

# WWTPViz: A Visualization Tool for Global Wastewater Treatment Plants

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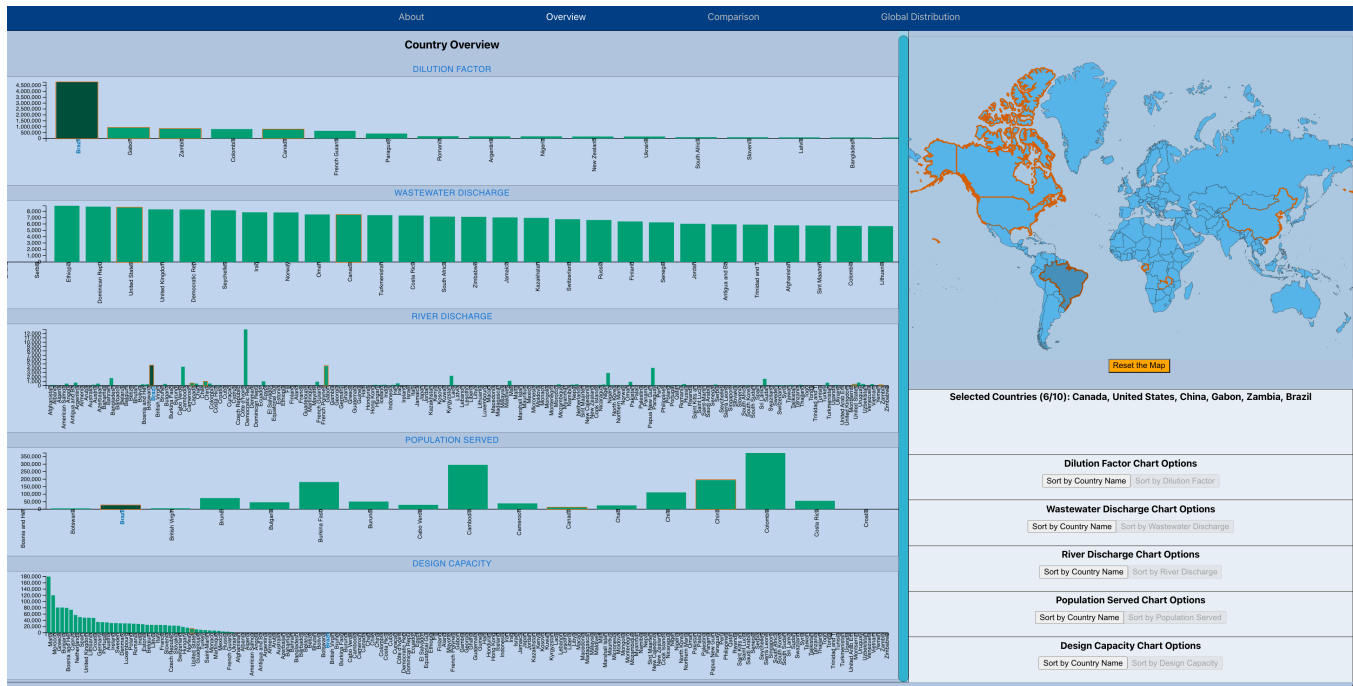


Figure 1: Screenshot of the overview page of WWTPViz, available at <https://github.com/mikeyin97/547Project>

## ABSTRACT

Wastewater treatment is a multi-step, complex engineering process that involves the removal of chemical contaminants from water, making it safe for human use. Despite its important role in human health, information regarding wastewater treatment plants (WWTP) has largely been scattered in the past - information regarding wastewater treatment plants has only been recently aggregated into a global dataset. This presents a ripe opportunity for visualization; as such, we develop WWTPViz, a visualization tool for global wastewater treatment. Developed using React.js and d3.js, this web-based dashboard allows users to easily perceive and understand country-aggregated WWTP metrics, affording opportunities for comparison and overview. In this paper, we discuss the implementation of our solution, highlighting specific features that increase usability of our system. We furthermore consider the strengths and weaknesses of our dashboard, and finally, we consider the limitations of the tool and possible future extensions.

## 1 INTRODUCTION

Water pollution from industrial chemicals has become a rapidly pressing concern for the global society. Pollutants arising from

chemical agents can have significant, long-term deleterious effects on human water consumption, marine life, and climate change - salvaging our water sources requires a massive effort on the part of environmental and economic policy [12]. One important facet in addressing the water pollution crisis is that of water purification. Pollutant-contaminated water is coined as wastewater, and the purifying process of removing the solids in wastewater is termed wastewater treatment [25]. Wastewater treatment is a complex and ever-evolving process that may involve a number of steps involving the physical removal of solids, decompositions of minerals through chemical interactions, membrane technology to separate based on molecular weights, etc [5, 14, 25]. Globally, wastewater treatment presently takes place on-site at highly specialized facilities called wastewater treatment plants (WWTPs).

Although WWTPs all share similar goals of water purification, they vary greatly in terms of design and treatment processes, which vary depending on regulation and requirements. For instance, country-level regulation and industrial processes can affect both the needs for wastewater treatment as well as specific requirements for technology and innovation [22]. The consequences of urbanization and population growth in a rapidly changing world have also affected

the need for WWTPs to provide safe and sufficiently abundant drinking water [28]. As the needs of each community served by a WWTP can vary, WWTP themselves can vary by a number of different metrics, such as the number of people served, treatment efficiency, energy efficiency, etc [19, 24]. Certain WWTPs may also run into a variety of different challenges, mainly revolving around energy usage and process demands [11].

A recent dataset released by Ehalt Macedo et. al. provides global metrics regarding WWTPs, including their geometric locations, population served, etc [8]. The researchers additionally provide an initial exploration of the dataset, highlighting the relationship between WWTP metrics and the river basins along which they are located. However, we find that the current analysis is rather esoteric, and that this dataset provides the potential for any user to understand and perform analysis on WWTP metrics. The recency of this published dataset, coupled with the importance of the application, motivates our present proposal. In terms of personal expertise and motivation, none of our group members have any particular research tie into the area, but we identify it as a pressing issue within our lives, and something that we share an interest in exploring.

Our primary contribution in this project is WWTPViz - an interactive dashboard tool to visualize and compare the efficiency metrics and degree of treatment for global wastewater treatment plants. Our target audience for the tool are researchers and policy-makers that want to understand WWTP metrics at a national level, especially how the metrics for specific countries of interest might compare to each other or fit within the broader context at a global scale. Beginning with data and task abstraction, we decomposed the complex, high-level problem into a more workable, specific set of requirements. Based on our requirements, we would build out our visualization tool, which primarily focus on abstracted tasks of overview and comparison. More specifically, our tool allows users to understand wastewater treatment statistics at a per-country basis at a glance, allowing more fine-grain navigation through zoom and pan functions and detailed comparisons between countries through juxtaposition and linking. Specific design decisions, such as cross-page linking, selection of encoding, and colour scheme choices, are outlined in detail in the paper. We additionally provide exploratory use cases of our tool, discuss the strengths and weaknesses of our design, and reflect upon lessons learned during the process.

