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Effects of Uncertainty Visualization on Decision Making and User Confidence: An Empirical Study

Thesis by Metrine Bwisa

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INTRODUCTION

Motivation

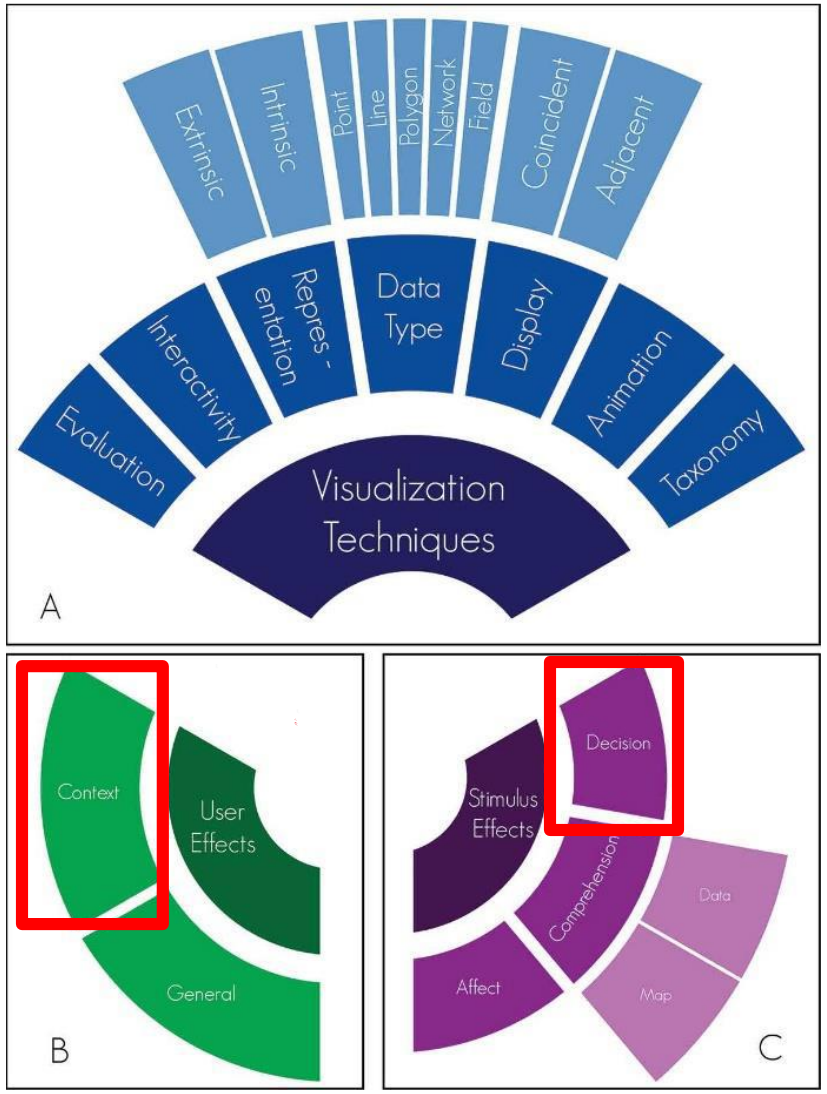

Figure 1: Domains of uncertainty visualization research by Smith et al. Copyright © 2019 Informa UK Limited [1]

