Tactile Maps Presenting SDG 6: Clean Water and Sanitation

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

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PARIS-LODRON UNIVERSITY SALZBURG (PLUS)

Faculty of Digital and Analytical Sciences

Department of Geoinformatics

and

PALACKÝ UNIVERSITY OLOMOUC (UPOL)

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submitted by

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With the support of Erasmus+ programme of the European Union. This Master's Thesis has been developed in the framework of the Erasmus Mundus Joint Master Degree (EMJMD) "Copernicus Master in Digital Earth", jointly coordinated by Paris-Lodron University Salzburg, Department of Geoinformatics, Austria together with University of South Brittany, Computer Science Department, France and Palacký University Olomouc, Department of Geoinformatics, Czech Republic.

ANOTATION

The main goal of this diploma thesis is to create a series of tactile maps for people with severe visual impairment presenting Sustainable Development Goal 6: Clean Water and Sanitation. To achieve this goal, the work objectives were divided into theoretical and practical parts which focus on researching the implementation of and the actual production of the maps and accompanying materials respectively.

Data was sourced from authoritative global sources including the United Nations and Copernicus Programme. Pre-processing and standardization of the data were done using the spreadsheet editor, Excel, and generalization and simplification of the data was completed using the GIS software, ArcGIS Pro. The final layouts and accompanying materials were produced using the graphic design software, Adobe Illustrator. In addition to the maps, various explanatory texts providing context for the project as a whole as well as each individual map were included in the series. These texts were made available as audio files to ensure the greatest extent of accessibility possible.

User testing with students with visual impairment was conducted using an interview and questionnaire format in order to assess the usefulness and effectiveness of the maps and to identify areas for improvement in the map design. The results of the user testing were evaluated and necessary improvements were implemented in the map design. The result of this diploma thesis is a digital version of a series of tactile maps on the sixth Sustainable Development Goal. Along with the series of maps, accompanying explanatory texts are provided in digital form and audio recordings of these texts are available online.

KEYWORDS

Tactile maps; Sustainable Development Goals; SDG 6; Swell paper; User testing

Number of pages: 50
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This thesis has been composed by Madeline Mulder for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master in Digital Earth for the academic years 2022/2023 and 2023/2024 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg, and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

20.05.24, Olomouc

Madeline Mulder

I extend my sincere gratitude to my supervisor, Dr. Alena Vondráková, for granting me the opportunity to work on a project of immense personal and professional significance. Her invaluable guidance and dedication were instrumental in my completion of this work, as she generously invested her time and expertise to help me achieve my aims. Through her remarkable knowledge and unwavering support, I have accomplished feats I once deemed beyond reach. I am equally indebted to my co-supervisor, Dr. Strobl, whose insightful perspectives and probing inquiries significantly enriched my research journey. I am profoundly grateful to all the students who participated in user testing, providing invaluable insights that enhanced my thesis immeasurably. Without their collaboration, completing this work would have been impossible. To those who accompanied me during user testing, Dr. Veronika Růžičková, Václav Čech, and Tereza Vocílková, thank you for your time and patience keeping me company and translating for me. Lastly, I extend a heartfelt thanks to those who made the underlying data accessible and those who conducted research on tactile maps of all kinds before me, their efforts paved the way for the completion of this endeavor.

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ASSIGNMENT OF DIPLOMA THESIS

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Theses guidelines

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, defined the 17 Sustainable Development Goals (SDGs). Goal Nr. 6 aims to ensure the availability and sustainable management of water and sanitation for all. Regarding the fact that there is a lack of maps for the environmental education of people with severe visual impairment, the aim of the thesis is to create a series of tactile maps for people with severe visual impairment presenting this selected SDG. The student will use Copernicus data as one of the data sources. Sub-goals of the thesis are to implement an analysis of available teaching materials and maps for this specific target group of users, to make a set of maps and complementary materials designed for environmental education of pupils/students with severe visual impairment, and to make a simple proposal of methodology for how to implement materials in the practical teaching. User testing of the selected maps will be carried out in cooperation with the Institute of Special Pedagogical Studies of the Palacký University Olomouc. All the outcomes (digital files for printing) will be available to a wide target group of users via an online website.

Extent of work report:	**max. 50 pages**
Extent of graphics content:	**as needed**
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CONTENT

LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
CSV	Comma-separated values
FAO	Food and Agriculture Organization
ESRI	Environmental Systems Research Institute
ESD	Education for Sustainable Development
GIS	Geographic Information System
GPCP	Global Precipitation Climatology Project
JPEG	Joint Picture Experts Group
MP3	MPEG-1 Audio Layer III
NetCDF	Network Common Data Form
OECD	Organisation for Economic Co-operation and Development
PLUS	Paris Lodron University Salzburg
RNIB	Royal National Institute for Blind People
SDG	Sustainable Development Goal
SHP	Shapefile
SVG	Scalable Vector Graphics
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nation Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-Habitat	United Nations Human Settlements Programme
UNICEF	United Nations International Children's Emergency Fund
UNSD	United Nations Statistics Division
UPOL	Univerzita Palackého v Olomouci
WHO	World Health Organization
WMS	Web Map Service

INTRODUCTION

Providing students who are blind or have a visual impairment with cartographic teaching aids not only promotes their educational autonomy but also ensures equitable access to geographic and environmental education (Przyszewska & Szyszkowska, 2011). **Tactile maps** enable students who have a visual impairment to **develop spatial awareness and orientation skills** crucial for independent navigation. Additionally, accessible cartographic information facilitates a more comprehensive understanding of societal, cultural, and global issues, enhancing the ability to adapt to living without sight (Olczyk, 2014). Therefore, **integrating tactile maps into educational curricula** is imperative for promoting inclusivity, enhancing learning outcomes, and empowering individuals with visual impairments to **actively participate in global initiatives** such as the Sustainable Development Goals (SDGs).

The need for tactile maps, particularly concerning the sixth SDG, becomes evident when considering the inclusive dissemination of crucial information to people who are blind or have a visual impairment. Educational materials and information in various formats tailored to their specific needs are essential for **fostering autonomy among individuals with visual impairments** (Escanilla et al., 2009). This inclusion extends to understanding global challenges such as those outlined in the SDGs, which impact everyone regardless of visual ability. Unfortunately, there's **a notable scarcity of educational programs and materials addressing the SDGs**, particularly those that are accessible to individuals with visual impairments. This imbalance in educational coverage disproportionately affects goals like SDG 6, despite its paramount importance as water is fundamental for human survival and achieving other SDGs (Ferrer-Estévez & Chalmeta, 2021). The fulfillment of SDG 6 supports all other SDGs, particularly those related to health, education, food, gender equality, energy, and climate change.

Tactile thematic maps, such as those related to the SGDs, are crucial for understanding spatial and geographic concepts, but they remain largely underexplored in research and educational settings (Lobben, 2015; Wabiński and Mościcka, 2019). This gap leads to a deficiency in educational resources, barring students with visual impairment from fully engaging with subjects like geography or history. Students who are blind or have a visual impairment have to follow the same curricula as children with normal vision (Przyszewska & Szyszkowska, 2011). The lack of accessible tactile maps **limits their ability to fulfill curriculum requirements** and gain essential knowledge about the world around them. Furthermore, thematic maps, especially those showing the geographic dimensions of the SDGs, serve as invaluable tools for challenging biases, promoting critical thinking, and fostering inclusivity among students of diverse backgrounds and abilities (Kraak et al., 2018). There is a clear need for tactile maps on the SDGs, a gap that this thesis aims to narrow with a focus on developing a series of maps on just one SGD, SGD 6, Clean Water and Sanitation, in order to provide a template and methodology for **creating tactile maps for the environmental education of people with visual impairments**.

Besides the academic and societal need for such maps, this subject holds profound personal significance for the author. Her grandfather, with whom she shares a close bond and who always supports and takes keen interest in her academic pursuits, is entirely blind. This project serves as a means for her to communicate her academic work and passion to her grandfather in a manner accessible to him. It is a labor of love, inspired and driven by affection.

1 OBJECTIVES

The aim of this diploma thesis is to **create a series of tactile maps for people with severe visual impairment** presenting **Sustainable Development Goal 6: Clean Water and Sanitation**. Subgoals of this thesis include conducting an analysis of available teaching materials and maps for people with severe visual impairment and to propose a simple methodology on how to implement the produced materials in practical classroom curricula. These goals can be divided into both a theoretical and a practical part.

The **theoretical part** relates mainly to the research conducted on available environmental educational material for students with visual impairment, existing methodologies for creating tactile maps, and the specifications of designing tactile graphics on microcapsule paper. Additionally, the theoretical part includes research on the content of the maps, SDG 6. The **practical part** focuses on the actual production and evaluation of the maps and additional complementary materials. The main objective for this part is to create a series of maps and complementary materials on environmental topics to be used in the education of students with severe visual impairment, making sure to use data from the European Union's Copernicus Programme. After the creation of the maps, user testing will be conducted in cooperation with the Institute of Special Pedagogical Studies of the Palacký University Olomouc with a focus on the correct implementation of data presentation for the selected user group.

The goals of this thesis can be summarized as follows:

Theoretical goals:

- Conduct research on methodologies for creating tactile maps, focusing on their application for individuals with visual impairments and their integration into classroom curricula for environmental education.
- Determine the specific content focus for each tactile map.
- Identify potential sources of data to be utilized in map creation.

Practical goals:

- Collect and process relevant datasets.
- Simplify and generalize the data to meet user specifications.
- Compile map contents and layouts.
- Perform user testing to assess usability and effectiveness.

As the final output of this thesis, the produced series of maps with audio tracks can serve as a useful source of information on environmental topics for students with severe visual impairment. The methodological aspect of this thesis can also be beneficial for cartographers and teachers who are concerned with the production of microcapsule thematic maps related to environmental topics for students with visual impairments. In addition to the maps, accompanying explanatory text will be generated for each map. This text will offer further context, explain the map's content, provide guidance on interpreting the map, and briefly outline the data processing methods utilized. All of the resulting materials will be made available for a wide target audience through a website: https://www.geoinformatics.upol.cz/dprace/magisterske/mulder24/.

2 STATE OF ART

There is a notable lack of accessible geographic educational materials for people with severe visual impairment. The state of the art chapter describes the target audience of this thesis and how this group processes information in a tactile form. It then describes tactile maps. Finally, it describes microcapsule paper and fuser technology and provides a summary of the main recommendations and best practices for designing microcapsule maps.

People with visual impairment

Our society is built on the ability to see (World Health Organization, 2019). Vision is the most dominant human sense and plays a critical role in one's ability to communicate, learn, walk, and participate in academics and the professional world (Ibid.). However, according to the World Health Organization, at least 2.2 billion people worldwide have some form of visual impairment (2023). Moreover, the risk of visual impairment for a greater number of people is only expected to increase due to population growth and aging (World Health Organization, 2019).

Visual impairment refers to any level of limitation in visual abilities that impacts everyday activities and which cannot be corrected with aids such as eyeglasses. This designation includes those with low vision, meaning partial loss of vision, and those who are blind, meaning a complete loss in the ability to see or an extremely limited ability to see despite additional corrective aids (Alotaibi et al., 2020). Thus, any individuals who are low-sighted and require corrected vision, have a color vision deficiency, or are non-sighted can all be considered to have a visual impairment (Kraak et al., 2018).

Visual impairment can have a huge impact on the success of an individual. Vision is especially critical in an educational setting where vision enables ready access to educational materials and is critical to educational attainment (World Health Organization, 2019). Unfortunately, due to the fact that our society is primarily built to cater to those who can see, children with visual impairment can experience delayed motor, language, emotional, social, and cognitive development, and can also experience lower levels of educational achievement (Ibid.).

People with visual impairments absorb information differently than their sighted peers. People who are blind use touch and auditory senses to learn and complete functional tasks whereas those with less severe visual impairment also rely on their auditory and tactile senses for educational and functional tasks but may also have the ability to use limited visual abilities to perform said tasks (Alotaibi et al., 2020). In other words, people with visual impairments primarily acquire information through touch (Escanilla et al., 2009). Those with visual impairment train themselves to depend on their other senses such as hearing, touch, taste, and smell to take in and process information (Alotaibi et al., 2020). Yet some people with less severe visual impairment can still distinguish strongly contrasting colors through their limited visual senses (Vondráková et al., 2021). Even though people with visual impairment rely on different senses to gather information, they are able to learn just as well as their sighted counterparts. However, they need assistive tools, such as specialized teachers, and different methods to learn things that depend on visual concepts (Alotaibi et al., 2020; Olczyk, 2014). One such tool of great importance in the education of someone who has a visual impairment is a tactile map.

Tactile maps enable users to acquire spatial information as well as form and update mental maps (Gkanidi & Drigas, 2021). Due to the fact that students with severe visual impairments take in information mainly through touch and have a reduced ability to visually perceive a map, they most often read maps sequentially, that is to say, in pieces, in order to memorize and create a model of the map in their minds (Olczyk, 2014; Vondráková et al., 2021). Despite this difference in informational perception and processing, research has shown that people with server visual impairment have the same cognitive spatial abilities as people without visual impairment, though their formative knowledge is less complex due to different access to information and past experience (Gkanidi & Drigas, 2021). Building on the understanding that individuals with severe visual impairment possess comparable cognitive spatial abilities despite differences in informational access and past experiences, the challenge arises in providing them with equivalent access to geographic information, particularly through maps.

Tactile maps

The purpose of a map is to symbolically depict the world in a visual way (Escanilla et al., 2009). However, people who are blind or have visual impairment cannot access the geographic information housed in optically oriented maps as easily as those who are fully sighted. Instead, people who are blind or have a visual impairment turn to tactile maps to gain geographic knowledge about the world around them (Blades et al., 1999). Tactile maps are those that are read through the sense of touch or, to a limited extent, by eye for those with less severe visual impairments (Ojala et al., 2016). These types of maps employ relief and symbols which can be explored through touch to convey information (Gual et al., 2015). By manipulating the haptic variables associated with these elements, such as height, size, grain, profile, shape, texture, orientation, temperature, and resistance, mapmakers are able to represent geographic information in a way that people who are blind or have a visual impairment can understand (Wabiński et al., 2021).