## 2 RELATED WORK

In order to contextualize the scope of our vis design, we consider past research into ecological assessments, WWTP data visualizations, geovisualization, and interactive designs.

### 2.1 Existing Ecological Assessments

There have been significant efforts in both academia and governments to assess the impacts of wastewater effluent on ecosystems and biodiversity. Researchers examine factors such as the ratio between the discharge of WWTP effluent and the natural discharge of the nearby water bodies to provide better regulations of WWTP outflows [16]. Other studies require consistent and comparable geospatial data of WWTP in water quality modeling to identify the source of pollutants discharged into the water cycle [8]. Municipal

wastewater treatment is also of great concern in environmental protection planning. The Canadian government reports the population served and discharge volume of WWTPs annually to analyze the level of wastewater treatment and risk of wastewater contaminates at a national scale [18]. However, WWTP-related vis is lacking in academic papers and government publications except for statistical analysis results and simple graphics like static visualization of a single attribute.

### 2.2 Existing WWTP Data Visualizations

Our work builds on HydroWASTE, a global database of 58,502 WWTPs and their characteristics published by researchers from McGill University in 2021 [8]. HydroWASTE is the first database to combine all regional data worldwide and include derived attributes missing in the source datasets [8]. Ehalt Macedo et al. focus on documenting how they manipulate and augment datasets to construct HydroWASTE in their paper [8]. The visualization published with the database therefore only includes limited information: the quality of attributes, ratios of treated wastewater discharge, and statistical analysis results using geographic maps like the topographic terrain map and other common visual encodings like scatter plots [8].

Wongburi et al. highlight the importance of data visualization to help assess the operational status of WWTPs [31], but the visualization in their study is data analytic oriented rather than an information visualization approach. The tool most similar to our work is the interactive geovisualization of WWTP compliance status [29], however, its scale is limited to the national dataset published by the U.S. Environmental Protection Agency (US EPA) in 2020.

Other applications in the visualization of hydrographic data use the HydroSHEDS database, which incorporates HydroWASTE as one of its products [27]. For example, the freshwater ecosystems explorer developed by the United Nations Environment Program is an interactive tool with a high geographic resolution to show the change in surface water and wetlands at national, sub-national, and basin levels [21]. Users could quickly navigate through the parallel layout to select the region of interest, view the dynamic changes, and zoom into case studies shown as point marks. World Wide Fund for Nature also creates a Water Risk Filter that uses choropleth maps with attribute filtering to evaluate the risk of water quality for industry stewardship [9]. Our work differentiates from this kind of application by the target domain since no prior vis tool exists for WWTPs.

### 2.3 Geovisualization

Since our database consists mainly of geographic attributes of WWTPs, we investigate research on geovisualization in particular. Visualizing geographic data is tricky: mark representations, screen estates, and factors alike could all affect the usability of vis tools. For example, Klippel et al. show that adding values to the point marks on the map could slow down the decision-making process [13]. Dillemath suggests that a larger map extent could lead to higher performance of navigation tasks [6].

Based on prior work of visualizing a hydrological dataset similar to ours [21], we adopt the dot map, which is good for visualizing absolute values in thematic cartography [10], to allow users to

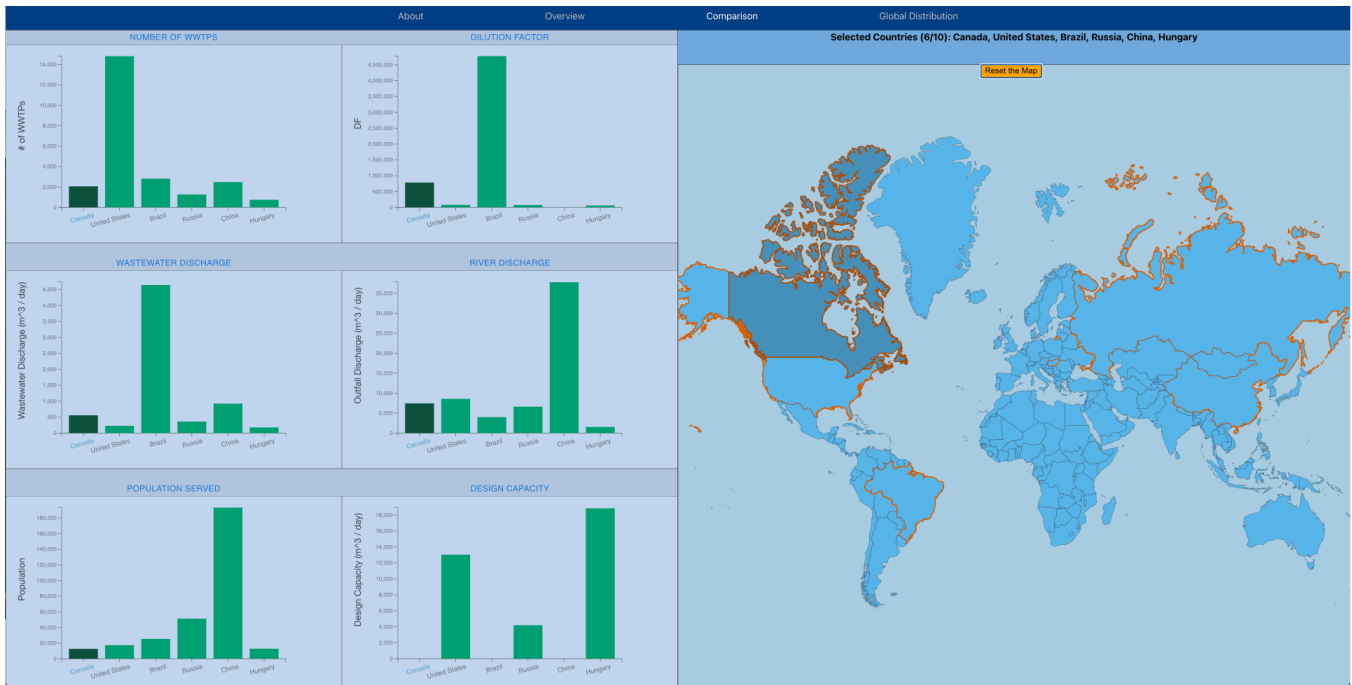


Figure 2: Screenshot of the comparison page of WWTPViz.

navigate through each individual WWTP and view its detailed statistics. However, it is difficult for users to count the total number of dots in the map when the scale is small [20]. Therefore, we add the stacked bar chart at the bottom of the dot map to length code the number of WWTPs by countries and color code the waste water treatment levels. The full combined bars are easy for users to compare the total amount of WWTPs in each country because all the bars have the same, flat baseline [15].