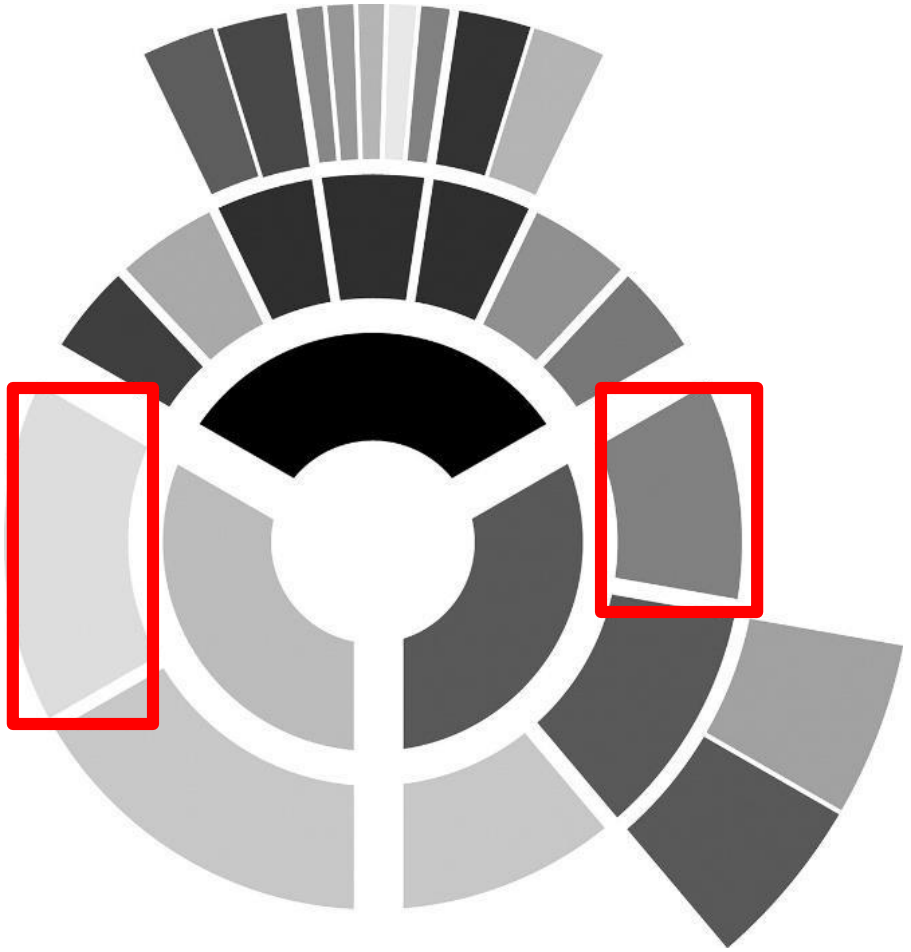

Figure 2: A reflection of how often a domain has been researched based on 40 research papers reviewed by Smith et al. Copyright © 2019 Informa UK Limited [1]

Objectives and Research Questions

1. Literature review

Which uncertainty visualization methods recommended by previous research are applicable to flood risk maps?

2. Prepare fictional flood risk maps (with and without uncertainty information)

3. Online map-based study with Kenyan participants

Are the novice and expert user groups from Kenya able to understand and interpret uncertainty correctly?

4. Investigate respondents' decision making patterns

Do the users change decisions when presented with uncertainty?

5. Investigate respondents' confidence in their decisions

How does user confidence in decisions vary with uncertainty?

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RESEARCH

Literature Review

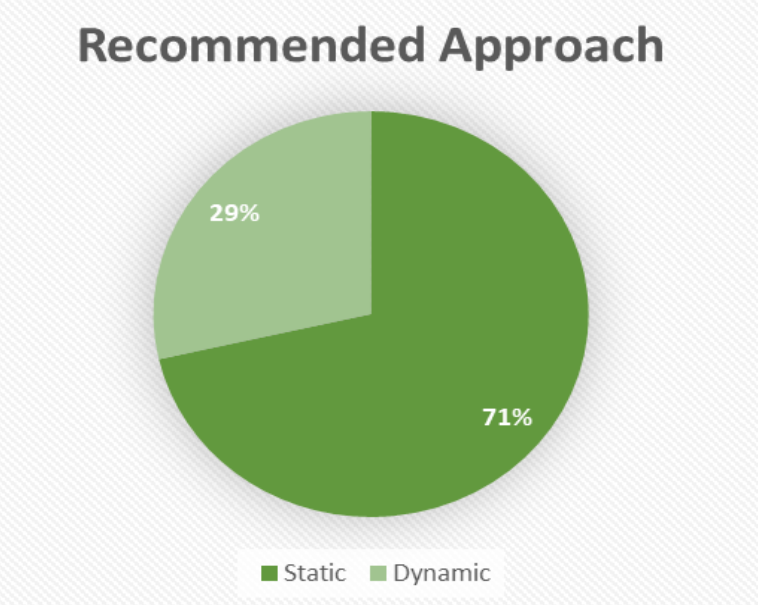
- **18 papers**
  - **Written between 1992 to 2017 (25 years)**
  - **Retrieved from ScienceDirect, Google scholar, mendeley and Google search**
  - **Compared uncertainty visualization techniques theoretically or empirically**
- **Recommended techniques**
  - **Coincident approach**
  - **Static methods**
  - **Intrinsic color value**
  - **Extrinsic texture overlay**