The main focus for creating maps for those who are blind or with visual impairment is a need to transform visual information into a form that can be perceived by other senses, mainly touch and hearing (Wabiński et al., 2022). However, it is not possible to simply turn a non-tactile map into a tactile map by making all of the features haptic in some form for a variety of reasons, chief among them being the fact that haptic perception is much less detailed than visual perception and much less information can be taken in and processed through touch than through sight (Gardner, 1996). Moreover, people with visual impairments read maps in a different manner than sighted individuals. Research has shown that people who are blind or have a visual impairment tend to read tactile maps in fragments and memorize each fragment rather than reading the map as one coherent whole as those with sight do with non-tactile maps (Griffin, 2001). In fact, people who are blind or have a visual impairment tend to perceive each element in a tactile map sequentially, and only then do they integrate each element into a coherent whole (Ibid.). Given the particularities of how people who have a visual impairment “read” information, tactile maps must be designed in a specific way in order to best inform this user group. Thus, the creation of tactile maps has come to be guided by two main principles: simplicity and legibility (Wabiński et al., 2022)

In terms of legibility, tactile maps must be less detailed than non-tactile maps with a great degree of differentiation between elements. In order for a tactile map to be legible to those with visual impairments symbols must clearly contrast with each other, be unambiguous, and constructed with the simplest graphic elements possible, but, at the same time, their design should suggest their meaning (Wabiński et al., 2022). Moreover, the symbols on tactile maps should be differentiated along as many tactual dimensions as possible (Ibid.). Finally, although additional map elements such as title and scale are of lower importance on tactile maps in order to maximize space for the map content, these elements must still be present and grouped together on a tactile map so that it remains legible (Ibid.).

Simplicity is considered the second most important principle after legibility in tactile map design (Wabiński et al., 2022). Tactile maps require a greater level of map content simplification and abstraction, through methods such as generalization, omission, exaggeration, and distortions, in comparison with traditional maps (Ikhuoria & Irabor, 1998). The symbols commonly used in traditional cartography are usually too small or too complicated to be read correctly using the sense of touch or a damaged sense of sight when raised to the third dimension (Wabiński et al., 2021). In fact, tactile maps that have been simplified through the use of a smaller quantity of symbols or less complex symbols, have been shown to be better received by audiences (Wabiński et al., 2022). Thus, when translating traditional maps into tactile maps, the symbols, layout, and content of the map must be simplified in order to meet the needs of the users. Unfortunately, there is a lack of standardization for tactile maps in terms of creation methods, symbols, or layouts. There is a limited range of possible symbol designs and textures that are distinctly discriminable from one another through touch, a fact that stands in direct conflict with the the fact that there is also an overwhelming amount of information that needs to be distilled into simple graphics in different ways depending on the needs of different users and constraints of different production technologies and physical mediums (Brittell et al., 2018).

The physical medium chosen is of great importance to the effectiveness of a tactile map as the capabilities of tactile map users are limited primarily by the medium that they use (Cole & Robinson, 2023). The major considerations when choosing a physical medium for a tactile map are related to the physical sensations a user will experience when interacting with the map and ensuring that the physical medium minimizes unpleasant or misleading sensations. Map makers should be mindful when choosing their physical medium so as to make sure to use materials that will not cause allergic reactions, or get too hot or too cold due to the environmental conditions (Wabiński et al., 2022). Moreover, matte finishes are preferred as they prevent glaring and enhance the movement of a finger over tactile maps which facilitates the reading process (ISO, 2016; Wabiński et al., 2022). On the whole, tactile mapping remains a specialized field, with many papers noting that tactile maps are still expensive, hard to come by, difficult to make, and inherently unable to match the resolution of data that is possible with a visual map (Cole, 2021).

Three primary shortcomings exist for tactile mapmakers and users. Firstly, cartographic conventions for tactile maps are not widely applied for reasons previously discussed (challenges related to haptic discriminability, differing specifications based on user needs and production methods, etc.). Secondly, tactile map production software and hardware are not widely used. Thirdly, there is a large gap in content that is available to non-sighted users. While there are many thematic maps available for free download by and for map-readers who are sighted, very few are available in tactile form (Lobben, 2015). This lack of available tactile maps is in part related to the difficulties of designing the content of a tactile map which arise from the complex composition of thematic layers on top of background layers, and the common practice of using data from different heterogeneous sources (Wabiński et al., 2022). The challenges encountered when designing the content of tactile maps are further exacerbated by the difficulties in producing tactile maps. The production process for a tactile map can be expensive and time-consuming, and often requires a great deal of technical expertise. These challenges, when combined with a user group with limited purchasing capacity, have contributed to a lack of available navigational and educational tactile maps (Lobben, 2015; Lobben & Lawrence, 2012).

Technologies for printing tactile maps

There are many different printing methods that can be used to create tactile maps today. Studies have shown that two of the most popular production methods are thermoform and microcapsule paper (Rowell & Ungar, 2003). The popularity of these methods is primarily based on user needs with users who preferred the thermoform production methods citing the durability of the medium and the greater ability to produce a greater range of tactile symbols and elevations as the reason for their preference (Ibid.). The thermoform production method, also referred to as vacuum forming, requires a physical master copy of a tactile graphic in the form of a three-dimensional model. Copies of this model are made by placing thin sheets of plastic over the model where they are then heated and vacuumed onto the model (Lobben & Lawrence 2012). Many copies can be made of a model, but the production process is costly and time-consuming (Wabiński et al., 2022).

For users who preferred microcapsule paper, convenience, in terms of the speed and low cost of production, was the main reason given for their preference (Rowell & Ungar, 2003). Studies have also shown that users tend to prefer the feel of and ease of movement provided by microcapsule paper over other mediums (Rowell & Ungar, 2003; Gkanidi & Drigas, 2021). The microcapsule production method works by first generating an image in a graphic editing software, such as Adobe Illustrator, CorelDRAW, or Tiger Software. The image is then transferred to microcapsule paper (also known as Minolta, Micropearl, Zy-Tex, Swell paper, Flexi-paper, Puff paper, or Stereocopy paper) by a photocopier or printer using black carbon-based ink (Braille Authority of North America & Canadian Braille Authority, 2012). The microcapsule paper includes chemical-filled capsules situated between two substrates and when the black ink is applied to the paper and then exposed to heat, the chemicals under the black ink are agitated causing raised relief (Lobben & Lawrence 2012). Once the image has been printed on the microcapsule paper, the paper is then fed through a fuser, shown in Figure 1, which is sometimes also referred to as an enhancer, in order to develop the tactile graphic.

Figure 1 Fuser at Palacký University Olomouc.

The fuser usually contains a halogen light bulb which supplies the heat needed to raise the areas outlined in black ink on the paper. The temperature and speed at which the paper passes through the fuser can be controlled by dials on the machine. The more heat an image receives as it passes through the fuser either by way of a higher temperature or a greater time spent in the fuser, the more the image outlined in black ink will expand (Braille Authority of North America & Canadian Braille Authority, 2012). This method does not require a physical master copy, allows for the use of color and curved elements, and the graphics can easily be altered or duplicated (Wabiński & Mościcka, 2019). Furthermore, a study conducted by Brittell et al. investigating the impact of various production technologies on tactile symbols found that there is greater symbol discriminability, durability, and user satisfaction when using microcapsule paper as the physical medium for tactile maps (2018). However, this technique requires many trials in order to achieve the desired results, it is restricted to a single uniform height, and the microcapsule paper is rather expensive and can be damaged easily (Wabiński & Mościcka, 2019; Rowell & Ungar, 2003).

Another popular production technique is braille embossing. With this method, tactile maps are created using graphics software, such as Adobe Illustrator or Microsoft Word, and then printed using braille and graphics-capable embossers, such as the Tiger family of embossers, with card stock paper (Braille Authority of North America & Canadian Braille Authority, 2012). Generally, these printers can quickly yield crisp raised relief but they come at a high price (commonly used printers cost between $4,000 and $14,000), and the produced graphics can be hard to read tactually as there is little variation in height, point symbols are difficult to discern, and the number of textures that can be produced are limited (Lobben & Lawrence, 2012; Braille Authority of North America & Canadian Braille Authority, 2012). Furthermore, it is not easy to produce curves or diagonal lines with as much accuracy as other methods (Brittell et al., 2018).

While thermoforming, microcapsule paper, and braille embossing are among the most popular production methods for tactile maps, there has recently been a great deal of advancement in the field of tactile map printing thanks to 3D printing technologies (Wabiński et al., 2022). Proponents of 3D printing tactile maps argue that the cost of 3D printing one map is much cheaper than using traditional printing techniques as 3D printing not only cuts down on the overall cost of production for producers and users but also on the cost for prototyping and testing maps while allows for a more rapid production of maps (Wabiński et al., 2021). Wabiński and Mościcka, have even argued that 3D printed maps are characterized by a higher total cartographic information value as compared with tactile maps produced through other more traditional methods because 3D printing allows tactile-map designers to fully experiment with the appearance of a tactile map as there is no limit on the shapes that can be created (2021). However, some limitations for 3D tactile maps do exist as there is a limit to the maximum size of printed elements due to the size of existing 3D printers and 3D printers are still not as ubiquitous in the visually impaired community as braille embossers and fusers are due to the fact that the cost of 3D printers is still high (Wabiński et al., 2021; Brittell et al., 2018). However, nowadays these constraints are becoming less of an issue due to the availability of larger-sized printers and the capability of most 3D printers to produce maps in acceptable sizes (Vondráková, 2024).

There is also an emerging trend in tactile map production which involves audio feedback and refreshable touch display technologies which provide audio or haptic feedback in the form of vibrations in order to enhance the interactive and accessible nature of tactile maps (Wabiński & Mościcka, 2019; Vondráková et al., 2021). As technology evolves, these innovations promise to further revolutionize the landscape of tactile mapping, aiming for greater inclusivity and enhanced user experience. Yet, as it stands now, each production method for generating tactile maps comes with its own parameters and requirements which makes the standardization of tactile maps difficult (Wabiński et al., 2022). Additionally, overall tactile map production remains very expensive. Due to the high cost of printing tactile maps, people who are blind or have visual impairment do not have equitable access to spatial information as compared to their sighted peers (Wabiński et al., 2022).

Specifications for microcapsule graphics

There are no international standards for creating tactile graphics with microcapsule paper, however, various researchers around the globe have conducted their own studies and published their own findings on best practices for creating microcapsule graphics. The work of researchers from Sweden, Canada, the United States, Australia, New Zealand, Germany, Brazil, Japan, and the Netherlands was reviewed for this thesis. While each author has their own specifications, the following paragraph summarizes the general findings of this group of authors.

The guiding principle to follow when creating tactile graphics is to make sure each element is as distinguishable as possible, be that through the element design or placement. Authors contend that a single graphic can effectively incorporate only 5 to 7 distinct textures (Hashimoto & Watanabe, 2016; Presher & Bornschein, 2016; Round Table on Information Access for People with Print Disabilities Inc, 2021). In terms of specific types of elements, generally speaking, in order to be distinguishable, lines for different elements must be double the width of each other (Araújo et al., 2020; N.S.W. Tactual and Bold Print Mapping Committee & Vision Australia, 2006). For instance, it would be acceptable to have lines with a width of 0.5 mm, 1 mm, and 2 mm all present on the same graphic, but having lines of 0.25 mm, 0.5 mm, and 0.75 mm width would not be discernable as distinct lines on a graphic even if sighted users would be able to tell the difference between them. Opinions vary with regard to the maximum width of a line. However, consensus suggests that lines of a width greater than 2 mm run the risk of bubbling and obscuring the element, while those less than 0.5 mm are inadequate (Braille Authority of North America & Canadian Braille Authority, 2012, N.S.W. Tactual and Bold Print Mapping Committee & Vision Australia). In regards to dot symbols, which either stand alone as point symbols or are used within textures, the dots should be less than 0.7 mm or greater than 2 mm in size so as not to be confused with braille (Ibid.). Acceptable symbols, such as circles, squares, triangles, crosses, or asterisks, should be at least 6 mm in size, with larger symbols left unfilled and outlined with a 1 mm thickness to prevent bubbling (N.S.W. Tactual and Bold Print Mapping Committee & Vision Australia; Presher & Bornschein). Moreover, a gap greater than 3 mm is recommended between tactile elements and braille text in order to differentiate them tactilely (Schuffelen, 2002). These recommendations informed the creation of the map series, leading to the author's own recommendations for refining and expanding previous work (refer to Chapter 5 Map Creation).

3 METHODOLOGY

This chapter presents the methodology employed in this thesis, including the methods utilized in both the theoretical and practical parts, along with details regarding data sources and processing.

Used methods

The initial phase of work in this thesis was focused on the theoretical aspect related to research on the target user group, specifications of tactile map design, and microcapsule and fuser technology requirements. Scientific articles concerning the previously mentioned topics were accessed through online databases including Google Scholar, ScienceDirect, and ResearchGate. Much of the time researching was spent on identifying existing educational resources for users with visual impairment and on existing methodology for microcapsule map creation. Furthermore, additional research efforts were dedicated to exploring the selected SDG, SDG 6, in order to identify pertinent aspects of the SGD to showcase in the maps and to find relevant data sources. After the background research was conducted, the content, map layouts, and technological features concerning microcapsule paper, including textures and braille size, were developed and refined based on consultations with tactile maps and graphics expert, Dr. Veronika Růžičková from the Faculty of Pedagogy at Palacký University Olomouc (UPOL) and the thesis supervisor, Dr. Alena Vondráková.

Due to the intricacies and particularities of designing tactile graphics on microcapsule paper for users with visual impairments, a great deal of time was dedicated to data processing, data simplification and generalization, and the development of textures and layouts. Once all the necessary datasets related to SDG 6 were obtained, data processing and standardization were conducted using a spreadsheet editor and GIS software. Designing the final layouts was completed using a graphic editing program. After the production of a series of sample maps, user testing was conducted with students with visual impairments to evaluate the effectiveness of the content and layout of the prototype maps.

Based on the result of user testing, improvements were made to the content and layout of the maps. Then all of the maps that were to be included in the series were completed. As the final step in the process, explanatory texts that provided additional context on the SDGs, SDG 6, and each map specifically were created using word processing software and designed using graphics editor software. These documents were subsequently converted into audio files utilizing the freely available desktop application Any Text to Voice. This application offers voice customization, the ability to save audio in MPEG-1 Audio Layer III (MP3) format, and unrestricted saving of MP3 files. All files (maps, texts, and audio tracks) were made available for public download through an openly accessible website created using a code editor. Throughout the entire process, several consultations regarding the map design, textual content, and audio file creation were conducted with the thesis supervisor to ensure high cartographic quality and maximum usability of the final product.