## 2.4 Interactive Designs

Interactivity is one of the most widely used concepts to provide users with different perspectives of spatial data and the capability to configure vis contents. Crampton provides a ranked typology of interactivity types in geographic visualization (GVis) [4]. Nöllenburg elaborates on two types of user interactions in geovisualization: focusing on individual views and linking multiple views [17]. While 3D visualization and animation are gaining momentum in GVis, Dorling’s study shows that cartographic animations need more careful justification due to potential perceptual overload [7].

Another important facet that has been explored is the concept of linking views within geovisualizations. Roberts highlights the various architectures in which different views can "share" data to coordinate entire visualizations, contextualizing the discussion around prior geovisualization software such as ArcView and xGobi [23]. Such systems extend the features found on the basis of an interactive map.

With these backgrounds in mind, we wish to build an interactive vis article to illustrate WWTPs distribution and crucial attributes that assist in detailed water quality assessments.

## 3 DATA AND TASK ABSTRACTION

In this section, we describe and provide abstractions for the data and tasks of the proposed vis tool based on the framework discussed in the textbook [15].

### 3.1 Data Abstraction

As highlighted in the previous section, we use the HydroWASTE database as the dataset in this project, which describes characteristics of WWTPs at a global scale - the full data can be downloaded in CSV format from the following website: [https://figshare.com/articles/dataset/HydroWASTE\\_version\\_1\\_0/14847786/1](https://figshare.com/articles/dataset/HydroWASTE_version_1_0/14847786/1). This dataset combines national and regional datasets based on their most recent updated versions as of writing to provide a global snapshot of WWTPs [8]. The dataset comes in the form of a simple flat table - each row encodes information about a single WWTP item, and columns represent its specific characteristics. There are a total number of 58502 items and 25 attributes in the dataset. To better understand our data, we start with an abstraction process to explain and analyze the properties of each attribute. We detail information regarding the semantic meaning, type, cardinality/range of each attribute in Table 1.

25 attributes is a large number to visualize, as such, we performed reduction to focus on the most important attributes within the context of our research project and our initial goals. As we wanted allow for geographically-based comparisons and summaries, location attributes (country, longitude, and latitude) were important variables. In particular, as we aimed to support comparison at a global level, we required the country attribute to serve as the variable for aggregation. The selection of metrics for comparison and

overview was based on a mixture of a priori knowledge, background research, and data exploration. For instance, the QUAL metrics all serve to judge data quality of other attributes [8], as such, we did not consider them important in our visualization tool. Similarly, we discarded river-based metrics, since we were not focussed on rivers as a geographical feature. STATUS as a variable was discarded because of the lack of information gain provided by the variable, as the vast majority of WWTPs did not report a status. As such, our final set of metrics for comparison were:

- **Treatment level:** same as the attribute of level in the original dataset with a more descriptive name. This attribute is the level of waste water treatment based on the depth of the process. Deeper levels of treatment have increasingly complex processes for removing contaminants [2].
- **Population Served:** the number of people that the WWTP provides for.
- **Design Capacity:** the volume of water that the WWTP can handle, as per design specifications.
- **Wastewater Discharge:** - the volume of purified water discharged by the WWTP per day.
- **River Discharge:** the volume of water discharged by the WWTP into a body of water.
- **Dilution Factor:** the ratio of the natural discharge of the receiving waterbody to the WWTP effluent discharge [3].

To represent these values as a singular metric for a country, we chose to take the aggregated mean as the representative central tendency. As for the categorical attribute of treatment level, we computed the amount of WWTPs at different treatment levels in a country. We furthermore added a new derived variable to represent the degree of aggregation - the count of WWTPs included in it (representing the number of WWTPs in a country). Reduction, aggregation and cleaning was performed in Python to transform the raw dataset into a more usable, compact version passed into the front end.

### 3.2 Task Abstraction

Our main goal is to provide an interactive display of WWTPs for policymakers and researchers to understand, evaluate, and adjust current wastewater treatment regulations in their countries of interest. Under this study's context, Policymakers refer to government officers and intergovernmental organizations in the environment protection sector. Our database HydroWASTE includes key metrics in regulatory requirements and ecological risk assessment of wastewater systems: the level of treatment, the discharge volume of wastewater effluent, the number of the population served, etc. Since our dataset combines both global and regional data, ideally the tool can allow users to investigate WWTPs at different granularity: individual, provincial, national, and global. The tool may additionally provide different measures of attribute values such as mean, median, and sum.

However, due to time and technical constraints, we design the WWTPViz to only address higher-level tasks such as discovering global distribution and aggregating the attribute values by countries instead of examining individual WWTP in details. Imagine that policymakers can quickly grasp the key metrics of WWTPs in their country, especially in comparison to others. Researchers

can also easily find answers to questions like "which country has the highest average effluent discharge?". Even ordinary water users can glance at the global distribution of WWTPs to better understand their surrounding water quality compared to the rest of the world. Specialized analysts might take an overview of WWTPs in the selected regions to compare their population served and discharge amounts relative to that of the receiving waterbodies (i.e., the dilution factor) to estimate the impact of excessive effluent.

We summarize the tasks our target users can accomplish with WWTPViz as follows:

- **T1.** Discover the national and global distribution of WWTPs.
- **T2.** Understand WWTP metrics in the region of interest.
- **T3.** Compare WWTP metrics across selected countries and all countries in the world.

We do not assume that users for T1 needs specialized knowledge about WWTPs in advance while users for T2 and T3 require domain knowledge to better perform the tasks.

Abstracting the tasks, our tool targets the five most important attributes for all WWTPs in each country. Users are able to find and understand the minimum and maximum *extremes* of individual metric, the *dependency* among multiple metrics, and the global *distribution* of all metrics. With WWTPViz, users can *analyze*, *search*, and *query* the key metrics of WWTPs for water quality assessment.

WWTPViz allows users to *analyze* the data by *discovering* the global distribution of WWTPs. *Presentations* of WWTPs through static and dynamic vis idioms also help end users in decision-making and planning. WWTPViz supports four *search* actions: *lookup*, *locate*, *browse*, *explore*. Users can quickly *look up* a specific WWTP metric of a country by remembering the alphabetical order of the country name. If users do not know the location of the country that has some interesting metric values, they can *locate* the country of interest through the bidirectional linking between visual encodings of WWTP metrics and countries. This linking is also useful when users have a country in mind but do not know which WWTP metric to investigate, because they can quickly *browse* all metrics of a country. Even if users do not know which WWTP metric or which country they want to look at, they can *explore* all the metrics for all the countries in the globe to have an overview. In addition, users should be able to easily perform *queries* to *identify* characteristics of WWTP-related metrics, *summarize* the overall distribution of metrics, and *compare* metric values across different countries.