Coincident versus adjacent methods

- **Kinkeldey et al. [2] and Viard [3] recommended coincident approach because it:**
  - **Saves time for data and uncertainty exploration**
  - **Suitable for complex tasks (decision making with risk maps and uncertainty)**
  - **Suitable for retrieval of data and uncertainty concurrently**
  - **Minimizes user cognitive burden**

Static versus dynamic methods

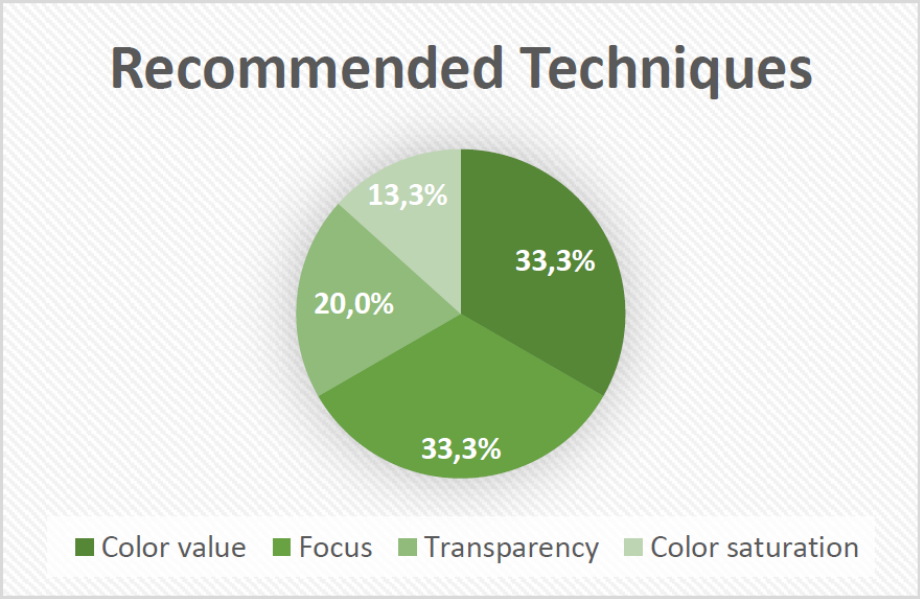
- **Based on six papers [4-9], five recommended static whereas only two favoured dynamic.**