Used data

This thesis relied on publicly available spatial (GIS) and tabular data from official sources. Additionally, some graphic elements were sourced from open-source repositories and other authoritative sources.

GIS data

International boundaries provided by the United Nations (UN) were used as base layers for the thematic content of the maps. These boundaries were provided by the Food and Agriculture Organization (FAO) of the UN and accessed through a Web Map Service (WMS) which can be found here: https://data.apps.fao.org/catalog/dataset/6aecaf08-c7d0-4e16-8778-b8dddae9da14. Once accessed, the boundary layers were saved locally in shapefile (SHP) format. These boundaries were simplified and generalized to meet the needs of the target user group and are stored in the digital archive included with this thesis. Data on precipitation was accessed through the Copernicus Climate Change Service in Network Common Data Form (NetCDF), version 4 format. Precipitation values were based on estimates from various satellites, for more information see: https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-precipitation?tab=overview. For this thesis, monthly precipitation data for the entire world for each month of 2020 was downloaded and mosaicked into one combined raster and then divided into the seven Sustainable Development regions.

Tabular Data

Most of the data that served as the thematic content for the map series was sourced from the UN-Water SDG 6 Data Portal (https://www.sdg6data.org/en) which collects all of the UN's water and sanitation data in one place. This site provides data on every SDG indicator that is related to water and sanitation. This means that data for each indicator covered under SDG 6 was available as well as additional data for indicators that fall under different SDGs. While data collection for all of the SGD 6 indicators is coordinated by UN-Water, there are a variety of different organizations responsible for collecting data for each specific indicator. The custodian agency for each SDG 6 indicator can be viewed below in Figure 2Figure 2.

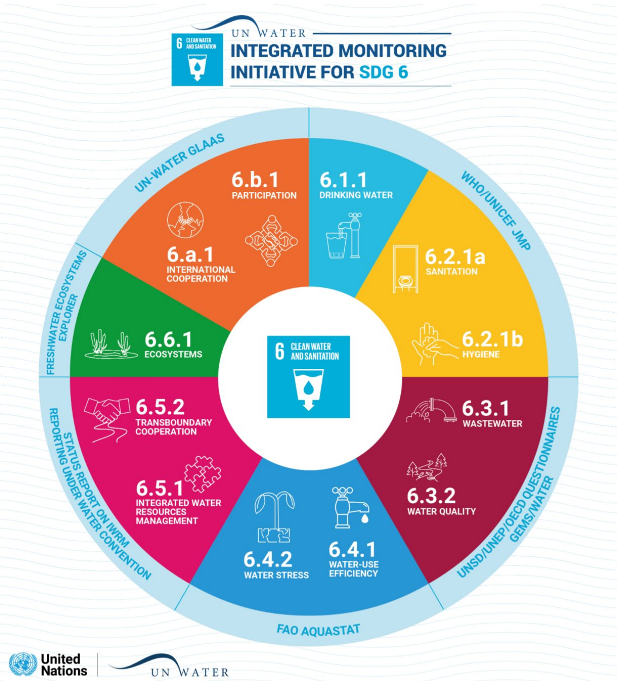

Figure 2 Custodian agencies of data for SDG 6 indicators (Source: Monitor and Report | UN-Water (unwater.org))

Data provided on the UN-Water SDG 6 Data Portal is available at many different scales and in many different formats. For the purpose of this thesis, country-level data was downloaded for each SDG 6 indicator, a total of 12 indicators, in tabular form. Data was downloaded in comma-separated values (CSV) file format to facilitate data processing. When processing the tabular data, extraneous data was removed, country names were standardized to match the official names of UN member states, and raw values were categorized into groups as a first step in data and map simplification in order to meet the needs of the target user audience. The most recent complete dataset for each indicator was used. For most datasets, this was the year 2020, though one dataset was most recently updated in 2015 and one was most recently updated in 2021. The tabular data was then joined to the simplified boundaries created based on the UN international boundaries in GIS software.

Graphics

Open-source graphic elements (e.g. icons and images) were also used throughout the map series and associated website. The icons were taken from SVG Repo in Scalable Vector Graphics (SVG) format. The images used in the text accompaniments to the maps, most specifically for the introductory pages in the map series, were downloaded from the official UN communications materials in Joint Photographic Experts Group (JPEG) format.

Used software

Various software were used for data processing, layout design, and user testing. Licenses for these programs were obtained either from the Paris Lodron University of Salzburg (PLUS) or with a personal license. A spreadsheet editor, GIS software, and graphic editing software were all used in the production of the map series. Microsoft Excel was used for data cleaning and ArcGIS Pro version 2.9 was used for the processing of spatial data and the production of maps. Adobe Illustrator CC 2023 (v.28.41) was used for further map and layout design.

The user testing aspect of the thesis relied on an interview and questionnaire. For the testing and subsequent analysis of results a spreadsheet editor, a word processor, and an online survey tool were used. The online survey tool Survey123 was used for the creation of the user testing questionnaire and was used to record user responses. Later analysis of the responses was done using Microsoft Excel.

Processing procedure

The chart, Figure 3, on the following page details the general steps followed during this thesis. The main software used, especially during the data processing and graphic designing steps where the bulk of the work happened, is also shown. A more detailed explanation of these procedures is discussed in Chapter 5 Map Creation.

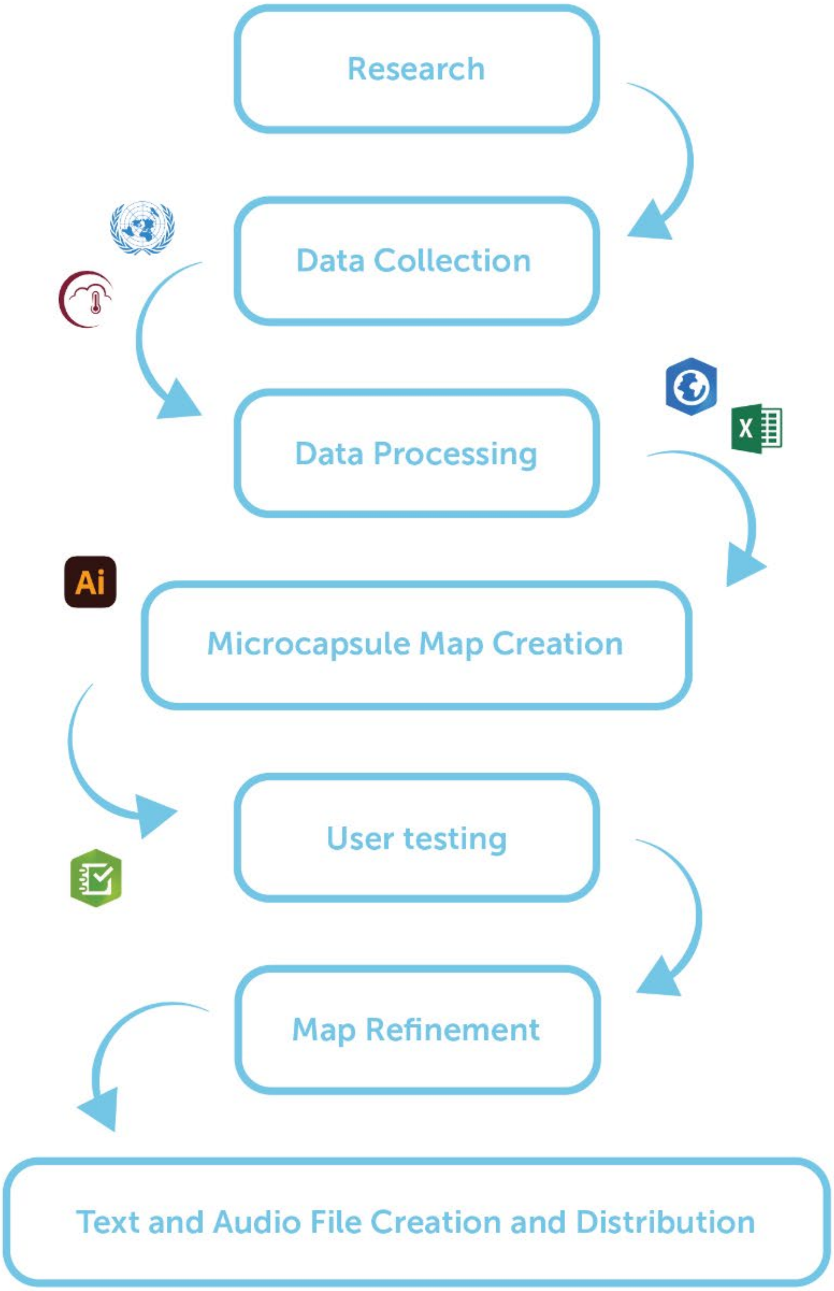

Figure 3 Thesis methodology.

4 MAP CONTENT

This chapter covers the theoretical portion of the thesis which focused on researching available environmental educational resources for students with visual impairment as well as on the thematic content of the map: SDG 6. While only one SDG, SDG 6, is presented in the map series, the analysis of available teaching materials was conducted in the whole thematic extent of SDGs.

4.1 The Sustainable Development Goals

In 2015 every member state of the UN adopted the 2030 Agenda for Sustainable Development in an effort to collectively address the most pressing global problems. At the heart of the 2030 Agenda were 17 SDGs, as shown in Figure 4, which address a variety of themes concerning security, sustainability, and human and natural health, with the ultimate aim of creating a more inclusive and just society (Garcia et al., 2017). The SDGs provide a framework for collectively making progress toward a more sustainable world by way of addressing broad social, economic, and environmental challenges in order to achieve the UN's shared vision to "end poverty, rescue the planet, and build a peaceful world" (Kraak et al., 2018). The SDGs are not legally binding. However, because each member state adopted the 2030 Agenda, each member is expected to establish frameworks, policies, or other measures in order to implement and achieve the goals (Ibid.). The work of realizing all of the SDGs is not limited to governmental entities but includes private sector and civil sector agents as well (Ferrer- Estévez & Chalmeta, 2021).

Figure 4 The 17 Sustainable Development Goals icons established by the United Nations in the 2030 Agenda for Sustainable Development
(Source: Communications materials - United Nations Sustainable Development (2024)).

Each SDG has a set of targets and indicators to assist members in measuring progress toward meeting the larger goal. Each goal has a range of targets that indicate the circumstances to be obtained or the means of implementation to be executed in order to fully realize the larger goal and each target typically has a few indicators that can be used to measure progress toward reaching a target (Bartram et al., 2018). Furthermore, the indicators are broken up into three tiers (Tier I, Tier II, and Tiering Pending) to signify the methodological consistency in the collection and availability of the data in terms of global coverage associated with the indicator; not all indicators have an associated dataset with complete global coverage, a fact which can make accurately measuring progress on the SDGs difficult (Kraak et al., 2018). In total, there are currently 169 targets and 225 indicators for all of the 17 goals (The Sustainable Development Goals Report 2023: Special Edition, 2023). Unfortunately, while progress is being made toward realizing the goals, it is not happening fast enough (Ferrer- Estévez & Chalmeta, 2021; The Sustainable Development Goals Report 2023: Special Edition, 2023).

4.2 Sustainable Development Goals in school education

Efforts to achieve the Sustainable Development Goals (SDGs) have been ongoing, yet the persistence of environmental degradation, the intensification of climate change, and the exacerbation of inequality underscore the challenges that persist (Vasconcelos et al., 2022). In light of these realities, it has become increasingly imperative to empower citizens with the knowledge and skills necessary to confront everyday adversities. Recognizing this need, the UN introduced Education for Sustainable Development (ESD), a pedagogical initiative centered on integrating sustainability education into classrooms through participatory methods. ESD aims to equip students with the competencies needed to lead more sustainable lives, thereby playing a vital role in the realization of the SDGs and the broader aspiration for a sustainable future (Garcia et al., 2017; Ferrer-Estévez & Chalmeta, 2021). Education stands as a cornerstone within the SDGs framework; Goal 4 (Quality Education) focuses specifically on education in its own right and education is explicitly referenced in five other goals, though it is effectively intertwined with the achievement of all SDGs in one way or another (Filho et al., 2019).

Recognizing the multifaceted nature of sustainable development, universities have emerged as pivotal actors, collaborating with local stakeholders to advance the SDGs through curriculum integration and digital access to information (Garcia et al., 2017). The expertise housed within universities is indispensable for the realization of these goals; indeed, it can be asserted that the attainment of the SDGs hinges upon the contributions of these institutions. Findings from a survey by Vasconcelos et al. underscore the significance of higher education in shaping awareness of the SDGs, although secondary schools and social media also play substantial roles in fostering understanding of SDG principles (2022).

However, the application and teaching of the SDGs in the classroom is still limited (Filho et al., 2019; Vasconcelos et al., 2022). The reasons often cited by teachers for the absence of SDGs in the curriculum are a lack of training, opportunity, materials, and time. Many teachers also felt that the SDGs were not applicable to their course or felt that the idea of sustainability was too vague and ill-defined to feasibly incorporate into their lessons (Filho et al., 2019). Still, another obstacle to implementing and teaching the SDGs in the classroom is that for many higher education institutions, the curriculum is defined by disciplinary committees. Often, disciplinary committees overseeing curriculum design may lack awareness of the SDGs, resist change, or prioritize other content over the SDGs due to curriculum constraints. Consequently, addressing these limitations proves difficult, and navigating around them in course content becomes a formidable task in regards to implementing and teaching the SDGs in an educational setting (Filho et al., 2019; Ferrer-Estévez & Chalmeta, 2021).

In 2017, the SGD Accord was introduced as a mechanism to monitor the integration of SDGs within higher education, encouraging collaboration among higher education institutions, student organizations, and supporting entities to document their SDG initiatives (Filho et al., 2019). Currently, the Accord boasts a membership of institutions spanning 30 countries across 5 UN regions. The latest report underscores a notable increase in educational efforts supporting system-wide change, with SDGs 3 (Good Health and Wellbeing), 4 (Quality Education), and 13 (Climate Action) emerging as the most impactful among participating institutions. Notably, goals 1 (No Poverty), 6 (Clean Water and Sanitation), and 14 (Life below Water) received comparatively less attention. Looking ahead, institutions have identified goals 4 (Quality Education), 13 (Climate Action), and 17 (Partnerships for the Goals) as their primary areas of focus for implementation in the upcoming year (Alliance for Sustainability Leadership in Education [EAUC], 2021).