## 4 SOLUTION

We develop WWTPViz, a dashboard tool for WWTP visualization hosted on the web. Since the main target users of our tool is policy makers and researchers who generally have accesses to output devices, WWTPViz is designed for a 27-inch monitor screen, with a pixel resolution of 3840x2160. Our design solution features 4 pages - an **About** page that serves as the landing page and provides a description of the other pages, an **Overview** page that allows users to view a number of WWTP metrics across countries from around the world (Figure 1), a **Comparison** page that allows for a more detailed comparison between a subset of selected countries (Figure 2), and a **Global Distribution** page that allows users to view the distribution of WWTPs with more granularity within countries,

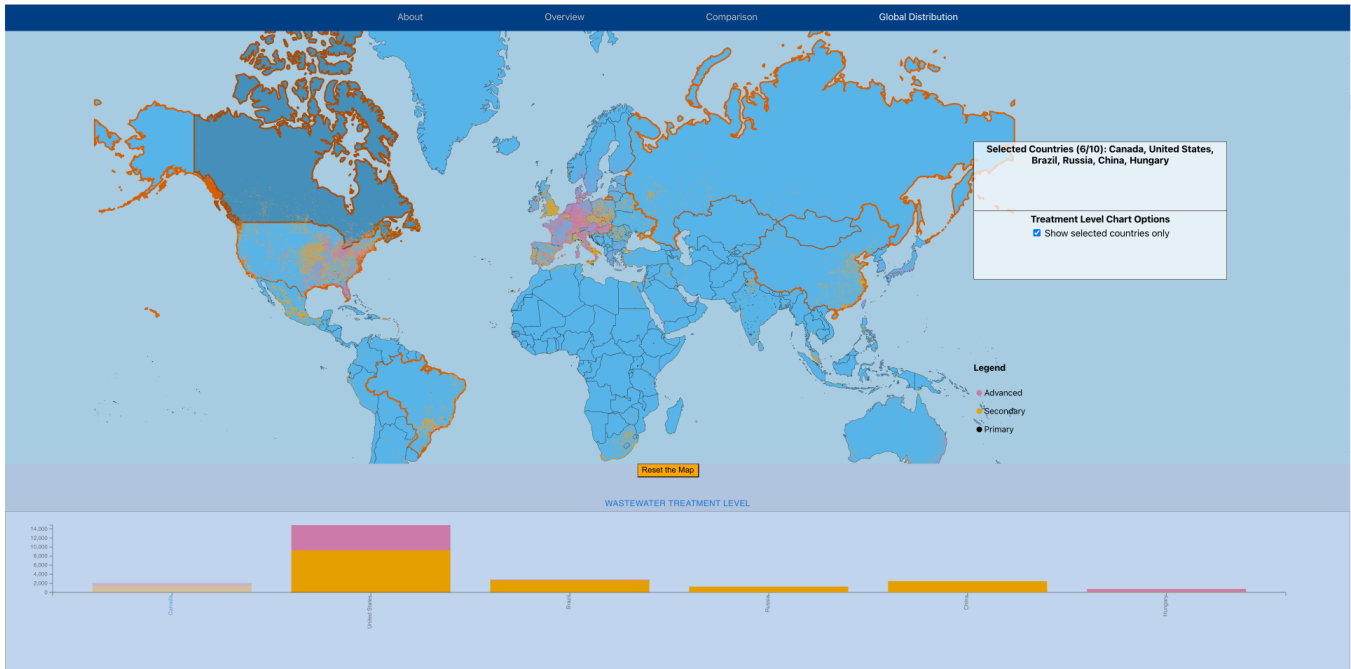


Figure 3: Screenshot of the global distribution page of WWTPViz.

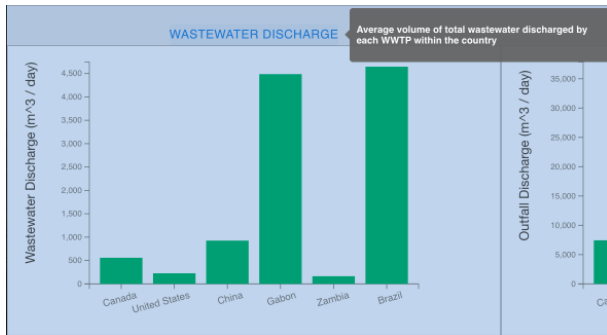


Figure 4: Screenshot of the tooltip in WWTPViz.

as well as offer summary and comparison of WWTP levels across countries (Figure 3). We exclude the About page from our discussion, and focus on the latter three pages, which specifically serve to address the task abstractions and research goals that we proposed earlier. In this section, we will further delve into the specific design decisions we made in creating the visualization. Some components are shared across pages (e.g. geographical map), while others are unique to specific pages.

#### 4.1 List Alignment for Single Key

As one of our main goals is to understand and compare WWTP metrics across countries, it is crucial to visualize all the WWTP-related attributes for each country. As country is the only key attribute of our dataset, it is intuitive to separate the visualization

into one region per country [15]. In particular, we adopt the bar chart and stacked bar chart idioms.

**4.1.1 Bar Chart.** Notice that only the key attribute and the attribute of treatment level are categorical while all the other five WWTP-related attributes are quantitative. Bar charts, which use one line mark for each level of a categorical attribute and encode a quantitative attribute with one spatial position channel, are therefore suitable for the tasks to *lookup* and *compare* quantitative attribute values [15]. We visualize each WWTP-related attribute using a bar chart, with five bar charts in total on the **Overview** page in Figure 1. We use the *small multiples* design for the five bar charts since they share the same dataset. Each bar chart illustrates a different partition of the original dataset, i.e., values of a different attribute. Sharing the same visual encoding allows users to *compare* the spatial position of attribute values easily based on a common reference frame [15]. Users can quickly *explore* different attributes for all countries in the world simultaneously to reduce interaction cost and memory load [15]. As our tool is designed for monitor-sized screens, which alleviates the typical issue of insufficient screen real estate for the *small multiples* design.

**4.1.2 Stacked Bar Chart.** We choose the stacked bar chart idiom to visualize the categorical attribute of treatment level on the **Global Distribution** page in Figure 3 since the dot map on that page is color coded by treatment level as well. There are two categorical attributes as keys, i.e., the country and treatment level, and only one quantitative attribute, i.e., the number of WWTPs by treatment levels in a country. According to the textbook, a stacked bar chart is good for illustrating this two-dimensional data with two keys [15]. Looking at a stack bar chart, users can *discover* the part-to-whole

relationship of WWTPs with different treatment levels in a country and *look up* the treatment levels of a country of interest [15].