- **Dynamic described as annoying, inefficient, complicated etc.**

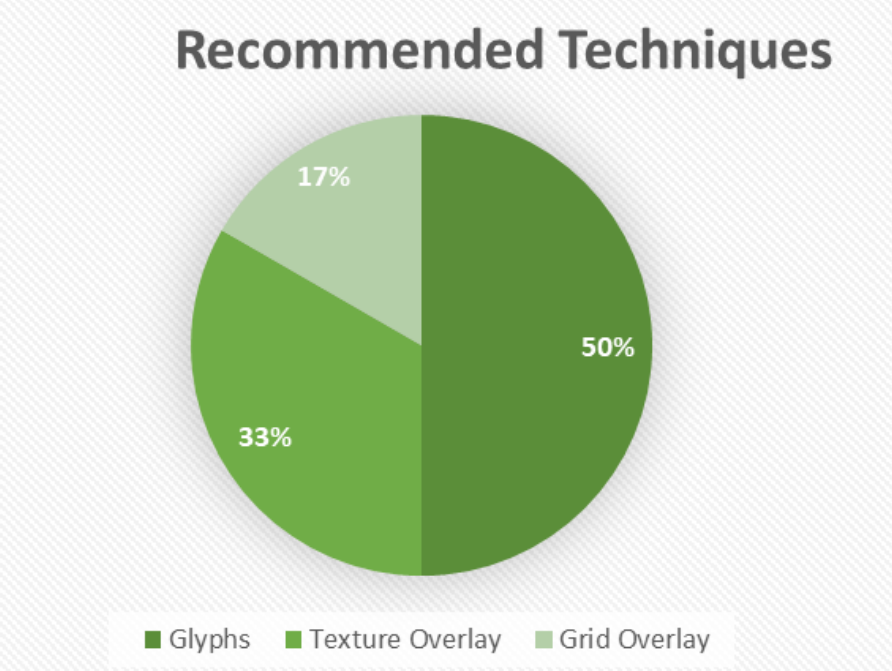
Intrinsic techniques

- **Based on 13 papers [4-6, 10-20], focus and color value were recommended five times, transparency thrice and saturation twice**
- **Fuzziness and focus were unsuitable for data sets with small areas or great variations according to Kunz et al. [11]**



Extrinsic techniques

- **Based on five papers [4,11,15,18,21], glyphs were recommended thrice, texture twice and grid overlay once**
- **According to Kunz et al. glyphs are unsuitable for data with great variation [11]**



Study methodology

Study creation

- Maps creation – Adobe illustrator
- Questionnaire – Google forms
  - Open ended, multiple choices, ranking

User study

- Preliminary – 9 respondents
- Main – 53 respondents
  - User information
  - Flood risk and uncertainty
  - Decision making and confidence measure

Data analysis

- Quantitative- Pearson´s Chi-square for independence, Fischer exact test, Mann Whitney u-test
- Qualitative – User opinions

Related Work

- **Paper 1: Evaluating the impact of visualization of wildfire hazard upon decision-making under uncertainty [19]**
  - **Decision-making to stay or leave under uncertainty**
  - **Choice of representation makes little difference to performance if subjects are allowed the time and focus**
  - **With time pressure color hue performed best**