The obstacles hindering the integration of SDG education in higher education settings also extend to primary and secondary educational institutions (Kwee, 2021). As a consequence of that fact that the SDGs remain largely unexplored in lower education, it is predominantly the higher education system that takes the lead in their instruction (Vasconcelos et al., 2022). In secondary education, an additional challenge emerges as students often perceive sustainability as irrelevant to their curriculum and feel powerless to effect change, especially when their influence is limited to local contexts or they struggle to mobilize others to action (Kwee, 2021). However, early childhood presents an opportune period for instilling lifelong learning for sustainability. According to Kwee, during this developmental stage, children exhibit a remarkable capacity to acquire socio-environmental resilience, cultivate care for both living and non-living entities, and foster respect for the environment, which can profoundly shape their later attitudes and behaviors (2021).

Despite challenges in implementing SDG in educational settings, there is a growing recognition of the importance of SDG education across all educational levels, with early childhood identified as a critical period for instilling lifelong learning for sustainability. One critical tool for promoting awareness and understanding of the SDGs is maps which allow for an educational and innovative way to engage in sustainability.

4.3 Existing maps on the Sustainable Development Goals

The main body of work that addresses mapping the SDGs is entitled *Mapping for A Sustainable World*, which serves as a guidebook on how to map geographic data related to the SDGs. However, it sets aside only a short page on mapping for visual impairment, briefly mentioning visual impairment and accessibility, but neglecting to include in-depth discussion on visual impairment and how to create maps of the SDGs for those who are visually impaired (Kraak et al., 2018). In addition, there are a few notable projects mapping the SDGs. One such notable contribution is the *Atlas of Sustainable Development Goals* created by the World Bank with four editions from 2017, 2018, 2020, and 2023. The Atlas draws from the World Bank's World Development Indicators database, as well as from a wide variety of additional data sources, including international organizations and researchers (Pirlea et al., 2023). The Our World in Data team has also produced a series of maps related to each of the SDGs in an effort to track progress towards achieving each goal using statistics from the UN and other international organizations (2023). Finally, the Environmental Systems Research Institute (ESRI), one of the leading mapping companies which specializes in Geographic Information Systems (GIS) software, solutions, and services, has published a Storymap with a series of maps visualizing trends in data gathered for each SDG and has developed a hub for resources related to the SDGs (ESRI, n.d.-a; ESRI, n.d.-b). Despite the existence of these projects, there remains a general scarcity of maps pertaining to the SDGs.

Educational institutions at all levels often lack teaching materials on the SDGs, but the deficiency is even more pronounced for individuals with visual impairment (Filho et al., 2019). Notably, many developing countries do not have specialized programs focusing on graphics for the geographic education of those with a visual impairment, though countries such as Australia, Brazil, Britain, China, Czechia, Japan, and the United States have dedicated social and educational initiatives for this population (Ikhuoria & Irabor, 1998; Vondráková et al., 2021).

The challenges associated with producing tactile maps contribute to their limited availability. Furthermore, existing tactile maps often prioritize navigation over thematic content (Cole & Robinson, 2023). Generally, thematic tactile maps are particularly scarce, with limited research on them as well (Cole & Robinson, 2023). Nevertheless, there are notable examples of tactile map initiatives. For instance, the *Atlas of the United States Printed for the Use of the Blind* was published in 1837 using embossed paper at the New England Institute for the Education of the Blind in Boston (Cole, 2021). Similarly, the Polish Office of Geodesy and Cartography created the *Geographic Atlas of Poland'* in 2003 and followed up with a *Geographic Atlas of Europe* in 2006, both utilizing microcapsule paper (Olczyk, 2014). Despite these projects, to the best of this author's knowledge, there are no widely available tactile maps of the SDGs.

Overall, there is a lack of materials related to mapping the SDGs for people with visual impairment which is not reflective of the need for or value that these materials provide. Maps make it possible to see trends and make comparisons between different areas and over different time periods as well as to help audiences better understand the stories and implications of each SDG for every country (Kraak et al., 2018). To achieve the SDGs, governments and people need to understand each challenge that the goals address and be able to monitor progress toward addressing them. Well-designed maps and diagrams support this process because they effectively illustrate spatio-temporal patterns such as global population growth, socioeconomic disparities, and climate change. Maps increase the capacity of the human mind to understand the complexity of the world (Ibid.). As such, they are a necessary tool for understanding and bettering the world and should be accessible to all.

4.4 SDG 6: clean water and sanitation

There are a lot of topics focusing on SDGs that may be presented in maps. As mentioned above, there are currently 169 targets and 225 indicators for all of the 17 goals. It would be possible to create a set of maps for each goal, target, or indicator with the total possible number of visualizations in the hundreds or even thousands. Given the time constraints, this thesis focuses exclusively on one selected goal, SGD 6. However, the resulting methodology can be used by others to reproduce tactile maps of this kind with other datasets. SDG 6 was chosen because water is a critical component of life and well-being, making this goal essential for ensuring the other goals are achieved.

The sixth SDG outlined by the UN focuses on clean water and sanitation. The goal is composed of 8 targets (United Nations, 2023):

- **6.1** by 2030, achieve universal and equitable access to safe and affordable drinking water for all
- **6.2** by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
- **6.3** by 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
- **6.4** by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
- **6.5** by 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
- **6.6** by 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
- **6.A** by 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
- **6.B** support and strengthen the participation of local communities in improving water and sanitation management

The sixth SDG expands its focus beyond merely addressing access to drinking water, sanitation, and hygiene services to also encompass the quality and sustainability of water resources themselves. Recognizing water's central role in sustainable development and its intersection with the success of other SDGs, this goal underscores the critical need for concerted action to ensure equitable access to clean water and sanitation for all. Access to safe water and sanitation is not only crucial for basic human health and well-being but also plays a pivotal role in poverty reduction, food security, ecosystem well-being, and educational attainment change (“The Sustainable Development Goals Report 2023: Special Edition,” 2023). However, billions of people worldwide still lack access to these fundamental resources, perpetuating cycles of poverty and disease (Ibid., p. 24). Additionally, climate change poses another risk to the availability and quality of water resources, further threatening human survival and well-being, particularly in vulnerable communities (Pirlea et al., 2023).

Global trends have shown a lot of progress in some areas, but overall progress on the goal worldwide is lacking. Access to safe drinking water and sanitation services improved significantly in rural areas but stagnated or decreased in urban areas. Countries that monitor water quality have been successful at reducing their proportion of untreated wastewater, however, many countries (over a quarter) do not report on water quality, so the bigger picture in terms of global water quality is still largely unknown. Additionally, water-use efficiency has increased by 9%, but water stress and water scarcity remain pressing concerns for most around the globe, issues which are only worsened by conflicts and climate change (“The Sustainable Development Goals Report 2023: Special Edition,” 2023). Moreover, even though overall global water-use efficiency has improved, there is a great regional variation; Central, Southern, and Western Asia, as well as Northern Africa and the Middle East all face dire water stress (water stress refers to the amount of pressure on a country's renewable freshwater resources). The global water stress level was 18% in 2020, which is classified as no stress by the FAO, but about 67% of UN member countries have faced an increased level of water stress since the 1960s (Pirlea et al., 2023). Furthermore, wetland ecosystems face increasing threats from pollution, climate change, and overexploitation, further exacerbating water resource challenges ("The Sustainable Development Goals Report 2023: Special Edition," 2023). Finally, perhaps one of the most concerning trends in regard to water resources is the diminishing availability of freshwater resources.

Despite water covering approximately 70% of the Earth's surface, only a tiny fraction—2.5%—of it is freshwater, with a mere 0.5% being readily accessible. Much of the freshwater is locked in glaciers, while groundwater, the largest component of accessible freshwater, often requires drilling for access. Concerningly, surface freshwater sources, which comprise only 0.3% of all accessible freshwater, are under increasing pressure due to factors such as climate change, population growth, and economic demands (Pirlea et al., 2023). The planet's renewable freshwater supply is essentially finite, but freshwater withdrawals have long been increasing; freshwater withdrawals are estimated to have more than doubled since 1960, largely due to increased usage in the agriculture sector driven by population and economic growth (Ibid.). While water-use is becoming more efficient, the overall demand for water is blooming. There is an increase in demand for water resources at the same time as there is increasing pressure on the water cycle due to climate change, both factors which are limiting or even depleting freshwater resources (Ibid.).

Despite some progress since the establishment of the SDGs in 2015, significant challenges persist. Furthermore, the lack of comprehensive data on water resources hinders efforts to address these challenges effectively. To address these challenges and achieve SDG 6, there is a pressing need for increased investment in water and sanitation infrastructure, improvements in water use efficiency, and the adoption of integrated water management approaches. Moreover, enhanced transboundary water resource management and robust monitoring mechanisms are essential for fostering cooperation and addressing water-related challenges at regional and global scales ("The Sustainable Development Goals Report 2023: Special Edition," 2023). The critical areas where progress towards achieving this goal needs to accelerate have been laid out in the 2020 SDG 6 Global Accelerator Framework (Figure 5).

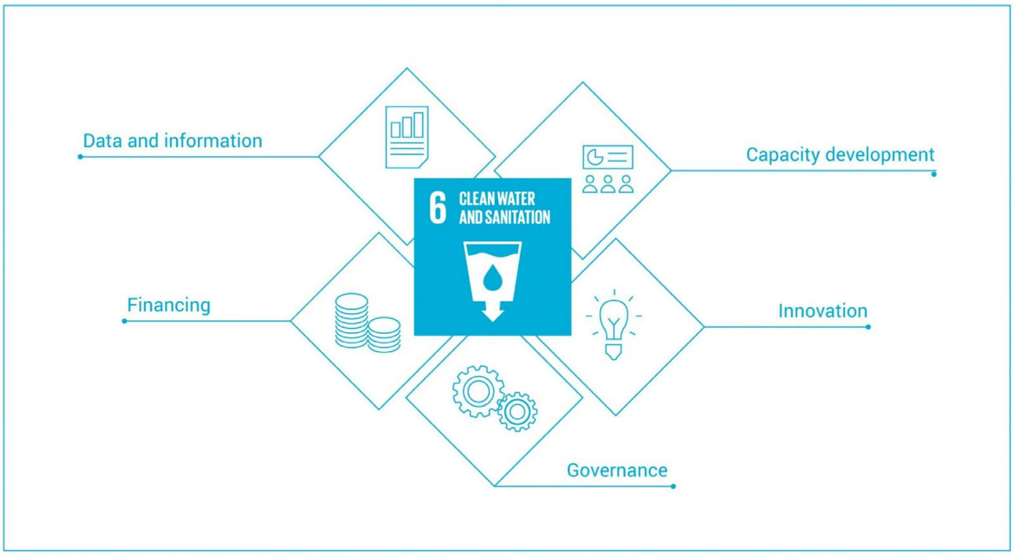

Figure 5 SDG 6 The five accelerators of the SDG 6 Global Accelerator Framework are critical to getting SDG6 on track (source: SDG indicator 6.3.2: Global updates and acceleration needs (arcgis.com))

Ultimately, ensuring access to clean water and sanitation for all is not just a matter of sustainability but also a fundamental human right essential for fostering inclusive growth and ensuring the well-being of current and future generations. Water is the basis of life, humans need it in order to survive and thrive. Thus teaching about this SDG is a necessity, and everyone should have access to information about it, making it all that more important that there are available and accessible educational materials available to all people related to this SDG. However, to the best of this author's knowledge, there are no tactile maps on SDG 6 for people with visual impairments, and there are only a handful of maps available for sighted users.

5 MAP CREATION

Once the background research on the content of the maps and accompanying documents was completed, work began on the second phase of the thesis work: the practical implementation of creating maps focused on SDG 6 using microcapsule paper. A few samples of maps with various techniques, layouts, and content focuses were developed for user testing in order to gain a better understanding of the best techniques to implement for the final series of maps. These map samples were tested with users during the creation of the map series to ensure the highest quality of the final product. After user testing was conducted, the results were analyzed and improvements were applied to the final series of maps and additional tactile graphics. The following sections go into detail about data processing, map creation, user testing, and map refinement. The documentation of this work can serve as a guide for others looking to create thematic tactile maps for use in the classroom. The resulting series can be downloaded online in its entirety or as individual pages according to the users' desires.

5.1 Data processing

For this thesis, a series of maps were created to display data for each of the 12 indicators for SDG 6. For indicator 6.6.1: Water Extent Changes, there was insufficient data for a map of individual countries or regions so a tactile chart was created instead in order to best display the information. In addition to these 12 maps, another seven maps were produced showcasing the average annual precipitation for each SDG region in 2020. As almost all of the complete data related to SDG 6 was from 2020, it made sense to use precipitation data from the same year. Creating maps for users with visual impairment requires a great deal of simplification and generalization. Consequently, a substantial portion of the time spent working on the practical portion of this thesis was spent on data processing which is discussed in the following sections.

5.1.1 Data sources

Much of the data for this thesis was sourced from official UN sources, including the UN-Water SDG 6 Data Portal and the FAO, with additional data from the Copernicus Climate Change Service. This thesis deals with three primary data types: tabular data for each SDG 6 indicator, vector data of country and regional borders, and raster data of global precipitation. The data source and license for each graphic are shown in Table 1.

Table 1 Data sources for all maps and charts.

Map #	**Region**	**Indicator/Focus**	**Custodian Agency**	**License**
1	World	SDG regions	FAO	based on UN map provided by United Nations Geospatial
2	World	SDG regions	FAO	based on UN map provided by United Nations Geospatial

3	World	6.6.1	UNEP	public
4	Central and Southern Asia	Precipitation	GPCP	GPCP (2024)
5	Central and Southern Asia	6.4.2	FAO	CC BY-NC-SA 3.0 IGO
6	Eastern and South-Eastern Asia	Precipitation	GPCP	GPCP (2024)
7	Eastern and South-Eastern Asia	6.1.1	WHO, UNICEF	CC BY-NC-SA 3.0 IGO
8	Eastern and South-Eastern Asia	6.5.1	UNEP	Public
9	Europe and Northern America	Precipitation (Europe)	GPCP	GPCP (2024)
10	Europe and Northern America	Precipitation (Northern America)	GPCP	GPCP (2024)
11	Europe and Northern America	6.3.2	UNEP	Public
12	Europe and Northern America	6.5.2	UNECE, UNESCO	CC BY-NC-SA 3.0 IGO
13	Latin America and the Caribbean	Precipitation	GPCP	GPCP (2024)
14	Latin America and the Caribbean	6.A.1	WHO, OECD	CC BY-NC-SA 3.0 IGO
15	Northern Africa and Western Asia	Precipitation	GPCP	GPCP (2024)
16	Northern Africa and Western Asia	6.3.1	WHO, UN-Habitat, UNSD	CC BY-NC-SA 3.0 IGO
17	Northern Africa and Western Asia	6.B.1	WHO, OECD	CC BY-NC-SA 3.0 IGO
18	Oceania	Precipitation	GPCP	GPCP (2024)
19	Oceania	6.4.1	FAO	CC BY-NC-SA 3.0 IGO
20	Sub-Saharan Africa	Precipitation	GPCP	GPCP (2024)
21	Sub-Saharan Africa	6.2.1a	WHO, UNICEF	CC BY-NC-SA 3.0 IGO
22	Sub-Saharan Africa	6.2.1.b	WHO, UNICEF	CC BY-NC-SA 3.0 IGO

As mentioned previously, tactile graphics for users with visual impairment require a high degree of data generalization and simplification as less information can be obtained through touch than through sight. To make the data presented in the maps as comprehensible as possible for the selected user group many rounds of simplification and generalization occurred. Editing the raw values of the downloaded data for each SDG 6 indicator in a spreadsheet editor was the first step in the simplification process.