In the stacked bar chart, the line marks encode the the number of WWTPs using length in an aligned vertical position [15]. Each subcomponent of the treatment level is color-coded according to the same key [15]. Since each subcomponent of the bar is stacked, the full bar length shows the total number of WWTPs in a country [15]. All bars share the same scale, so users can easily compare full combined bars and the lowest bar components [15]. However the stacked bar chart idiom has a common pitfall for users to compare other subcomponents of a bar that are not the lowest because they do not start from the same baseline [15]. We intentionally pick the secondary treatment level to the lowest subcomponent as most countries have WWTPs at the secondary treatment level. The number of subcomponents of the treatment level attribute is only three, so the stack bar chart works well with our data especially on a large screen we design the tool for [15].

## 4.2 Maps

We adopt two types of maps: a general-purpose atlas map and a thematic map, i.e., the dot map, to visualize the geographic features of countries and the distribution of WWTPs.

**4.2.1 Atlas Map.** WWTPViz displays a world atlas map at the right side of the **Overview** page in Figure 1 and the **Comparison** page in Figure 2. An atlas map, is a collection of maps of Earth that illustrates geometric features and political boundaries [1]. The static atlas map alone does not show any information of our dataset. However, users can perform various *search* and *query* actions by interacting with the atlas map and the bar charts. We will explain with more details in section 4.3 Interactivity.

**4.2.2 Dot Map.** We present a dot map that uses the point mark on a spatial field to visualize the geographic distribution of WWTPs on the **Global Distribution** page in Figure 3. As explained in the related work of Geovisualization, we choose the dot map to show the global distribution of WWTPs accurately and offset its disadvantage of not showing the total number of WWTPs through a stacked bar chart placed at the bottom as shown in Figure 3. We use the color hue channel to encode the dots that represent WWTPs on the map according to the values of the treatment level attribute. A dot map is easy even for layman to grasp the general distribution of WWTPs and compare their population densities by inspecting the concentration of dots [?].

## 4.3 Interactivity

Interactivity was a key factor that we wanted to implement within our solution - we aimed to present users with the options to affect the page in order to easily and efficiently perform the task requirements. In this section, we outline several features that helped increased the interactivity of our visualization.

**4.3.1 Sorting.** Initially, all bar charts and the stacked bar chart are sorted by the alphabetical order of country names, which supports quick *lookup* of the attribute values of a specific country. However, it is hard for users to *identify* interesting characteristics of attributes by looking at the bars ordered by country names. Therefore, WWTPViz has "Sort by [Attribute Name]" buttons as shown

in right panel of Figure 1, which allow users to sort the charts by descending attribute values. Users can *identify* the countries with maximum and minimum attribute values by looking at the two extremes of the charts. Users can also sort the charts back to the alphabetical order of country names using the "Sort by Country Name" buttons in Figure 1.

**4.3.2 Navigation: Zoom and Pan.** One way in which interactivity was present in WWTPViz was through the use of navigation tools. Navigation tools present options for the user to change the view-point in which they are looking at the visualization, and appears within our system as the option to **zoom** (moving the camera closer or further to enlarge or diminish on-screen objects respectively) and **pan** (translating the camera). These tools are present in two visualization views - the maps (on all 3 pages), and the bar charts (on the Overview and Global Distribution pages). Navigation on the map provides a heightened degree of control, as users can navigate the world if they are aiming to lookup a country of interest. This is particularly important if the country is small, making it difficult to interact with at the default level of zoom. Navigation on the bar chart serves a similar purpose. Visualizing a large set of countries (188 in total) on a bar chart can allow a user to quickly grasp a sense of where the metrics of a specific country falls, but scaling can become cramped if a user wants to see more specific details. Navigation through zooming and side-to-side pan, along with an adaptive y-axis that scales with navigation, allows users to have a higher degree of control when viewing and allows them to more comfortably browse the bar charts that provide distributions that summarize information from the entire world. This provides the ability to filter a high-dimensional attribute (of countries) into a more manageable one. Different levels of navigation for each of the bar charts is shown in Figure 1.

**4.3.3 Bi-directional Linking - Metric Overview.** When the user is engaged in an overview task, users are considering the country and the metrics of the country; and how such metrics fall into the context of other countries. These overview tasks are accomplished on the Overview and Global Distribution pages. On these pages, multiple views are juxtaposed representing different features - the spatial map shows geographical information (in particular, countries), and the bar charts show the metrics aggregated by countries. Linking between these views is vital to highlight the shared country attribute. In our application, we perform linking between the bar chart and the map by changing the luminance of the country on the map, changing the luminance of the associated bar, and changing the hue and font weight of the country name on the x-axis of the bar chart. As such, when a user hovers over a country on the map (or a bar on the bar chart) while engaging in an overview task, this linking will trigger, allowing the user to quickly understand which rectangular mark on the bar chart corroborates which country-shaped mark on the map.

**4.3.4 Cross-page Linking - Metric Comparison.** Our tool also supports comparison of a specific subset of countries. On each page, users are able to perform selection up to 10 countries that they are interested in. This can be done in two ways - users can either click the country on the map, or they can click the bar mark associated with the country they are interested in (while performing an



overview task on the Overview and Global Distribution page). On these overview pages, the linked encoding between the juxtaposed views of the map and the bar chart is visually shown as a highlight on the country of interest and a highlight on the associated bar of the bar chart. If the user is performing a comparison task (e.g. on the Comparison page), the only way to select a country is through clicking on the country on the map.

These selected countries persist across the entire application, allowing users to easily and efficiently switch between comparison and overview tasks. For example, on the Overview page, a user might select a few countries of interest (e.g. top 10 countries in population served). Switching over to the Comparison page provides a more granular depiction of these countries without extra marks. As such, selecting these countries can help serve as a form of reduction, filtering a large amount of data (from all countries) into a more manageable set that the user is interested in.

#### 4.4 Other Design Choices

A number of other design choices were involved in the more detailed decisions of the user interface, as briefly described here.

*4.4.1 Pixel Density and Spatial Juxtaposition of Views.* Each page in WWTPViz was optimized to present all the views on a single display without the need for scrolling, as this would allow for juxtaposition (facilitating comparison of information) across all views rather than only a select few. As such, we chose to facet our views in such a way as to maximize our use of space across in all three pages; this was particularly relevant in the Overview page, being the most pixel-dense.

*4.4.2 Colour Scheme.* As the various views of the dashboard involved marks superimposed on top of other marks (e.g. the dot map), or highlighted marks that we wanted to stand out (e.g. selected countries), we aimed to pick a colour scheme that was distinctive and colourblind-friendly. As such, our colour-based encoding for marks was derived from Wong's suggestion of a palette of colours for colourblind individuals [30].

## 5 IMPLEMENTATION

WWTPViz was implemented using the visualization grammar of D3.js (<https://d3js.org/>), which allows for web-based displays through DOM manipulation. We integrate D3.js (D3) with web-based development frameworks and languages - React.js (React) for the backend, and HTML and CSS for the frontend. The App.js describes the main framework. We organized application-level management in React, which serves as a container for D3 [26]. When hosted on a server, users can navigate to the dashboard website to begin using the tool. The updates and interactivity within the application are done using React hooks, which dynamically call code upon detecting changes in defined variables. In developing the solution, we initially bootstrapped the application using <https://github.com/facebook/create-react-app>, which sets up a basic empty front-end hosted on the web. Our code then develops the React hooks and components that exist on top of this initial skeleton. Table 2 shows the split of work.