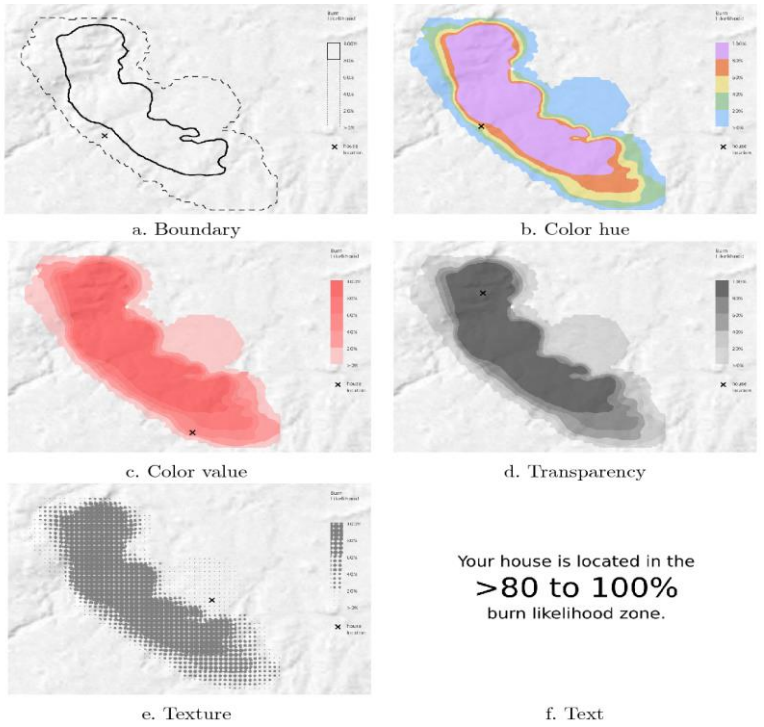
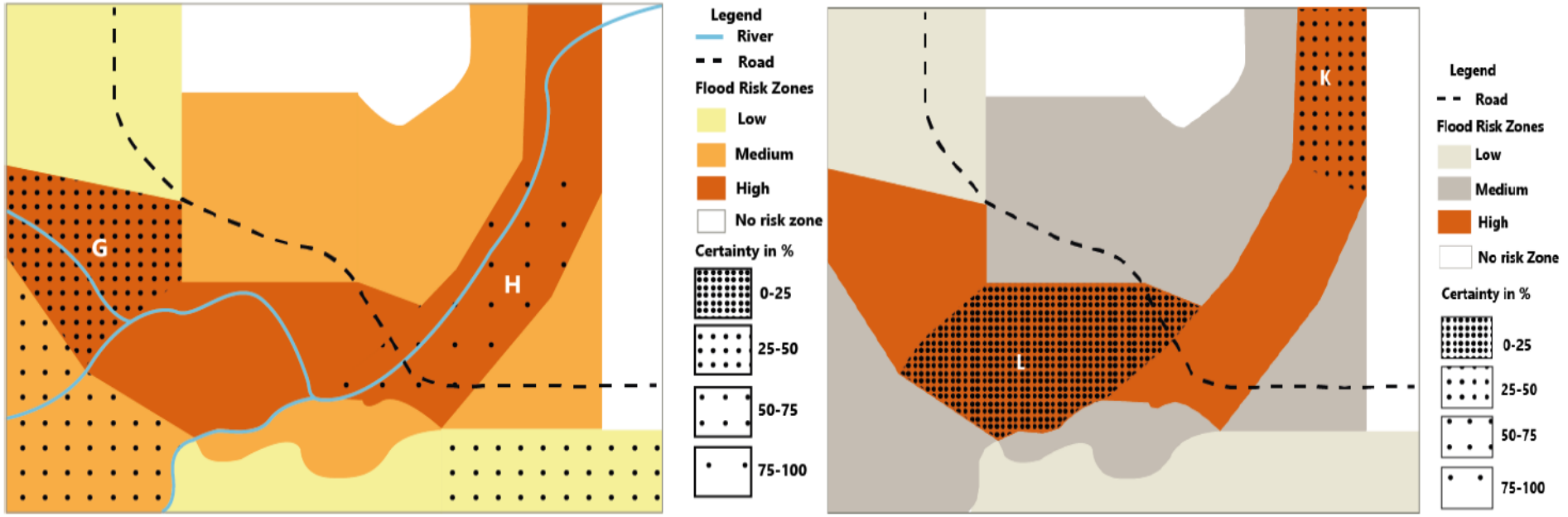


Figure 3: Six experimental stimuli types for representing uncertainty in impact of fire on house location by Cheong et al. Copyright © 2019 Informa UK Limited [19]

- **Conference paper 2: How does the visualization of uncertainty influence decision making with hazard prediction maps? [22]**
  - **Decisions for house locations for purchase influenced by uncertainty (focus,texture,color value)**