5.1.2 Tabular data

The thematic content of this map series centered around the SDG 6 indicators. Data for each indicator was exported at the country level from the UN's SDG 6 data portal (Figure 6) in CSV format. The files were then processed in Microsoft Excel where non-essential data was deleted, country names were corrected, and data was organized. The raw values for each country were categorized into generalized groups of five or fewer. This threshold was decided as a result of the fact that much of the literature on microcapsule graphics suggests that this is the maximum number of textures that can be distinguished by touch. This conclusion was further reinforced during user testing.

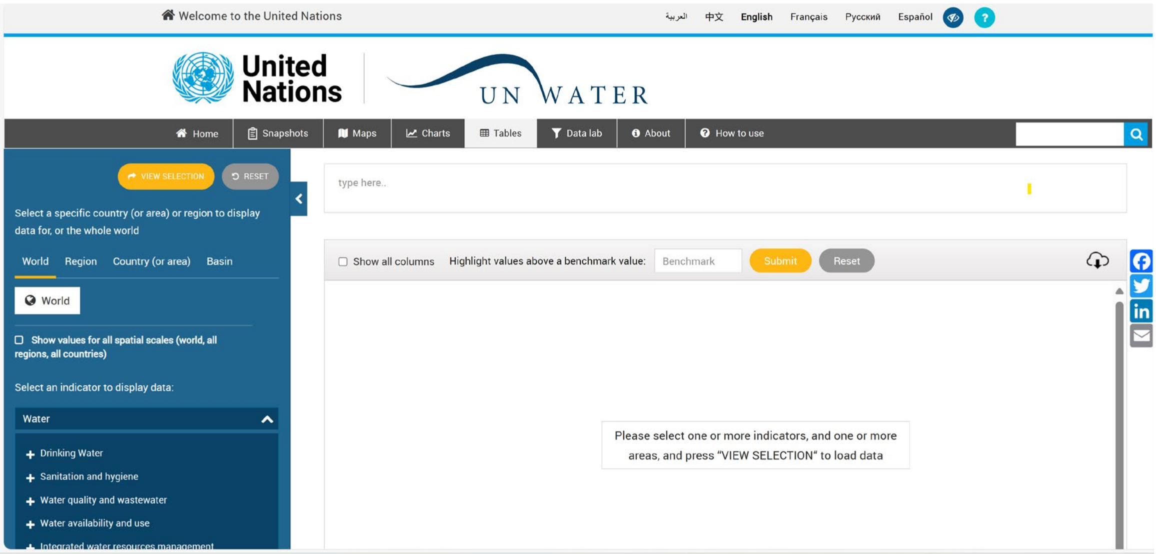

Figure 6 UN-Water SDG 6 Data Portal (Source: https://www.sdg6data.org/en).

Different indicators collected different types of data (i.e. percentages, raw dollar values, rankings, etc.). The raw values for each indicator were divided into high, moderate, or low value groups on an individual basis based on their type and range. Additionally, a category for "no data" was included for countries that did not provide data for certain indicators. The map showing water stress in Central and Southern Asia was the only map that deviated from this value scale as the FAO has pre-established five levels of water stress. Once the data had been cleaned and categorized it was imported into GIS software as a table to be joined to vector data of country and regional borders.

5.1.3 GIS data processing

Boundaries

Pre-processing of the borders involved accessing UN boundary files using the publicly available WMS (https://data.apps.fao.org/catalog/dataset/6aecaf08-c7d0-4e16-8778-b8dddae9da14) which provided layers containing the boundaries of countries and the SDG regions for the whole world. Firstly, all of the layers were projected into the Robinson projection in accordance with the advice of Eriksson et al. (2003), who recommended using an equal area map projection for tactile maps, and based on consultations with the thesis advisor. Secondly, the borders were generalized and simplified. The borders were initially generalized using the Simplify Polygon tool in ArcGIS Pro. The parameters of the tool were set to retain critical bends using the Wang-Müller algorithm, with a simplification tolerance of 100 kilometers and a minimum area threshold of 20,000 square kilometers. The chosen simplification tolerance adequately simplified the areas without distorting their shapes and maintained smooth, non-jagged borders that are conducive to tactile exploration while the minimum area threshold eliminated areas too small for tactile detection while retaining critical landforms. This was followed by additional generalization and simplification done through manual editing to address small areas (which were either removed or grouped into larger landforms), fix geometry issues, and smooth sharp corners.

Once the polygon layer was simplified, a table with data from a selected indicator was joined to the border layer based on the country name and exported as a new shapefile into a geodatabase. Countries belonging to the selected region of interest for the indicator were then selected and exported into a new shapefile. The final step in data simplification involved merging adjacent areas with common values using the Merge tool in ArcGIS Pro. Final adjustments for the layer were made manually using the editor toolbar in ArcGIS Pro to ensure correct form, and the layer was symbolized based on the value groups assigned during the data processing. Additionally, a white outline approximately 3 pt thick (which translates to about 1 mm) was applied to all groups in order to facilitate adding white space between textures in later steps in graphics editing software. This process was repeated for each indicator spreadsheet.

Precipitation

Given that the map series was focused on water and sanitation, maps on regional precipitation were created to allow users to familiarize themselves with each region and to give further context for the water situation in each region. The following steps were taken to transform precipitation data into a vector layer of annual precipitation using ArcGIS Pro so that it could be further designed in graphic editing software.

Initially, monthly precipitation data for the entire globe for the entire year of 2020 was downloaded in NetCDF format from the Copernicus Climate Change Service, which provides gridded precipitation data derived from satellite measurements. Subsequently, the Make NetCDF Raster Layer tool was used to import the Copernicus rasters into ArcGIS Pro. The Mosaic to New Raster tool was used to combine the monthly rasters into one raster showing the average annual precipitation values for the entire globe for the year of 2020. Using this tool involved adding all of the rasters from each month, saving them in a geodatabase without file extensions, and specifying parameters such as projection (Robinson), pixel type (32-bit float), number of bands (1), mosaic operator (Mean), and mosaic colormap mode (First). The resulting raster was then clipped to the regional borders discussed previously using Extract by mask. Next, the Reclassify tool was applied to categorize annual precipitation into four categories: minimal, low, moderate, and high. Following this, the raster was converted into polygons using the Raster to Polygon to, thereby delineating areas corresponding to the precipitation categories. Finally, the resulting polygons were smoothed and generalized using the Smooth Polygon tool, with parameters set to use the Polynomial Approximation with Exponential Kernel (PAEK) smoothing algorithm and a smoothing tolerance of 500 km. Manual edits using the editor toolbar in ArcGIS Pro were made to ensure the precipitation borders matched the regional borders.

5.1.4 Data selection

In this thesis, showcasing data at the appropriate scale was a crucial consideration. Since the data was provided at a country level, a larger area was needed to effectively display it, given that there would be no intra-country variations. Consequently, it was necessary to show multiple countries simultaneously to capture the values and variations. Moreover, attempting to display the entire globe for each indicator posed a challenge due to page size limitations conflicting with the need for larger map sizes for the target group. Thus, given the thematic focus on the SDGs and the requirements of the user group, the decision was made to utilize the Sustainable Development regions as the primary geography for presenting the data. However, due to time constraints, only one map of one region was produced for each indicator, along with a precipitation map for each region. There were challenges with the geographic coverage of the data, as most datasets had missing data for various countries. Therefore, the region with the most available data was selected for each specific indicator.

5.2 Map design

After creating the maps in GIS software, the maps were exported in SVG format and imported into Adobe Illustrator. In Illustrator, textures were added to the maps, and additional elements such as titles, map frames, and other page components were incorporated. Additionally, text pages providing introductory information and further context for the maps were designed within the same software.

5.2.1 Textures

Given that this map series used microcapsule paper and fuser technology, it was essential to design textures (patterns using only black ink) that would rise when heated in the fuser, giving the maps a tactile form. The final set of textures was selected for maximum distinctness and clarity based on user testing and expert consultation. All textures were created using Adobe Illustrator's pattern functionality.

Each precipitation map or indicator map depicted variations in the intensity of a single phenomenon. Therefore, the textures used for these maps needed a consistent fundamental design based on one shape. In this instance, a line was chosen. However, to represent changes in intensity, these line-based textures were varied by altering a specific variable, line spacing. Most thematic maps showing data related to an SDG 6 indicator used a three-part value grouping—low, moderate, and high—plus a category for no data, resulting in four distinct textures. These textures varied in line spacing: wider spacing indicated lower values and closer spacing indicated higher values. Areas with no data were left without texture to clearly show the absence of information. For the precipitation maps an additional texture was developed to represent the values present. The precipitation maps used a four-part value grouping—minimal, low, moderate, and high—

requiring four distinct textures. These maps used the same line textures as the SDG 6 indicator maps, with an additional small dot texture for the minimal classification (Figure 7). In both of these map types, the moderate classification texture was rotated 90° to help users distinguish between textures.

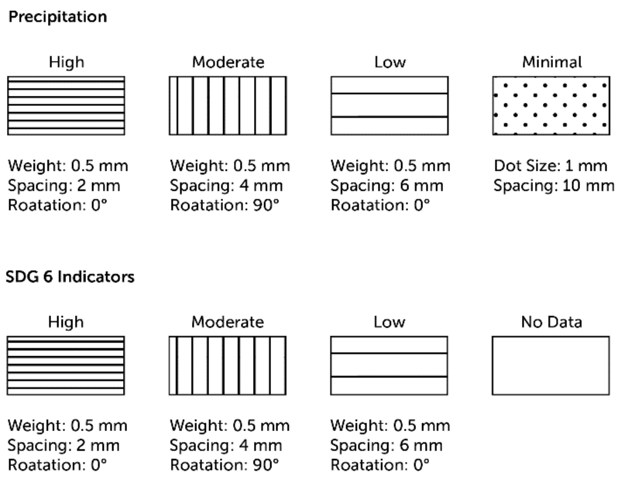

Figure 7 Textures for indicator and precipitation maps.

The maps and charts of the SDG regions required seven different textures (Figure 8), with each region needing a unique texture. Given that there was no relation between the areas being depicted there was a need to make each texture distinct from each other. Only two main shapes—lines and dots—were used to ensure clarity, as introducing more shapes made it difficult for users to differentiate them as became apparent in user testing. The textures varied in line orientation and continuity, resulting in five distinct textures: dashes at 0° and 90°, and lines at 0°, 45°, and 90°. All lines were 0.5 mm thick. The dot textures included 1 mm and 2 mm dots, chosen to ensure they would be big enough to rise in the fuser without becoming too large or bubbling.

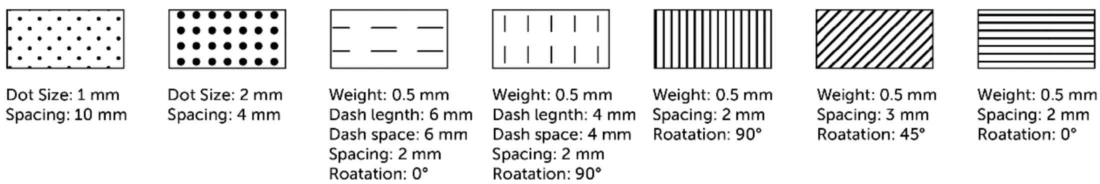

Figure 8 Textures for SDG Regions.

5.2.2 Colors

Given that the primary target group for this series of maps was primary and secondary school students, a bright color palette was designed to make the maps engaging and visually accessible. Bright, contrasting colors were selected to enhance visibility for users with some remaining sight. The colors (Figure 9) were chosen in consultation with the thesis advisor, with separate palettes created for each specific phenomenon (e.g., SDG regions, precipitation, etc.). However, these colors were not tested with users.

Figure 9 Color palettes used for various maps in the series.

Most of the maps used a four-part value grouping. Consequently, most maps of the SDG 6 indicators employed four primary colors (an exception was made for indicator 6.4.1, water stress, due to a pre-established value grouping) to indicate the severity of the phenomenon: gray for no data, red for low, yellow for moderate, and green for high. For the precipitation maps, the colors were slightly adjusted to reflect the separate phenomenon: red for minimal, yellow for low, green for moderate, and blue for high. For maps with additional values, such as the SDG regions maps, an expanded color palette was used.

5.2.3 Layout

The map series included five types of pages: maps or graphics, legends, map texts, indicator texts, and auxiliary texts (Figure 10). The layout of each page type was intentionally simple and standardized to enhance user navigation and understanding. For map pages, both landscape and portrait orientations were used to maximize map frame size and accommodate different region shapes. To assist users who have visual impairment, each page features an arrow in the top left corner indicating the correct orientation. Additionally, the map page displays a title and the year of the data at the top of the page, followed by a scale above the map frame. The largest part of the page is dedicated to the map frame. In the lower-left corner, text and braille indicate the page's section within the series, page type (map, legend, or audio), and map number.

The legend page maintains a similar layout, including an orientation arrow, title, and page identifier. However, it also provides the target and indicator of the data beneath the title, followed by the legend elements. These two pages are the only ones with tactile elements (though all pages include the page identifier in braille). Additional text pages provide context for the series and individual maps. There are introductory text pages, pages that introduce the indicators showcased in each section, and pages that precede each map to introduce it. While each type of page is distinct, their designs remain consistent within their respective categories. In addition, every text page also includes a tactile page identifier indicating the section and accompanying audio track number.

