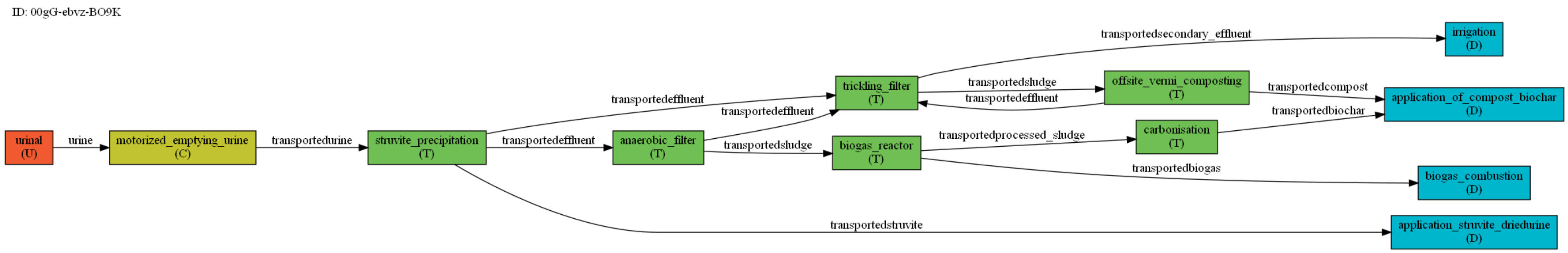


Figure 26: Invalid sanitation system: sludge is generated after the conversion of urine into effluent in the struvite precipitation and effluent into sludge in the anaerobic filter.

B.3 CWIS Plan for Changunarayan, Nepal

Step	Develop a citywide sanitation plan for a municipality in Nepal Activities	Validation of SaniChoice Webtool and Practitioners Guide Activities (SaniChoice Specific)	Prior to May 2022	Mai	June	July	August	September	Key Outputs
Step 1	**Develop understanding and commit to prepare CWIS**								
1.1	Selection of a Municipality based on: i) local demand, ii) linkages with other ongoing projects, iii) likelihood of local and external investments iv) accessibility with reference to post COVID-19 scenario								Implementation strategy and timeline
1.2	Create demand for sanitation Establish linkages, build rapport and sign an MoU to move forward with the plan	Prescoping of decision objectives (SaniChoice Step 1)		W0	W0				MoU
1.3	Agree on tentative road map of CWIS planning process and structure of task force								CWIS planning roadmap
Step 2	**Situation analysis**								
2.1	Form a task sforce								Task force
2.2	Stakeholder assessment								Stakeholder assessment
2.3	Consultations, field visit, identifying spatial boundaries	Define application cases							Typology of settlements Demarcation of zones
2.4	Review of secondary information, collection of existing data								
2.5	Design, plan and conduct baseline assessment								
2.6	Conduct FGDs in each zone to identify local needs and priorities (WASH team and communities)	Prescoping of decision objectives and technology selection criteria in zones (SaniChoice Step 1)			W1 W1				
2.7	Development of a situational assessment report								Situational assessment report
Step 3	**CWIS planning workshop**								
3.1	Prepare stakeholders consultation and planning workshop: present situational assessment and community priorities; collectively define a joint vision								
3.2	Prepare and conduct stakholders workshop	Define decision objectives (SaniChoice Step 1)			W2	W2			Joint vision for CWIS plan
3.3	Expert workshop	Expert workshop to define appropriateness criteria (SaniChoice Step 2)			W3	W3			Technology and system selection criteria per zone
Step 4	**Detailed analysis: technology options, financial and institutional arrangement**								
4.1	Identify potential technology options								
4.2	Quantify technology selection criteria for each zone	Define the application case profiles (SaniChoice Step 2) and select appropriate technologies (SaniChoice Step 3)							
4.3	Select a good combination of sanitation systems based on the priority and future projection	Identify appropriate sanitation system options (SaniChoice Step 4)							Appropriate systems options for each zone
4.4	Analyze sanitation results and do a detailed assessment of preselected systems	Detailed assessment of system options, discussion of trade-offs and selection of preferred options (SaniChoice step 5)							Detailed analysis of options
4,.5	Conduct stakeholder workshop to present technical options					W4			Discussion of options and possibly selection of preferred options
4.6	Highligh synergies with solid waste plan								
4.7	Development of service options and models								
4.8	Develop a draft sanitation plan incorporating potential sanitation system options and service model								Draft CWIS plan
Step 5	**CWIS Plan Finalization Workshop**								
5.1	Prepare topline findings								
5.2	Prepare workshop to share the CWIS plan								
5.3	Conduct workshop to share the CWIS plan						W5		
5.4	Develop the final draft CWIS plan for the municipality								Final Draft CWIS plan
Step 6	**Endorsement of the plan by the municipal authorities**								
6.1	Lobby for consensus and timely approval								