Results

- **Improvements based on preliminary study results**



Preliminary study

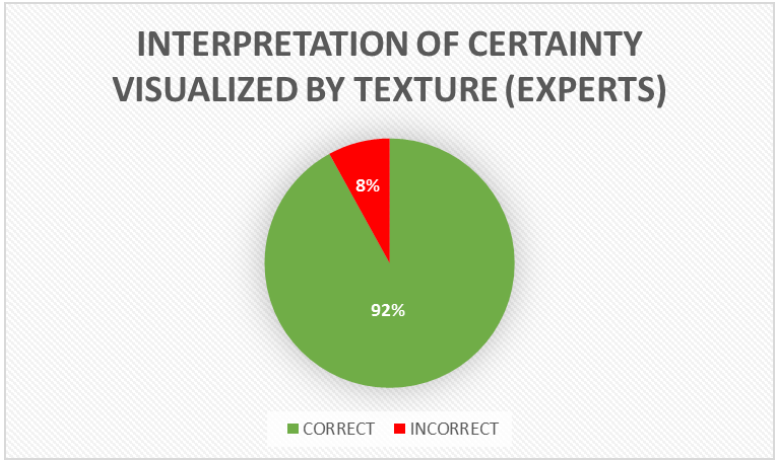
Main study

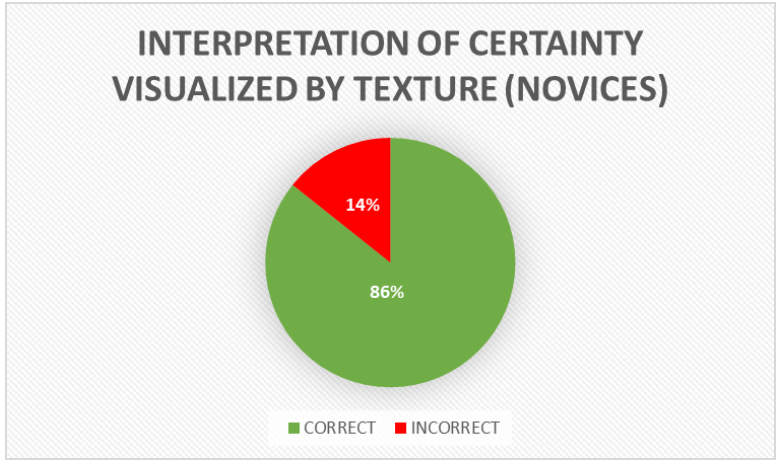
Section I - User information

- **User group**
  - **21 to 46 years, mean age of 28.08, standard deviation of 4.02**
  - **Divided into experts and novices based on profession**
    - **25 Experts - Geospatial science, statistics, disaster management etc.**
    - **28 Novices – Sports, law, accounting, communication etc.**
- **Previous experience with uncertainty visualization**
  - **13 out of 53**
- **Previous encounter with floods**
  - **28 out of 53**

Section 2 – Flood risk and uncertainty visualization

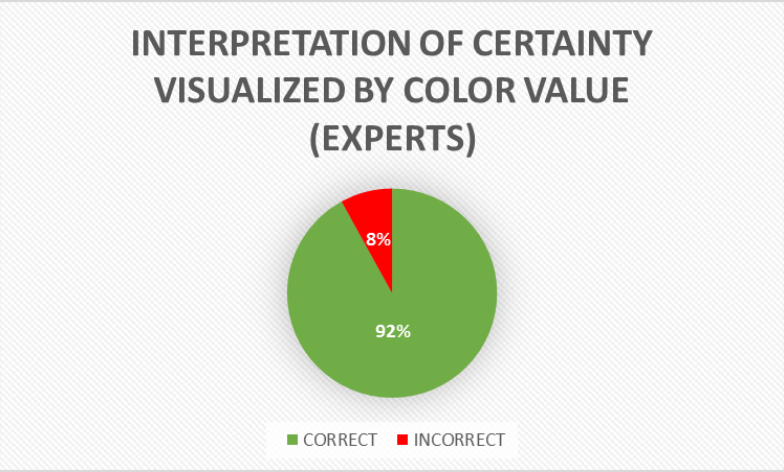
- **Experts versus novices' interpretation of certainty by texture overlay**