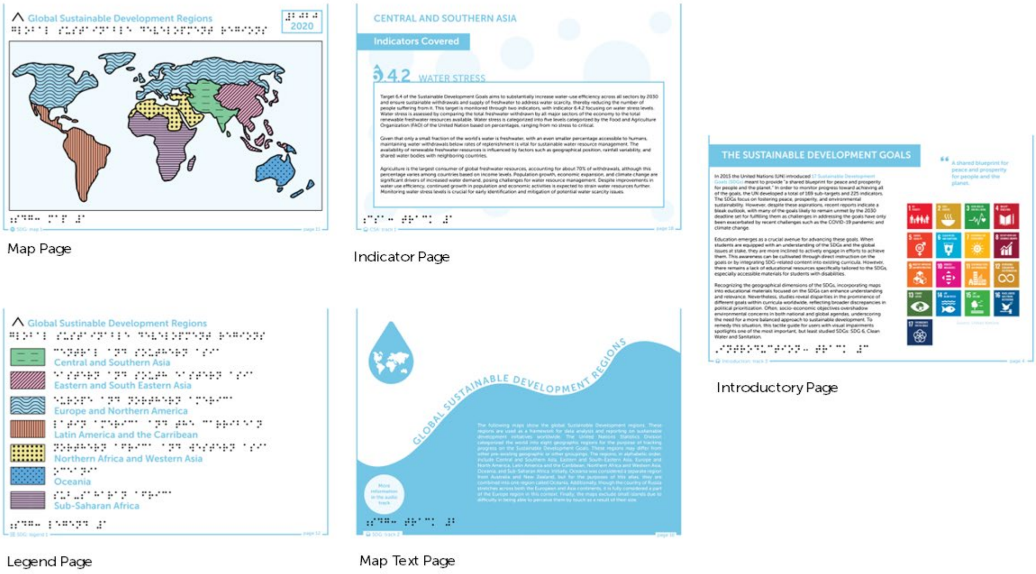

Figure 10 Examples of page types.

5.2.4 Text and Braille

All information on the page was presented in both tactile and visual formats whenever possible. Consequently, all textual elements were also provided in braille. The Museo font family was selected for textual elements in this map series and all accompanying materials due to its sans serif style, thereby enhancing legibility, and variety of styles within the family. Primarily, Museo with a weight of 500 was utilized for the text, while a weight of 700 was employed for titles, the year of data, and for emphasis. Two main font sizes were utilized: 12 pt and 24 pt. Size 24 was used for titles and years of data, as it was deemed the smallest size readable by users with visual impairments during user testing. Auxiliary information on the page, such as the scale, was presented in 12 pt to facilitate reading by sighted helpers. The Braille True Type font from the Royal National Institute for Blind People (RNIB) in size 24 pt was used for all braille elements on the page. Size 24 is a standardized size for braille font and must be used in order to ensure that users are able to read it (Braille Authority of North America & Canadian Braille Authority, 2012). Initially, a different braille font was employed, but issues arose with the numbering of braille characters, as they were slightly shifted downwards, hindering user comprehension (Figure 11). This concern was raised by Dr. Veronika Růžičková, an expert in tactile graphics and didactics. Upon the installation of a new font, this issue was promptly rectified.

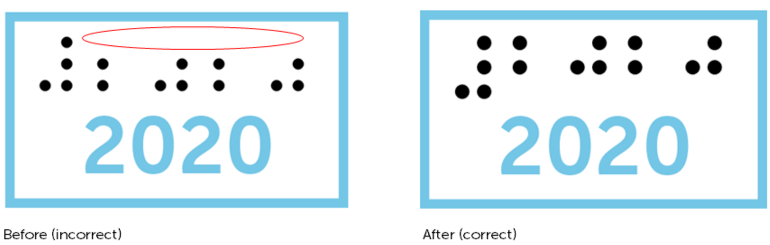

Figure 11 An example of the issue with the original Braille font.

5.3 User Testing

User testing consisted of a combination of both an interview and a questionnaire. Two rounds of user testing were conducted. For an overview of the demographics of the participants see Figure 12. The first round was held with two students at the Palacký University Olomouc in Olomouc, Czechia. Both students had some residual sight and had a bachelor's degree or higher in terms of educational achievement. The second round of testing was held at a school for the visually impaired in Prague, Czechia (Gymnázium pro zrakově postižené a Střední odborná škola pro zrakově postižené Praha) with four secondary school students, three of whom were completely blind while one had some residual sight. All of the users were between 17 and 29 years old. Most could read braille and had previous experience with tactile maps, though not necessarily with microcapsule maps. Half of the participants were blind while the other half had some residual sight.

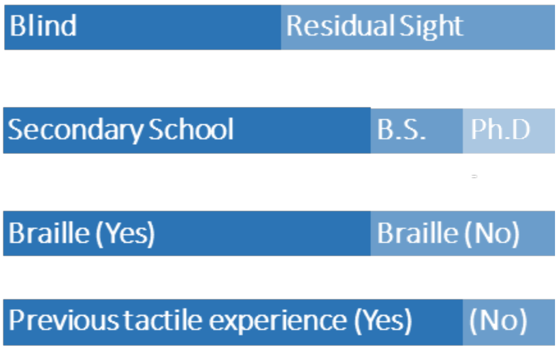

Figure 12 User testing demographics.

For the testing, users were presented with six tactile maps and a diagram of the water cycle all printed on microcapsule paper (Figure 13-15). Each user was asked a content-based question about every map or diagram in order to try and ascertain the effectiveness of the map design. After these questions, users were asked a series of twenty-four agreement statements about various aspects of the map content, page layout, and specific elements included on the page. In total users were asked thirty-one questions (see Appendix 1 for the questionnaire). Each test lasted around one hour, as the students were very motivated and took the initiative not only to answer the question being asked but to provide additional reasoning for their answer and suggest changes to better the outcome.

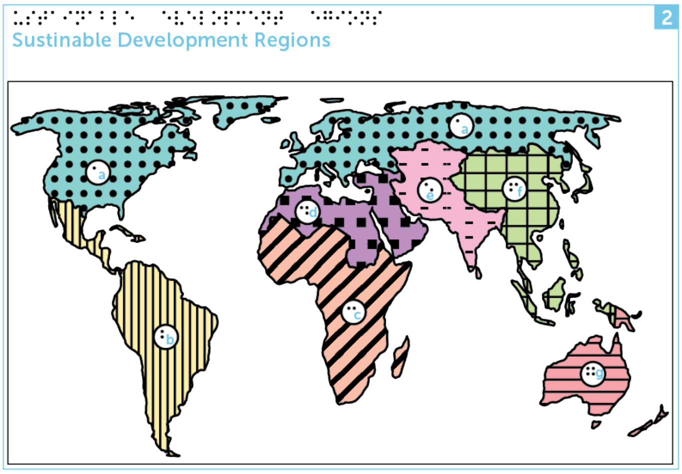

Figure 13 Map of Sustainable Development Regions used for user testing.

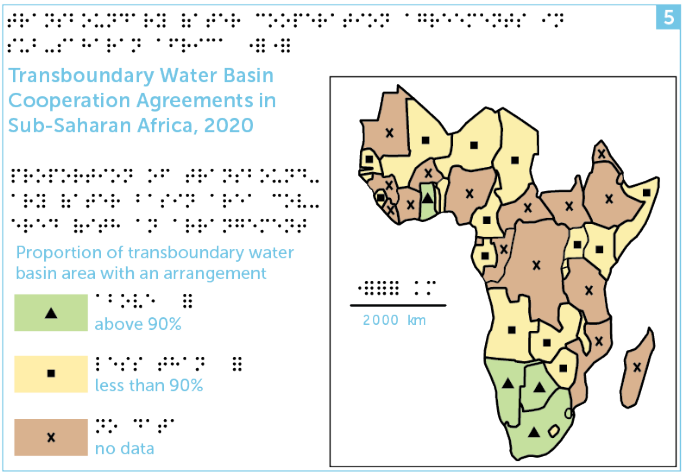

Figure 14 Map of Sub-Saharan Africa used in user testing.

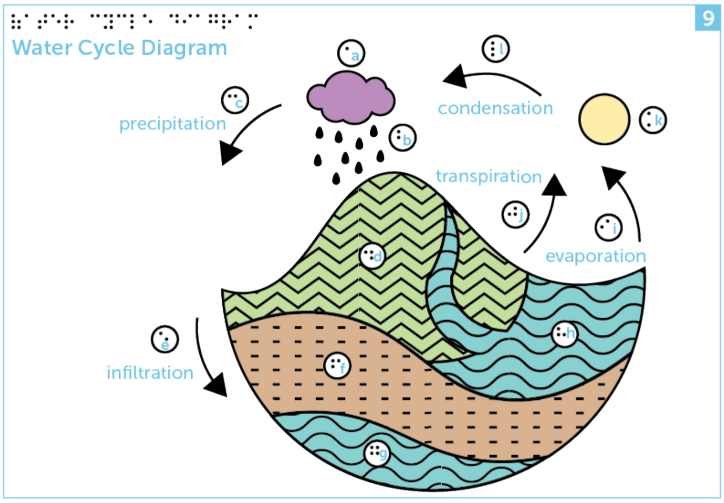

Figure 15 Diagram of the Water Cycle used in user testing.

5.3.1 User Testing Results

All of the users found the maps to be engaging and were excited about the possibility of interacting with environmental educational materials in this manner. However, while the maps worked well for users with some remaining vision, there were many difficulties that arose when using these initial maps for users who were completely blind. The main areas identified for improvement were the size of the maps, the complexity of the maps, and the distinctness of textures and symbols used in the maps.

The main concern with the sample of maps provided to the users was that they were too complex. This complexity was due to the amount and design of the textures used as well as the size of the map, as the small size of the maps only served to increase the complexity of the maps. For many users, there were too many textures on the maps; users expressed a desire to have five or fewer textures present in a map in order to best understand them. Moreover, of the textures used, many users felt they were not distinct enough to tell apart. In addition, there were often too many tactile elements competing for attention on each map. For instance, in the sample maps each country within a region not only had a tactile texture across its area indicating the value, but the country borders were also raised. This was a problem because many of the textures were based on lines of varying orientation and spacing, so the border lines and fill textures often conflicted with each other. Additionally, some of the smaller areas included in the map were not big enough to contain enough of a texture for a user to be able to determine the area's value.

Additional complicating features of the maps included the fact that in some of the maps and diagrams, circles with braille numbers were placed within textured areas to identify them in the accompanying legend. Users had trouble finding the braille identifiers and did not like that it interrupted the textures. The placement of braille lettering was of primary concern in the water cycle diagram (Figure 15), but users also had a hard time understanding the diagram overall due to the symbolic design of the diagram. Another element complicating the map design was the use of symbols on some maps (Figure 14). For many users, the symbols were too small and it was impossible for the users to distinguish the different shapes from each other. Lastly, the scale confused many users. The placement of the scale within the map frame was unexpected, hard to find, and sometimes mistaken for a part of the map and not a distinct element. Additionally, the scale was designed as a bar scale which simply identified a distance of 2,000 kilometers. The scale did not provide any additional comparative context as is usual with other types of linear or ratio map scales (i.e. 2 cm = 2,000 km or 1: 25,000,000). This led to the scale often being disregarded and users expressed a desire for a different type and design of scale.

Besides issues with the content and design of the maps, there were a few technical issues that arose during the testing as well. The black ink on each page smudged easily and the raised areas were quickly worn down so it became harder for subsequent users to see the maps well. Additionally, not all of the areas in black rose adequately or as evenly as was anticipation. This led to some confusion for the users when they were unable to feel all of the elements on a page or when the same texture felt different in different areas on the maps, leading them to conclude that the same texture was actually two different textures. After consultation with the thesis advisor and Dr. Růžičková, these issues were believed to be due to technological problems associated with the fuser, paper, or a combination of using a LaserJet printer and fuser in quick succession. To address this issue, a different printer and fuser, provided by the department, were used for the final printing.

In addition to the feedback provided by users, the maps were also discussed with the teachers of Geography at the School for the Visually Impaired in Prague. The teachers only introduced students who were completely or near completely blind for user testing as they felt confident that students with some remaining sight would be able to fully understand the maps based on their design. In regards to the students with some remaining sight, the teachers appreciated that the maps employed the use of color as most students have some residual vision and rely on distinguishing colors with their visual sense along with their haptic senses to fully engage with classroom materials. Overall, the teachers were appreciative of the effort to create environmental educational materials as there were no such materials available before and committed to using the maps actively in the classroom. Feedback was also received from an expert in tactile graphics and didactics, Dr. Veronika Růžičková, who was present during the user testing. Based on all of the feedback from these many different sources, some parameters of the tactile graphics on the maps were changed accordingly as is discussed below.

5.3.2 Map Refinement

Many changes were implemented to answer the concerns raised by the users during testing, to incorporate the feedback from various experts in education for students with visual impairment, and to better address the needs of the target user group (for examples see Figure 16-18). A complete set of recommendations based on the outcome of user testing and map production are provided in Chapter 6 Results.

The main concerns addressed were the size and complexity of the maps. To address the issue of the small map size the legend and map were placed on separate pages so that the map frame could be enlarged on the page, which was an arrangement that the users expressed preference for. Additionally, for some of the regions, the orientation of the page was rotated to be in portrait orientation based on the geographical shape of the region in order to maximize the size of the map. To help users orient themselves to the page layout, an arrow was added to the top-left corner for every page with tactile elements (Figure 17).

To reduce the complexity of the maps and increase user comprehension, the borders between countries were removed and adjacent areas of the same value were merged together to give a general geographic overview of where the phenomenon occurred in the region instead of on a country-by-country basis. Furthermore, extra white space was left between areas of different textures to signal to users a change in textures and aid in the tactile reading process. Finally, all maps were made to use textured areas instead of symbols as the symbols were hard for users to discern so they were completely eliminated from the maps. Based on consultations with the thesis advisor, the additional changes were also made. Greater geographic context was provided for sighted users by lightly coloring the land and water surrounding the region. In addition, braille and text were added to each page to help users identify the region being shown on the page and the type of page (i.e. map, legend, or audio) in order to allow users to best independently navigate the work.