### 5.1 Data Preprocessing

We used the Google Colaboratory to handle the raw CSV file of HydroWASTE by loading the data into a Python dataframe object, removing null values, exploring the types and ranges of each attribute, aggregating the data by countries, and computing the mean values of each quantitative attribute in the aggregated data. Since the treatment level attribute is categorical, we need to calculate the sum of WWTPs at each treatment level in each country and store the results in another dataframe object. We further saved the dataframes as JSON files to be directly imported as JSON objects in React.

### 5.2 Maps

The map was drawn as a SVG using D3 functions using paths from a high-resolution GeoJSON file which we obtained here: <https://geojson-maps.ash.ms/>. The WWTP dot map shown on the Global Distribution page augments this base map with circles based on data passed in regarding the level of every WWTP. As such, the colour of each circle is dependent on whether it belongs to the "Primary", "Secondary", or "Advanced" level.

### 5.3 Bar Charts and Stacked Bar Chart

The bar charts are drawn iteratively through a for-each loop in D3. While all bar charts share the same scale (i.e., `d3.ScaleBand`) for the x-axis, they have different attribute values along the y-axis. Data from the bar charts is passed in from aggregated JSON files generated through preprocessing. The stacked bar chart is drawn in a similar way but the data is additionally transformed using the `d3.stack` function.

### 5.4 Interactivity

WWTPViz incorporates a variety of interactive features including sort, navigation, hover, and selection.

*5.4.1 Sort.* For the five bar charts and the stacked bar chart, we implemented click event handlers for the buttons to sort attribute values. Such an event handler sorts an array of domain values for the x-axis and rescales the x-axis to redraw the chart.

*5.4.2 Navigation.* The zoom and pan features on both maps and bar charts were implemented using the module `d3.zoom`. We further specified to what extent users can zoom and pan through the `d3.scaleExtent` and `d3.translateExtent` functions. The zoom behavior of bar charts has an event handler more complex than those for maps because we want to dynamically rescale the x and y axes when zoomed in and out.

*5.4.3 Mouseover Countries.* When the user is viewing an overview of the countries (involving seeing a bar chart with all the countries of the world), the user can mouseover any country on the map to focus attention on it, as well as the associated bar chart(s). When the user is comparing a subset of countries (involving seeing a bar chart with only the selected countries), the user can only hover over the selected countries or bars. This linking is accomplished through mouseover (i.e. `hover`) and mouseout (i.e. `unhover`) events in the program, which are generated upon initialization of the bars of the bar chart and the countries of the map. When the user

mouseovers a country, the luminence of the country mark changes to a darker shade as feedback. The country name is used to link the country on the map to the bar of the bar chart, and the luminence of the associated bar also changes to a darker shade, and the hue of the country name on the x-axis changes as well. When the user then mouseouts of the country, the process is reversed, and the luminence reverts back to normal, aligned with the rest of the countries. When the user is viewing an overview of all countries, this linking extends to all countries, but when the user is viewing the subset of selected countries, an additional check is done to see whether the hovered country is in the list of selected countries.

**5.4.4 Selecting a Country.** For the drawn country paths on the map, we add an click event on initialization that adds the country to a list of selected countries after performing some checks (such as seeing if the user has reached the maximum never of selected countries already). Once added to the list, the code re-executes the drawing of the countries, now with the selected countries highlighted with an vermilion outline. Due to the linking with the global bar charts when performing overview tasks, this also causes the associated bar of the country to also become highlighted (to stand out against the rest of the countries). After the country has been selected, clicking on the country again reverses the process, causing the country to be removed from the selected list and undoing the highlighting.

This process is identical for the bars of the global bar charts - the also have an click event that allows users to click on specific bars to add them to the same list of selected countries - after a set of checks, the code flow then follows the exact same functions as if a country had been clicked.

We wanted selected countries to be a continuous variable that extended across all 3 pages - so countries selected in the Overview page, for example, would persist into the Comparison page. To do this, we initialized the selected countries list variable at a higher application level and passed it into each of the individual pages, which could manipulate the variable by reference while maintaining its connection to each other page.

## 6 MILESTONES

The finalized timeline in Table 3 keeps track of project progress and delegated tasks. The timeline was modified in an iterative manner to refine the project scope, tool requirements, and task assignments.

## 7 RESULT

Due to the linked nature of our application, it is difficult to present each page as an individual component. Thus, we present two example usage scenarios of WWTPViz, one primarily focusing on browsing and overview and another focusing on lookup and comparison.

### 7.1 Browsing WWTP Metrics

Tony is part of an environmental NGO and is interested in understanding dilution factors for WWTPs. In particular, he is interested in understanding whether there may be any connection between the geographical features of a country and the dilution factor, and plans to use WWTPViz as an exploratory starting point for a more formal analysis.

Tony first starts off at the Overview page. He wants to understand which countries have a high dilution factor (i.e. the top 5). To get these countries, Tony sorts the dilution factor bar chart by clicking the button on the right panel, which sorts the marks by largest to smallest size from left to right. He zooms in on the bar chart to only filter the top 5 countries that he is interested in, and mouseovers over each of them in turn to understand where they are geographically located on the map (as the luminence changes on both the bar and the map) - see Figure 5. Tony decides he wants to perform some comparison later as well, so he decides to select all 5 of the countries. Tony then wants to look at the bottom 5 countries by dilution factor as well, as such, he navigates to the opposite end of the bar chart. Similar to before, he mouseovers over each of them, mentally notes their position, and selects them as well.

Tony now wants to explore whether other factors might be correlated to dilution factor, so he switches over to the Comparison page, which highlights the countries he has selected previously - the top 5 and bottom 5 countries by dilution factor. Ultimately, Tony wants to see whether other metrics show a significant difference after the first 5 bars, perhaps a massive drop-off similar to the dilution factor. Satisfied with this initial exploration, Tony makes note of the countries he considered and conducts more formal statistical analysis with these countries in the future.

### 7.2 Selecting Countries of Interest

Emi is an environmental engineering researcher working in wastewater treatment who is interested in understanding how wastewater is treated differently in several countries around the world. In particular, Emi is interested in understanding whether there exists significant differences between wastewater treatment between her own country (Canada) and select other first-world countries. She is particularly interested in 2 main metrics - the average population served, which she hypothesizes be an indication of how community density, and the distribution of WWTP level, which may be correlated with economic development. She wants to use WWTPViz to provide her with an exploratory first look at the relevant metrics.