Table 9: CWIS Plan for Changunarayan with implementation of SaniChoice activities. Five workshops are planned: (W0) Inception Workshop, (W1) Local Priorities in Focal Group Discussion per Ward, (W2) Situation Assessment and Setting Objective, (W3) Experts Consultation for Technology and System Selection Criteria, (W4) Presentation and Selection of System Options and (W5) Sharing the CWIS Plan and Selection of Service Delivery Models

B.4 Changunarayan in pictures

All the pictures were taken by Basile Weber between April and July 2022.

Figure 27: View of Changunarayan from the Municipality Office to the South. It illustrates the absence of building planning resulting with construction spread over the whole area

Figure 28: Rural character of the periurban municipality, Bhadrakali (ward 5)

Figure 29: Settlements nearby Sudal with Bageshwori in the hilly background (ward 7)

Figure 30: Type A: Road under construction in Duwakot with stormwater drains considered as a sewer system

Figure 31: Type A: Urban zone in Jaukhel with paved road and stormwater drains

Figure 32: Type B: Periurban settlement along the road to Nagarkot, Bhadrakali

Figure 33: Type B: Periuban settlement view from the Municipality Office, Kharipati

Figure 34: Type C: Urbanizing rural area, Saraswotikhel

Figure 35: Type C: Rural area in ward 9

Figure 36: Type D: Flood-prone area along the Manohara river

Figure 37: Type E: Flooded rice paddies (19.06.22) around urban settlement in Duwakot (type A)

Figure 38: Type E: Flooded rice paddies (17.06.22) around the periurban settlement of Kharipati (type B)