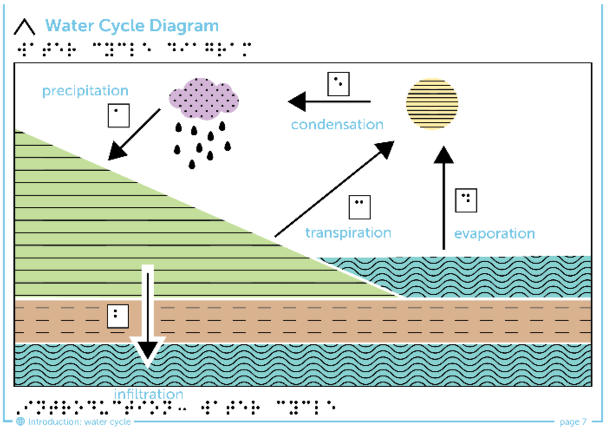

Figure 16 Updated diagram of the water cycle based on user feedback.

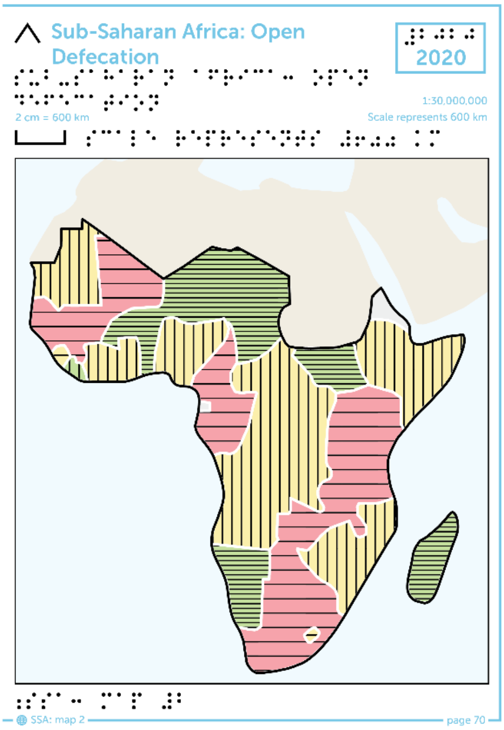

Figure 17 Updated map of Sub-Saharan Africa based on user feedback.

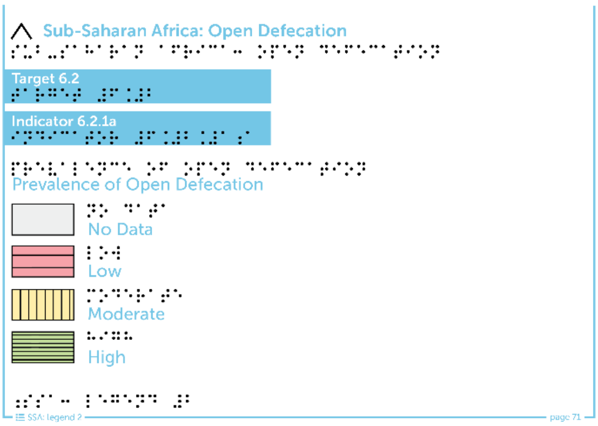

Figure 18 Updated legend for Sub-Saharan Africa map based on user feedback.

6 RESULTS

This section describes the results of user testing. It also details the final series of maps and the changes made based on the testing feedback, along with the production of additional materials produced to support the maps. Additionally, a section with recommendations for future users creating thematic tactile maps with microcapsule paper is included.

6.1 Results of user testing

Following research to determine the design requirements for microcapsule maps, a sample set of maps and a water cycle diagram were produced to implement the recommendations presented in the research in physical form. To evaluate the map designs, user testing was conducted. A questionnaire was developed to identify any issues users might encounter while using the maps (Appendix 1). This questionnaire included questions about the users' backgrounds, specific map-related queries, and a series of agreement statements regarding various aspects of the map pages and content.

User testing involved in-person assessments with six participants, employing both quantitative and qualitative methods. The outcomes of this testing included the identification of problems, improvements to the maps, and suggested design guidelines. Detailed user responses have been stored in the digital archive.

During testing, users were first asked specific questions about each map to determine if they could comprehend the content. The following chart (Figure 19) presents the results. The findings indicate that some maps were more easily understood than others. Users particularly struggled with the map of Sub-Saharan Africa (Figure 14) and the water cycle diagram (Figure 15) due to the size and placement of symbols and additional elements in both graphics. However, overall, most users were able to understand the maps, though users with some remaining sight had an easier time comprehending the maps than their blind counterparts.

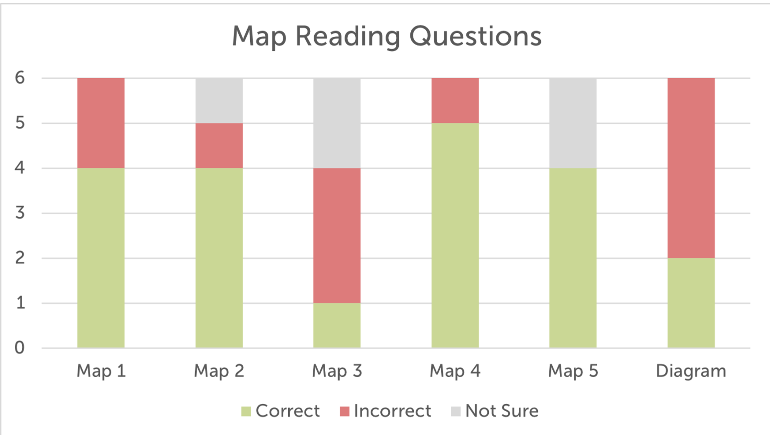

Figure 19 Results of user testing for map specific questions.

Users were also presented with twenty-four statements regarding the map content, page layout, and specific elements on the page, and were asked to rank their level of agreement with each statement. The results (Figure 20) showed that most users were generally satisfied with the layout, finding that it included all necessary elements, did not include superfluous elements, and was easy to navigate. However, users encountered difficulties with the map content, often finding it too complex, and noted that many of the textures and symbols were not distinct enough. Additionally, while the majority of the page elements were well-received, there were issues with the size and placement of certain elements. A significant problem identified was the size of the symbols used in the Sub-Saharan Africa map (Figure 14). These symbols were too small, hard to locate, and not distinct enough. Consequently, these symbols were removed from the final map series, and textures were used instead to delineate and identify different areas.

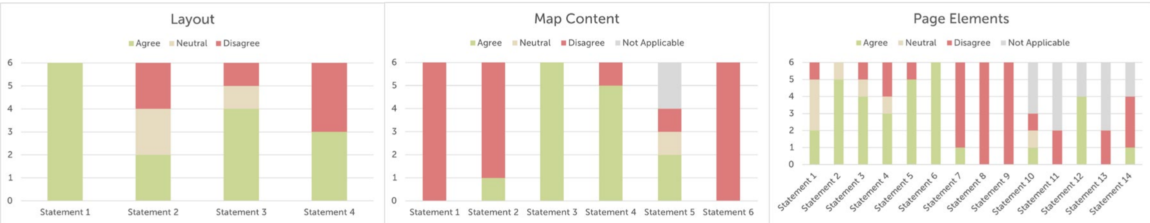

Figure 20 Results of user testing for agreement statements on different map aspects.

6.2 Results of analysis

In accordance with the stated aims of this thesis, a series of 21 maps presenting SGD 6 was created along with additional supporting materials including one chart, a diagram of the water cycle, and explanatory texts and audio files. The entire series of maps along with all of the supporting materials, including audio files, are available for download as a complete work or as individual maps from a publicly available website created as part of this thesis work.

As a result of numerous consultations with the thesis advisor, Dr. Alena Vondráková, and an expert in tactile graphics and didactics, Dr. Veronika Růžičková along with the feedback received from user testing, many changes were made to the final map design. The changes are summarized below. For more detailed information on the changes made see chapter 5 Map Creation.

The primary change was separating the legend and map frame into two pages, which allowed the size of the map frame to be increased, thus enhancing tactile comprehension. Additionally, some maps were reoriented from landscape to portrait to better fit the geographical orientation of the regions depicted. This split introduced many additional changes to both the map pages and the legend pages which are as follows. Tactile arrows were added to the top-left corner of each page with tactile elements to aid in user orientation. To address the confusion related to the design and placement of the scale, the scale was redesigned and placed outside of the top-left corner of the map frame. Additionally, while a word scale was provided in Braille, additional means of expressing the scale value were provided in text form for sighted users, ensuring that sighted helpers could assist users with visual impairment if needed. Lastly, with more space available on the legend page as a result of this split, information identifying the target and indicator numbers of the data shown was added.

As a result of the unfavorable opinion of using symbols to identify areas, symbols were eliminated in favor of using textures to delimit different areas. For the thematic SDG 6 content, three textures with 0.5 mm lines of varying spacing were used to represent different intensity levels. In addition, the moderate-level texture was rotated 90° to enhance its readability as users sometimes struggled to differentiate between high and moderate textures, especially in small areas. For the maps and graphics that did not rely on the three-level value scale (e.g. precipitation maps), additional textures were created. Textures were designed to be as distinct as possible. During user testing, it was found that textures with small dots, dashes, or squares felt similar when fused, despite their visual distinctiveness. As a result, new textures were developed by altering line orientations or significantly varying dot sizes. The final change made to enhance the distinctiveness of map textures and user comprehension was to remove the tactile country borders. Instead, adjacent areas with the same values were merged, and white space was left between areas with different textures to help users identify a change in texture.

Accompanying Information

Another significant aspect of this map series is the inclusion of additional explanatory texts to introduce the map series and each tactile map or graphic individually. Research conducted on the SDGs and SDG 6, detailed in Chapter 4 Map Content, informed the creation of introductory text pages and explanatory texts for each map. The introductory section includes texts on the SDGs, SDG 6 specifically, a tactile diagram of the water cycle, as well as information on how to navigate the series. Each subsequent section related to an SDG region is introduced by a text on the indictor(s) covered in that section and each tactile map was preceded by a short text explaining the general trends found in the following map.

These texts were then converted into audio recordings using the free Microsoft application Any Text to Voice in MP3 format. There are audio recordings available for every text page though the audio recordings include slightly more information than the text pages as they often introduce the title, year, and scale of the map as well. Each text page also identifies the corresponding audio track in braille, enabling users with visual impairment to select the appropriate audio track. Overall, there were five types of pages: maps or graphics (i.e. diagrams or charts), legends, map texts, indicator texts, and auxiliary texts (e.g. introductory texts or the data sources page). The layout for each page type was standardized to provide a cohesive appearance to the series and facilitate user comprehension. Finally, a website was developed using HTML5 to enable users to access and download all materials.

6.2.1 Recommendations

In addition to the series of maps produced for this thesis, a list of recommendations on technical specifications to consider when creating thematic microcapsule maps was developed and is provided here for later users who want to create tactile thematic maps of their own.

Braille

Creating thematic tactile maps requires careful attention to both visual and tactile elements to ensure accessibility for users with visual impairments. Incorporating both visual and tactile components is crucial, considering that many students with visual impairment have some remaining sight. One critical way to convey information to users with visual impairment is through the incorporation of braille text on a page. Font specifications are important for readability in regard to braille. It is recommended to use size 24 font (Braille Authority of North America & Canadian Braille Authority, 2012). The Texas School for the Blind and Visually Impaired maintains a page of Braille fonts for English that are reliable and free. They can be accessed at the following address:

https://www.tsbvi.edu/campus-resources/accessibility/braille-and-asl-fonts). It is crucial that all the braille text present on a page is the same 24 pt size in order to ensure users comprehension. Additionally, went writing in braille it is important to remember that numbers one through ten in braille are represented by the letters A through J, preceded by a special symbol (Figure 21).

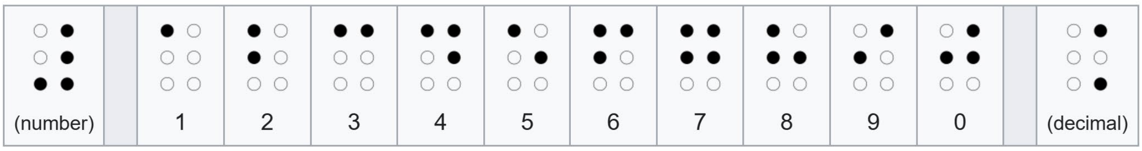

Figure 21 Braille numbers must be preceded by a special character to specify that what follows is a number (source: English Braille - Wikipedia).

Finally, when using braille numbers to identify elements in a tactile graphic it is best to place the braille within a shape with a plain, solid background and a thin tactile outline of 0.5 mm. This can help users more easily identify the braille number without interfering with comprehension of the number. Based on user feedback it is suggested to use a rectangular shape at least 8 mm wide, though preferably 10 mm wide, which mimics the shape of a braille block. It is important to place the braille number close (within 3 mm) to the element it is identifying or use leader lines to connect the number to the element to which it is referring.

Tactile Elements

In terms of tactile elements, simplification and generalization are key principles. Map design should prioritize simplicity and size, with the map being as large as possible on the page. The map frame should be outlined tactilely to ensure that users can find the frame. Using a 0.5 mm thick outline is significant enough to be felt without overwhelming other elements on the page or the map. Moreover, within the map, smooth curves should be favored over jagged edges and white space should be used to delineate areas with different textures instead of tactile lines which can conflict with textures. In addition, the number of textures used in one map should be kept to a minimum (five or fewer textures in any one graphic). To aid in this, it is suggested to reduce the number of categories present in the data in favor of fewer broad groupings as this will lead to the reduction of the number of necessary textures on the map for users. Finally, ensuring texture consistency between the legend and map is crucial as sometimes textures no longer correlated to their legend items when textured elements are moved. Rasterizing textures in Adobe Illustrator or another graphic editing software is one possible way to ensure consistency between maps and legends.

Regarding the development of textures, texture design should involve using distinct shapes with different orientations and/or spacing. It is best to avoid using small shapes in textures that might feel similar when put through the fuser. For instance, small circles, dashes, and crosses all feel similar when heated. Overall, it is a good idea to avoid small elements that may swell during fusing; symbols must be larger than 3 mm to avoid this. For lines, the lines should be no less than 0.5 mm to ensure they can be felt after fusing and no more than 2 mm to avoid bubbling, though 1 mm is usually a sufficient thickness for important features. See Figure 22 for the test sheet that was used to determine the best parameters to ensure the best tactile experience for various elements on microcapsule paper.