As such, Emi first navigates to the Comparison page of WWTPViz. She clicks on Canada, the country she is mainly interested in, and then subsequently clicks on 5 other countries that she wants to compare the metrics with. Because some of these countries are small and difficult to click on, she is required to zoom in and pan in order to click on the countries she wants. This highlights all the countries that she is interested in, and displays their aggregated metrics as bar charts on the left side of the display, including one of the metrics she is mainly interested in, population served. Emi is now interested in understanding how such metrics fall into the entire global distribution, so she then navigates to the Overview page. As the selected countries are maintained, Emi can quickly identify how the population served for each country of interest aligns with all other countries.

Emi is now interested in understanding the other metric of interest - WWTP level, which requires her to stay on the Global Distribution page. On the dot map, the countries she had initially selected are still highlighted, as are the relevant bars on the global distribution. She takes a quick glance at the dot map, which provides her with a rapid understanding of the distribution of WWTPs





Figure 5: Screenshot of the user scenario in section 7.1.

around the world, and where they are densely located; noticing in particular that WWTPs in Canada are mostly congregated near the southern border. She then considers the stacked bar chart, which shows the number of WWTPs by level aggregated by country. Finding that her countries are too small to differentiate well, she clicks the button "Show selected countries only", which changes the bar chart to only show the selected countries of interest. Finally, she makes note of how these countries compare to each other. 2. Looking up and Comparing WWTP Metrics between countries of interest

## 8 DISCUSSION AND FUTURE WORK

In this section, we analyze the strengths and limitations of WWTPViz, summarize lessons learned, and discuss future extensions to our work.

### 8.1 Strengths and Limitations

WWTPViz, the first vis tool of global WWTPs to our knowledge, has multiple compact views to show important WWTP-related metrics aggregated by countries. The tool provides fast visual feedback and various interaction designs for users to interact with the tool fluidly and stay focused on high-level tasks such as *discovering* the global distribution of WWTPs. The biggest challenge of diverse user interactions is latency [15]. WWTPViz has two low-level interaction mechanisms: click to (de)select countries and mouseover action to highlight the bars in the charts or countries on the map. Although clicking on the visual components is very slow [15], it provides users with flexible choices of items they are interested in. The mouseover events do not require dwell time nor click, which is therefore the fastest interaction mechanism with little latency [15]. We have comparatively slow visual feedback of showing the selected countries on a fixed detail panel at the side of the maps, slightly faster feedback of a popup window to show the tooltip contents, and fast feedback of highlighting the selected countries or their corresponding bars in the visual encodings [15]. Although

showing the selected countries in a separate pane has higher latency, it avoids occluding other visual components to display the full selection in detail [15]. Due to the fast rendering framework of D3, the system latency is negligible in WWTPViz except for a bit of jerkiness to draw the dot map, which in general has higher computational costs [?].

Both authors have little experience with frontend design and zero knowledge of D3 at the beginning of the project. Within a limited amount of time, WWTPViz only supports visualizations of data at the national and global levels. (Need to be integrated into the parts below)

### 8.2 Lessons Learned

Through the development of this research project, we learned quite a lot about the visualization process that we had not initially known when first starting. Even learning the visualization grammar technology (d3.js) was a major undertaking for us during the course of the project. Our expertise in d3.js increased rapidly throughout the course of this project, as we underwent many trials and tribulations. At a meta-design level, we learned about the importance of abstraction and developing clear tasks and research goals at the onset of the project. With a lack of clearly defined goals at the start, we were unable to fully justify the end result until much later, resulting in a lack of efficiency when building the tool. This is evident in the code, in which there are several repeating components - with a better initial framing, we would have developed a modular layout of the code at the onset, instead of adding components new features on constantly. With a stronger framing of tasks and usage, we were able to better justify our design decisions as well, including the use of space and pixel density and colour schemes. With the goal of presenting relevant information that would differentiate different countries, we were also able to better select out relevant attributes for our dashboard, as we found that some attributes (e.g. status) did not encode much in terms of added information.

### 8.3 Future Work

Based on prior discussion, we identify possible directions for future work on WWTPViz. Starting from a high-level technical level, our tool currently functions as an overview and comparison for nationally-aggregated WWTP data. Having different levels of user-selected geographic granularity (for example, at a regional or neighbourhood level), could allow for a higher degree of refinement for the user, such as if they were interested in the WWTPs serving their specific city. This could be done by augmenting the data, using longitude and latitude data as merge attributes with other datasets (e.g. ones that match it to a neighbourhood or city). At the most discrete level, a user could even select a single WWTP of interest, and compare between individual WWTPs. At an even broader level, we could extend our tool to even more tasks and targets. For instance, although our task allows users to visualize distributions, the onus is on the user themselves to draw any sort of conclusion or identify trends. In the future, we could extend our tool to detect patterns and outliers automatically.

However, when considering the tool as it is currently, there are definitely still improvements that could be made. Some of these are related to usability - for example, having a textual search bar for countries is a possible extension, especially if a user only knows a country by name and not by its geographic location. Other improvements that could be made are in regards to code efficiency and benchmarks. Although benchmarks were not tested for the tool, we recognize that there definitely exists a significant loading time, especially for the Global Distribution page. We identify that this is caused by the dot map, as the process of calculating the location of, and rendering over 50,000 circles each time is not computationally trivial. Methods of improving this were considered - paradigms such as pre-loading across the entire application when the application is first started, storing the mapped static mapped locations instead of re-calculating every time, or using the null projection in d3, are all possible solutions that could be tested and optimized through future benchmarking.

In addition, presently our visualization is limited in the variety of different idioms used. Although bar charts served the purpose of comparison well, using different idioms, such as a choropleth map, might be an alternative solution for visualizing geographic spatial data. We also considered using detailed statistical panels and integrating multiple views on a single screen in order to both extend and simplify our application, respectively. Ultimately, however, this ties into aspects of not completely understanding the needs and goals of our target audience. As such, usability analysis through actual assessment with the target demographic is an imperative step for future work. WWTPViz currently is designed for a hypothetical persona - interviews and observations of users actually using our application would reveal key insights into the strengths and weaknesses of our design, as well as suggest areas for improvement and extension. Thus, it could be said that our present design serves as an initial prototype for refinement and improvements based on user assessment.

## 9 CONCLUSION

In this research project, we present WWTPViz, a interactive dashboard visualization for global WWTPs. Our solution builds upon

the foundation outlined through data and task abstraction, choosing to focus on tasks regarding comparison and overview of WWTPs at a national level. Our solution involves 3 main pages - Overview, Comparison, and Global Distribution - that work in tandem to provide a suite of features and interactions for users to accomplish the goals. We outline the specific design decisions that formed the basis of the design, and discuss specific implementation details. We present two hypothetical usage scenarios, one formed around the basis of lookup and another around browse. Finally, we discuss the strengths and weaknesses of our design, what lessons we learned through the design process, and outline possible future areas of exploration.