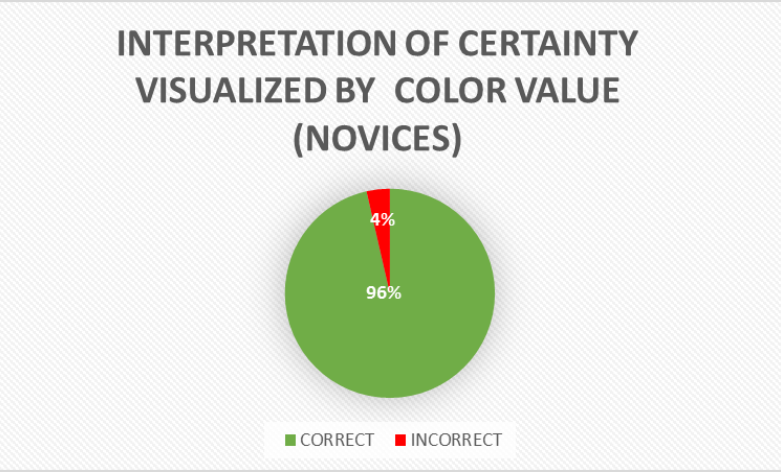




- ***Null hypothesis*: The event of being an expert/novice is independent of interpreting certainty represented by texture correctly/incorrectly**
- **Fischer exact test p-value of 0.6717 > 0.05 alpha**
- **Difference statistically insignificant**

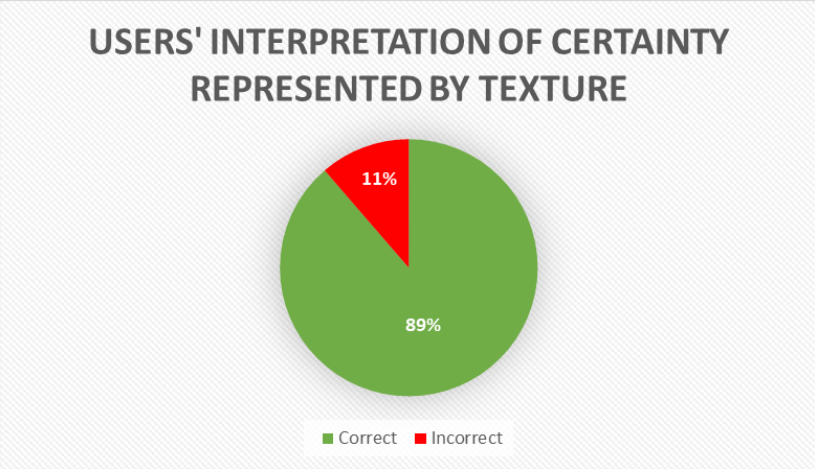
- **Experts versus novices' interpretation of certainty by color value**

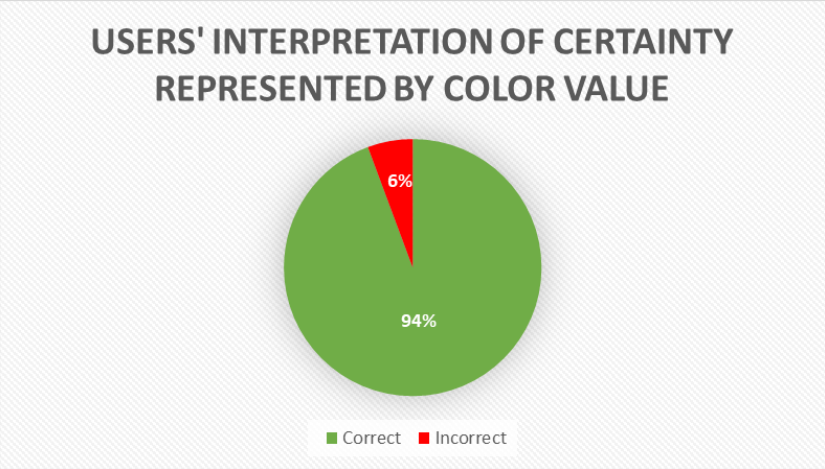




- ***Null hypothesis*: The event of being an expert/novice is independent of interpreting certainty represented by color value correctly/incorrectly**
- **Fischer exact test p-value of 0.5966 > 0.05 alpha**
- **Difference statistically insignificant**