B.5 Situation Analysis

B.5.1 Shit Flow Diagram

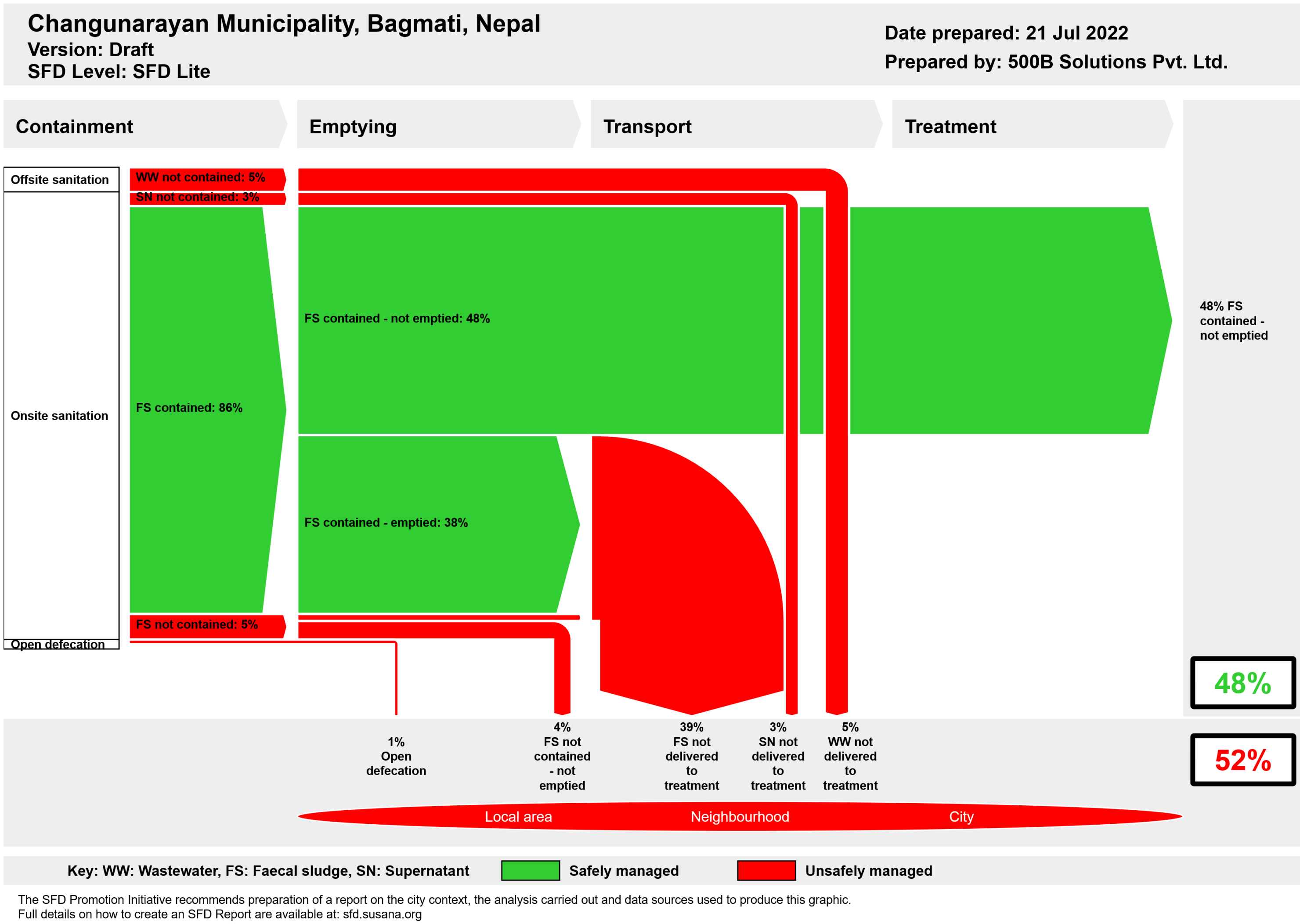


Figure 39: Changunarayan Shit Flow Diagram from households survey data 500B Solutions, 2022

B.5.2 Summary of Focal Group Discussion

		WARD 2	WARD 3	WARD 4	WARD 5	WARD 6	WARD 7	WARD 8
Requirement of community		Unsatisfied with existing services.	Unsatisfied / required	Unsatisfied / Required	Unsatisfied / Required	Not satisfied/ Required	Not satisfied / Required	Not satisfied / Required
U	**Open defecation**	No	No	Yes	Yes	Yes	Yes	No
			Urinal in school (but mix it with FS)			Open to urine diversion toilet (prevent filling of containment)		
S	**Space for onsite containment**	Available	Available	Available	Only in few areas	Only in few areas	Available	Only in few areas
	Upgrading to standard septic tank	Yes	Yes	Yes	Not willing to upgrade or change.	see the septic tank as waste of money	Yes	Yes
C	**Conveyance**	50-75% household connected to stormwater pipe system (-> river)			See the sewer system as the only solution (paid by government)			
	Will to pay for conveyance	Only Half of pop^n are paying.	Only Half of pop^n are paying.	Very few percent of pop^n are paying.	More than 90% capable of paying but do not want to pay.	See as a waste of money	Some percent of residents are paying.	Only Half of pop^n are paying.
	Road access	Is an issue in the whole municipality (up to 40% of HH doesn't have proper vehicular access)						
T	**Land availability**	Land for treatment plant for Ward 2-3	Big issues (Only available in maps)	Available	Issue	Available in forest areas	Available	Available
		Treatment facilities planned (for Ward2+3)				feasibility study was done by ENPHO for DEWATS		
D	**Disposal of FS in open drain**	Discharged	Discharged +Manual application of sludge in field	Discharged	Discharged	Discharged	Discharged	Discharged
	Resource recovery (RR)	Compost popular	Compost popular Open to RR method if training					Open for biogas at local level
Others			Flooding but no dwelling			Hotels have greywater handling problem (soil clogging issues)	Flooding problems	Want to recover water for groundwater filing