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Name	Meaning	Type	Cardinality/Range	Other Notes
WASTE_ID	Identifier for WWTP	Categorical	Range: [1, 58,502], consecutive integers; Cardinality: 58502	Key attribute
SOURCE	Dataset from which the data was compiled from (national/regional)	Categorical	Range: [1, 12], consecutive integers; Cardinality: 12	
ORD_ID	Identifier for the national/regional dataset	Categorical	Range: {1, ..., 78,000,001,002}; Cardinality: 47497	not unique
WWTP_NAME	Name of the WWTP	Categorical	Range: {set of WWTP names}; Cardinality: 49261	not unique
COUNTRY	Country in which the WWTP is located	Categorical	Range: {set of countries}; Cardinality: 188	
CNTRY_ISO	Standard ISO Defining Codes for Countries, Dependent Territories, Special Areas	Categorical	Range: {set of country ISOs}; Cardinality: 180	
LAT_WWTP	WWTP location latitude	Quantitative (Diverging)	Range: [-54.8, 71.6]	
LON_WWTP	WWTP location longitude	Quantitative (Diverging)	Range: [-175.3, 178.5]	
LAT_OUT	Outfall location latitude for the WWTP	Quantitative (Diverging)	Range: [-54.8, 71.6]	
LON_OUT	Outfall location longitude for the WWTP	Quantitative (Diverging)	Range: [-175.3, 178.4]	
STATUS	WWTP Status	Categorical	Range: {Closed, Construction Completed, ...}; Cardinality: 9	
LEVEL	Level of treatment at the WWTP	Ordinal (Sequential)	Range: [Primary, Secondary, Advanced]; Cardinality: 3	
DESIGN_CAP	WWTP design capacity (empty if not reported)	Quantitative (Sequential)	Range: [0, 11,200,000], integers; Cardinality: 7329	15835 empty values
POP_SERVED	Total population served by the WWTP	Quantitative (Sequential)	Range: [0, 10,100,000], integers	
WASTE_DIS	Volume of discharged treated wastewater	Quantitative (Sequential)	Range: [0, 3,070,000]	
HYRIV_ID	Identifier for outfall location river; empty if outfall is ocean or large sink	Categorical	Range: {10000009, ... ,80323236}, integers; Cardinality: 42822	379 empty values
RIVER_DIS	River discharge at WWTP outfall location; empty if outfall is ocean	Quantitative (Sequential)	Range: [0.001, 127,000]	10551 empty values
DF	Estimated dilution factor; empty if estimated outfall is ocean or large lake	Quantitative (Sequential)	Range: [1, 703,000,000]	11200 empty values
COAST_10KM	Outfall Location is within 10km of ocean or large lake?	Categorical	Range: {0, 1}; Cardinality: 2	
COAST_50KM	Outfall Location is within 50km of ocean or large lake?	Categorical	Range: {0, 1}; Cardinality: 2	
QUAL_LOC	Quality rating regarding location accuracy	Ordinal (Sequential)	Range: [1,4], consecutive integers; Cardinality: 4	
QUAL_POP	Quality rating regarding the POP_SERVED attribute	Ordinal (Sequential)	Range: [1,4], consecutive integers; Cardinality: 4	
QUAL_WASTE	Quality indicator regarding the WASTE_DIS attribute	Ordinal (Sequential)	Range: [1,4], consecutive integers; Cardinality: 4	
QUAL_LEVEL	Quality indicator regarding the LEVEL attribute	Ordinal (Sequential)	Range: [1,2], consecutive integers; Cardinality: 2	
QUAL_CAP	Quality rating regarding the DESIGN_CAP attribute	Ordinal (Sequential)	Range: [1,3], consecutive integers; Cardinality: 3	

**Table 1: Attributes in the HydroWASTE dataset. Within this table, longitude and latitude values are rounded off to one decimal place, and the ranges of other qualitative attributes are rounded down to at most 3 significant digits.**

<b>Work Description</b>	<b>Michael</b>	<b>Madonna</b>
Design	50%	50%
Data Preprocessing	40%	60%
React-D3 Framework	40%	60%
Atlas Map	100%	0%
Dot Map	80%	20%
Bar Charts	60%	40%
Stacked Bar Chart	40%	60%
Sort	0%	100%
Zoom and Pan	20%	80%
Bi-directional Linking	80%	20%
Cross-page Linking	100%	0%
Layout and Aesthetics	50%	50%
Tooltips	60%	40%

**Table 2: Split of Work**

## A PROJECT TIMELINE

Task	Target Date	Actual Date	Target Hours	Actual Hours	Assignee
Prepare the pitch	Sept. 28	Sept. 28	4h	4h	Madonna
Define the scope and abstract data/task	Oct. 11	Oct. 11	4h	4h	Michael, Madonna
Write the proposal	Oct. 21	Oct. 21	18h	18h	Michael, Madonna
Implementation (before project updates)	Dec. 10	Nov.23	87h	40h	Michael, Madonna
- Clarify the tool requirements	Nov. 02	Nov. 02	2h	2h	Michael, Madonna
- Learn 3.js and set up the framework	Nov. 08	Nov. 08	15h	15h	Michael, Madonna
- Implement the dot map	Nov. 08	Nov. 08	5h	5h	Michael
- Implement the graduated symbol map which is abandoned	Nov. 11	Nov. 11	5h	5h	Madonna
- Implement the statistics panel	Nov. 19	N/A	20h	N/A	Madonna
- Implement the main page of the dot map	Nov. 26	N/A	20h	N/A	Michael, Madonna
Update the project writeup	Nov. 15	Nov. 15	20h	20h	Michael, Madonna
Project peer reviews	Nov. 16	Nov. 15	4h	3h	Michael, Madonna
Refine the task abstraction	Nov. 23	Nov. 23	5h	6h	Michael, Madonna
Implementation (after project updates)	N/A	Dec. 14	30h	50.5h	Michael, Madonna
- Implement the About page	N/A	Dec.14	N/A	0.5h	Michael
- Implement the Overview page	N/A	Dec.14	N/A	15h	Madonna
- Implement the Comparison page	N/A	Dec.14	N/A	12h	Michael
- Implement the Global Distribution page	N/A	Dec.14	N/A	15h	Michael, Madonna
- Beautify the dashboard	N/A	Dec.14	N/A	8h	Michael, Madonna
Draft the final writeup	Dec. 04	Dec. 14	14h	18h	Michael, Madonna
Prepare presentation and demo	Dec. 11	Dec. 14	15h	10h	Michael, Madonna
Finalize the writeup	Dec. 16	Dec. 16	15h	10h	Michael, Madonna

**Table 3: The final project timeline. If there are two assignees, the target and actual hours are the total number of hours for the entire group, with hours equally divided for each assignee. Items missing target dates and hours are not present in the initial milestone. Items missing actual dates and hours are never implemented.**