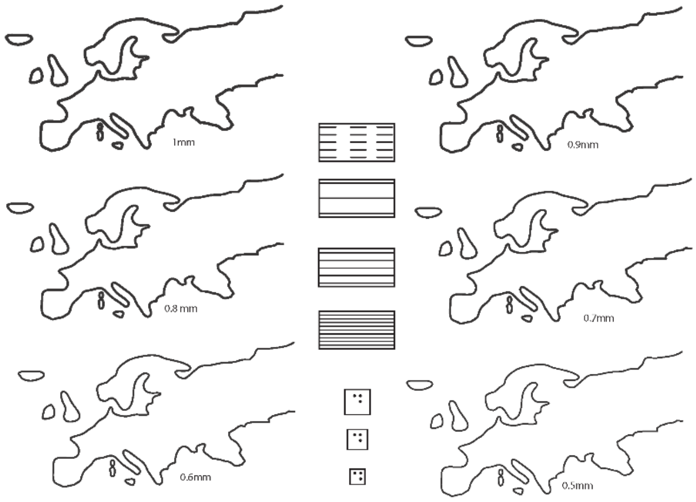

Figure 22 Test sheet used to determine optimal size and thickness for various tactile elements on microcapsule paper.

For additional page elements that are tactile but not included in the map frame, such as titles, scales, or page numbers, align the elements to one side, preferably the left, in order to facilitate identification and navigation for users. Effective scale bar design and placement are crucial for enhancing user comprehension of the maps and ensuring they utilize the scale appropriately. The scale should be placed outside the map frame and under the title to avoid confusion with other elements and ensure it can be found. The design of the scale should be distinct and not easily confused with other map elements. If using a line for both the scale and a texture, ensure that the scale has additional design elements to distinguish it from the texture. It is also a good idea to provide many different types of map scales to appeal to the widest audience possible, though users generally preferred ratio map scales. For an example of all the recommendations discussed above being implemented in a tactile map see Figure 23.

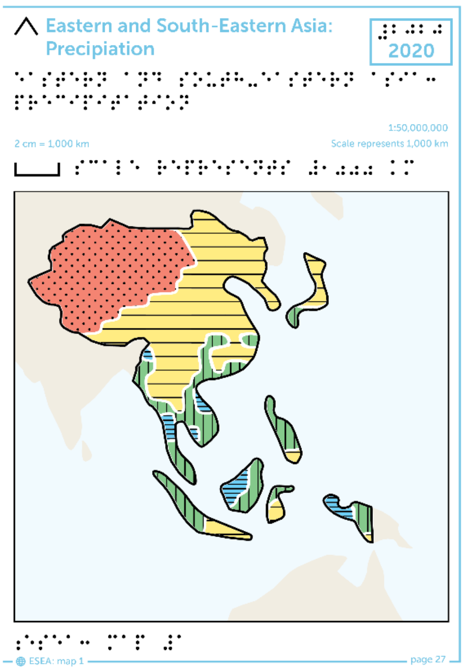

Figure 23 An example of a tactile map implementing the recommendations produced as a result of this thesis.

Additional Considerations

When creating a series of tactile maps or graphics intended for binding, it is advisable to arrange the pages in a manner that prevents tactile pages from facing each other. This precaution helps prevent the black ink on the microcapsule pages from rubbing off onto each other. Additionally, users who are blind or have visual impairments need to explore tactile graphics on a hard surface to fully feel and navigate the page. Therefore, it is recommended to use a binding method that allows for easy removal and reattachment of pages.

Finally, it is important to consult with both users themselves, teachers of students with visual impairment, and experts in tactile graphic creation. Only by incorporating feedback from all of these groups is it possible to accurately and effectively identify and address the needs of users with visual impairment. By adhering to these recommendations, thematic tactile maps can be effectively designed to meet the needs of users with visual impairment.

7 DISCUSSION

While creating the series of maps, a variety of different issues arose. It became apparent during user testing that there were significant design issues related to the specific needs of the target user group and technological considerations of microcapsule paper. These issues were taken into consideration and addressed in subsequent map refinement for the production of the final map series. The resolution of these issues along with other key decisions made while producing the map series are explained in this section.

Target group of users

The map series was developed for a diverse user group: persons who are blind or have visual impairment. This meant that the maps had to meet the needs of people with varying levels of visual ability and tactile needs. Users who have no vision would be satisfied with a completely tactile map without color or additional textual elements. However, these visual elements help users with some remaining sight. Bright, contrasting colors and large text elements are vital for users with some remaining sight. Moreover, blind users are often aided by sighted helpers when interacting with educational materials. Thus, both tactile and visual elements needed to be incorporated into the map design. As a result, the map design had to be generalized to fit the needs of a diverse target user group, rather than be tailored to a small subset of users.

The lack of materials

No other work of this scale or topic (a series of thematic tactile maps, specifically on the SDGs) is currently available. Finding research material or educational materials related to both the creation of microcapsule maps and the geographic nature of the SDGs was difficult. Overall, there is a general lack of available geographic and environmental resources on the SDGs, especially in a format that is accessible to users with visual impairments. Moreover, there is very little research on the creation of thematic tactile maps; most tactile maps and research on them relate to navigation and orientation. The thematic aspect of this series was novel which made it necessary to solve a number of problems and make decisions on how to make a product best suited for the user group. Consequently, the production of maps for this thesis relied on studies related to tactile graphics in general. The recommendations presented in these studies were then adapted specifically for tactile maps throughout the process of the thesis.

User testing

The timeline for user testing was limited as was access to users who matched the specific user criteria, which resulted in user testing being conducted with only six participants. However, this lack of quantity of users does not translate to a lack of quality. The nature of the user testing meant that the results were not necessarily quantitative, but rather qualitative, which provided a greater amount of information on the user experience. Each participant was interviewed and asked questions from a thirty-one-question survey. In their responses, users not only answered each question directly and succinctly but also expanded on their answers oftentimes explaining the issues they encountered or providing suggestions for improvements. This resulted in the user testing being an extremely time-intensive process, with each interview lasting over an hour. The consistency of responses and repeated suggestions for improvements indicated that a larger sample size might not have yielded different results, reinforcing the reliability of the feedback. Moreover, while it was a small group of users, it was representative of the larger target group in terms of age, educational level, and type of visual impairment.

A final note on user testing: due to the nature of the type of visual impairment the participants were experiencing it was not possible to test and receive feedback on the colors employed in the map series. However, another student completed testing concurrently and examined the color preference of people with visual impairment, the result of which can be accessed here:

https://www.geoinformatics.upol.cz/dprace/magisterske/cech24/

Generalization

The guiding principles of tactile graphics are generalization, distinctiveness, and simplification. It is harder for users to distinguish different elements through touch than through sight and they cannot absorb as much information haptically. Too much information, too many elements, or elements that are not distinct enough impede the users' ability to comprehend the map. Initially, generalization and simplification were carried out by broadly categorizing the data which reduced the number of textures involved in the maps. Additionally, the boundaries of regions and countries were greatly generalized, and small landforms were removed. However, during user testing, it became apparent that this was still an insufficient level of generalization. Moreover, adding tactile borders to outline each country impeded comprehension. After consultation with tactile maps and graphics expert, Dr. Veronika Růžičková, and the thesis advisor, Dr. Alena Vondráková, many adjustments were made to the design of the maps to make the elements simpler and more distinct to aid in user comprehension. As a result, for the final maps, country borders were removed, adjacent areas with the same value were merged, and white space was added between different textures to make transitions more distinct. In addition, some textures were changed to make them more distinct.

Page Size

The A4 paper size was chosen based on consultations with the thesis advisor, as it is the most commonly used size of microcapsule paper by the target group. However, this size limited the map dimensions. In the initial samples, the legend and map were on the same page, reducing the available map space. Users expressed frustration with the map size and preferred having the legend on a separate page. Consequently, in the final series, each map's legend was placed on a separate page, allowing for a larger map. For some regions, the orientation of the page was changed from portrait to landscape to better fit the geographical layout and maximize display size.

Future work

There is a plan to publish this series of maps as an online book which will include additional introductory and contextual information, expanding on what is currently available in the map series. However, the map series, as it is now, stands on its own as a usable and valuable resource. Future work to improve the map series and adapt it into a complete book will involve collaboration with co-authors who are experts in the fields of geography, education, cartography, and tactile graphic production.

8 CONCLUSION

The goal of this thesis was to create **a series of tactile maps for people with severe visual impairment presenting Sustainable Development Goal 6: Clean Water and Sanitation.** The goal of this thesis was accomplished as documented in Chapter 5 Map Creation. The initial part of this process was spent researching both the technical aspect of microcapsule map creation and the content of these maps. Research revealed a general lack of mapping resources focused on the SGDs, with even less material available on SDG 6 despite its importance to human survival and thriving. In this respect, the creation of this series of maps was novel.

Based on this research, a sample of maps was created using GIS and graphic design software. **Data was sourced from the official UN-Water SDG 6 Data Portal as well as from the Copernicus Climate Change Service**. Simplification and generalization of the data took place using Microsoft Excel and ArcGIS Pro. The final layouts and design of textual elements were created using Adobe Illustrator.

These maps were subsequently used in **user testing which was conducted with students with severe visual impairment from Palakcý University Olomouc and the School for the Visually Impaired in Prague**. The results of user testing revealed areas for improvement in regard to the maps, with the main concerns being the size, complexity, and distinctiveness of the presented materials. These issues were addressed and a final product of a series of tactile maps on the sixth SDG was produced.

The final series of maps includes 21 maps showcasing precipitation data and data related to each of the 12 SDG 6 indicators. The series is divided into nine sections: an introductory section, a global section introducing the SDG regions used for reporting progress on the SDGs, and one section for each sustainable development region. A tactile graphic of the water cycle is also included to help provide a more holistic understanding of this Goal. Each tactile map or graphic is accompanied by a tactile legend and an explanatory text.

This series includes elements for both fully-sighted users and users with visual impairment. In addition, each map is introduced **by a short text which is also available in audio form**, in order to make the contents of this series as accessible as possible. All of the contents produced for this series are **available freely online** to the general public so that they can be downloaded and printed or listened to at home. Users are able to download the entire work or just selected maps depending on their needs.

The products of this thesis can all be printed by any user, however, the **pages with tactile elements need to be printed on special microcapsule paper** and then inserted into a fuser where the parts in black ink are heated causing the black areas to rise into tactile form. The results of this work should **help students with visual impairments gain geographic and environmental knowledge on par with their fully sighted counterparts**. This work serves as a documentation of the process of creating tactile maps and provides recommendations for best practices when creating thematic tactile maps on environmental topics which can be used for further creation of similar tactile works.

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LIST OF ATTACHMENTS

Digital attachments:

Attachment 1 Map series (SDG6_maps.pdf)
Attachment 2 Questionnaire (SDG6_Questionnaire.pdf)
Attachment 3 Digital archive (Mulder.zip)

Free attachments:

Attachment 4 Poster

Digital Data Structure

- Thesis Text
  - PDF
- Input_Data
  - GIS
  - Tables
- Output_Data
  - Map Series AI
  - Map Series PDF
  - User Testing
  - Texts
  - Audio
- Web
  - assets
  - audio
  - docs
  - images
  - maps
  - pages
  - texts

APPENDICES

APPENDIX 1

USER TESTING SURVEY

1. **Time and date of testing:**
2. **Name:**
3. **Age**
   __ 1 – 12 __ 13 – 17 __ 18+

   Specific age if provided:

4. **Sex**
   __ Female __ Male __ Non-binary __ Prefer not to answer
5. **Highest educational achievement**
   __ Primary School __ Vocational School __ Secondary School __ Bachelor's Degree
   __ Master's Degree __ Ph.D. __ Other:
6. **What type of visual impairment is the user experiencing?**
   __ Blindness __ Low vision __ Color blindness __ I do not know
7. **Can user read braille?**
   __ Yes __ No __ I do not know
8. **Does the user have previous experience with tactile maps**
   __ Yes __ No __ I do not know
9. **Please describe user's previous tactile map experience (how often, what type, content focus, etc.)**

10. **Does the user have previous experience with microcapsule paper**
    __ Yes __ No __ I do not know

MAP SPECIFIC QUESTIONS

11. **How many Sustainable Development Regions are there?** Page 2: SDG Regions

12. **What is the most comment level of water stress in Central and Southern Asian region**

    Page 4: Water Stress in Central and Southern Asia

    __none (žádný) __low (nízký) __ medium (střední) __high(vysoký)

    __critical (kritický) __I don't know (nevím)

13. **How many countries in Sub-Saharan Africa have more than 90% of their transboundary water basin areas covered by water cooperation agreements?**

    Page 5: Water Basin Cooperation Agreements

14. **Which level of precipitation did most of Latin America and the Caribbean experience in 2020**

    Page 6: Annual Precipitation in Latin American and the Caribbean

    __ High (vysokà) __Moderate (mírnà) __Low (nízkà) __Minimal (minimàlní)

    __ I do not know (nevím)

15. **How many of the countries in Sub-Saharan Africa have between 0 and 50% of their population with access to basic handwashing services at home?**

    Page 8: Proportion of Population in Sub-Saharan Africa with Basic Handwashing Service at Home

    __None (žádný) __Half (polovina) __Most (většina) __ All (všichni)

    __ I do not know (nevím)

16. **What are the step of the water cycle described in the diagram?** Page 9: Water Cycle Diagram

    __ mrak __kapky deště __srážky __hora __infiltrace __půda __podzemní voda

    __řeka a ocean __evaporace __ transpirace __slunce __kondenzace

    __ I do not know (nevím)

RATING QUESTIONS

LAYOUT

	Disagree	Neutral	Agree	Not applicable
17. The layout of the page is well organized				
18. The layout of the page contains all necessary elements				
19. The layout of the page is confusing				
20. The layout of the page contains unnecessary elements				

ELEMENTS

	Disagree	Neutral	Agree	Not applicable
21. All of the textures used in the maps are distinct				
22. The maps have too many textures				
23. All of the colors in the maps are distinct				
24. All of the text on the page is legible				
25. The text on the page is a good size				
26. All of the braille on the page is legible				
27. The braille on the page is a good size				
28. The title properly describes what is being shown				
29. All the necessary information is included in the legend				
30. The map is a good size				
31. The scale was useful for comprehension				
32. The symbols on the page are legible and distinct				
33. The symbols are a good size				
34. The symbols are well positioned				

MAP CONTENT

	Disagree	Neutral	Agree	Not applicable
35. The maps are easy to read/understand				
36. The maps are informative				
37. The maps include a good amount of information				
38. The maps are too complex				
39. The maps are engaging				
40. The maps have too much content				

GENERAL QUESTIONS

41. Do you have any additional comments about the maps and/or graphics?