Figure 40: Summary of Focal Group Discussions (FGD) per Ward

B.5.3 Stakeholder analysis

		Stakeholder	Characteristics	Interest	Effect of project on interest (- / 0 / +)	Importance U=Unknown 1:little/no 2: some 3: moderate 4: very important 5: critical player	Influence U=Unknown 1:little/no 2: some 3: moderate 4: significant 5: very influential
Task Force	Municipal authorities	**Mayor** **Deputee Mayor** Mayor Pers. Assistant Chief Admin Officer	Busy men	Happy and healthy population, happy officials Reinforce sanitation policy in a short term (bylaws) Improve sanitation situation at medium/long term - Achieving WASH plans 2020 goals (municipal level) - Fulfil *Integrated Urban Development Plan (IUDP)* - Reach goals of the *Nepal WASH Sectoral Development Plan* (national level) - Achieving SDGs (especially 6.2) - Follow the *Changunarayan Municipality Capacity Development Plan 2021-2024*	+	3	5
		Ward representatives *from Ward 1, 2, 5, 6, 8*	Implementation and coordination at the local level	Ensure that their concerns are address by the CWIS and advocate for local needs and priorities (FGDs)	+	4	4
		WASH Officer	Contact person, very active Coordination of CWIS-P from the municipality side, of the WASH team and amongst stakeholders (man power mobilization)	Improve WASH aspect within the whole municipality - Achieving WASH plans 2020 goals (municipal level) - Reach goals in Nepal WASH Sectoral Development Plan (national level)	+	5	3
		Municipal Executive Committee		Ensure that sanitation options are applicable to the municipality (administrative and legal)	+	3	2
	Civil Society		Fight for Citizens Rights	Ensure equity in the project	+	3	2
	Nepsemyak Sewa Pt. Ltd.		Private company hired by the municipality to collect the solid waste	Improve their business Responsible of the transfer station, trying to implement organic-inorganic waste segregation	+	2	1
	Water User Committee (WUC)		Responsible of the water supply, quality and tariffs	Ensure the quality and quantity of drinking water for everyone and in every area	+	3	2
	Sanitation expert resident		EcoConcern Director	Improve decision making	+	2	3
	Marginal groups representative			Ensure equity in the project	+	3	2

WASH team	The local WASH team provides coordination, input for preparation and implementation of local plans.	Improve total sanitation within the municipality	+	4	2
500B Solutions Pt. Ltd.	Sanitation consulting private company responsible of the CWIS planning	Develop CWIS Planning	+	5	3
Eawag - Sandec	Scientific partnership with 500B Solutions	Implement and assess SaniChoice Develop CWIS Planning	0 / +	2	2
Women committee	Almost one per ward, direct relation to the people, often responsible in awareness rising, extremely effective	Improve WASH at the household level	+	3	2
Households	Very low will to pay in certain wards	Get affordable working sanitation facility (operation and maintenance)	+ - (affordability)	3	2
Farmers union		Get water, fertilizer and land to run their business	0 / +	1	1
Informal Waste Collectors (Khaalisisi)	Collect recyclables from households/dumping site and sell them to bigger vendors	Improve waste segregation	0 / - (concurrence)	2	1
Faecal sludge emptier	Private vacuum tanker	Systematic collection system Optimal disposal system (treatment plant)	+	2	1
Nepal Red Cross	Present in the WASH team	Develop Sanitation Safety Planning Decreasing health risk Logistic support for local Health Post		U	U
Ministry of Water Supply (MoWS)	MoWS is the sector ministry responsible for the formulation of WASH policies and plans as well as planning, implementation, regulation, monitoring and evaluation of programs.	Assess the compliance of the municipal WASH plan (*Total Sanitation Guideline 2017)* Improve the efficiency of WASH Program (*Nepal WASH Sector Development Plan 2016-2030)*	0	1	1

Department of Water Supply and Sewerage Management (DWSSM)	DWSSM, under MoWS, is exclusively dedicated to plan and implement WASH projects in both rural and urban areas throughout Nepal.	Implementation of the *Nepal WASH Sector Development Plan 2016-2030* Develop/Improve CWIS Planning Guideline Approval of construction of treatment facilities (Env. Impact Analysis (EIA) / Initial Env. Examination (IEE)) Assess compliance with *Total Sanitation Guidelines 2017*	+	1	3
Ministry of Urban Development (MoUD)	Responsible for the development of urban areas in the country and deals with sanitation through integrated urban planning and development.	Improve socio-economic development through affordable safe sanitation (*National Water Supply and Sanitation Sector policy 2014*)	+	1	1
Department of Urban Development and Building Construction (DUDBC)	DUDBC, under MoUD, implements Asian Development Bank (ADB) financed Secondary Towns Integrated Urban Environmental Improvement Project (STIUEIP) and Integrated Urban Development Project (IUDP) which include water supply, sewerage and drainage as key components.	Develop an infrastructure for wastewater, drainage and solid waste (*Integrated Urban Development Plan*) Formalisation of land allocation, tenure and procurement	+	1	1
Department of Agriculture (DA)		Improved conditions for farmers: land, fertilizer, irrigation water	0 / +	1	1
Ministry of Health and Population (MoHP)	Contributes to WASH by promoting health and hygiene through water quality surveillance and emergency responses which are guided by National Health Sector Plan II (2011-2015)	Improve environmental health and hygiene to reduce diseases *(National Health Sector Plan II - Implementation)*	+	1	1