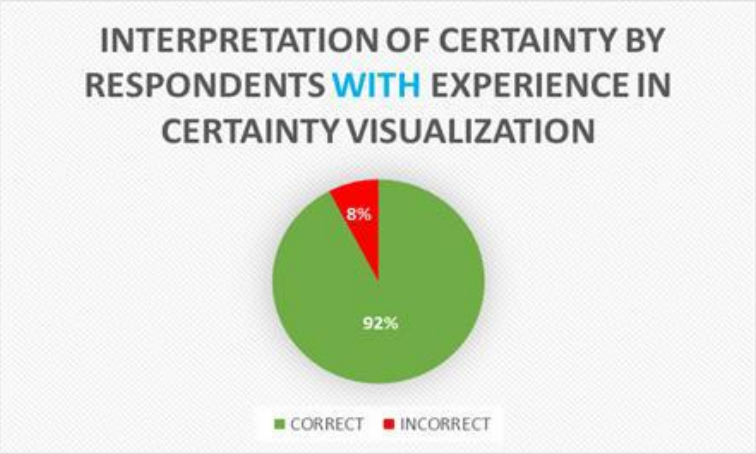
- **Comparison of texture overlay and color value interpretation**

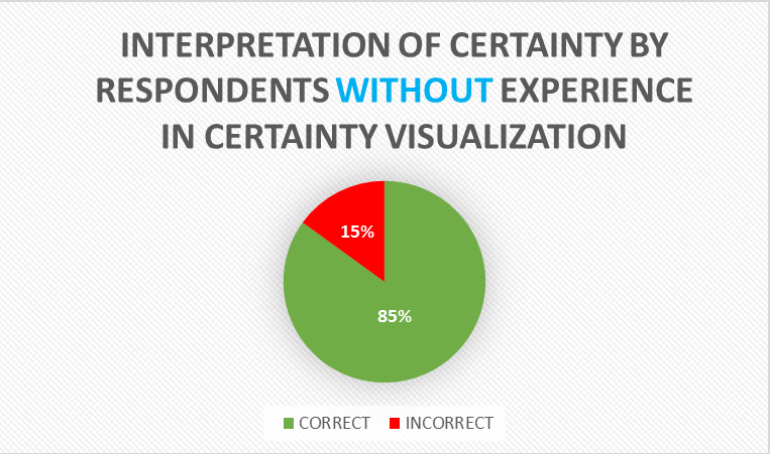




- ***Null hypothesis*: The interpretation of certainty correctly/incorrectly is independent of whether certainty is represented by texture overlay or color value**
- **Fischer exact test p-value of 0.16377 > 0.05 alpha**
- **Difference statistically insignificant**

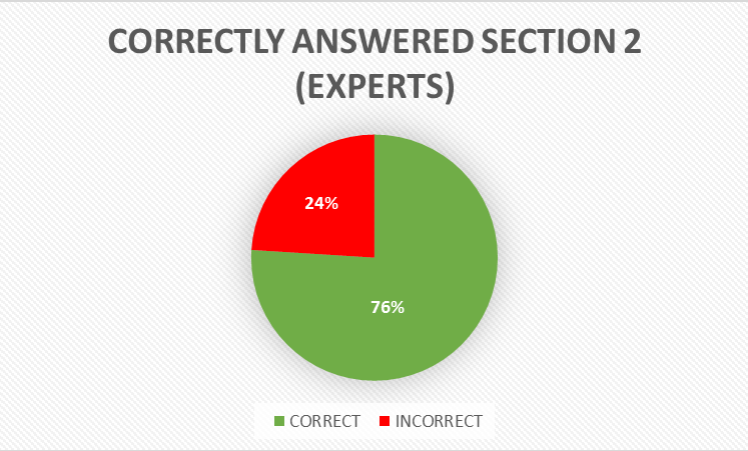
- **Users‘ experience versus inexperience in certainty visualization**

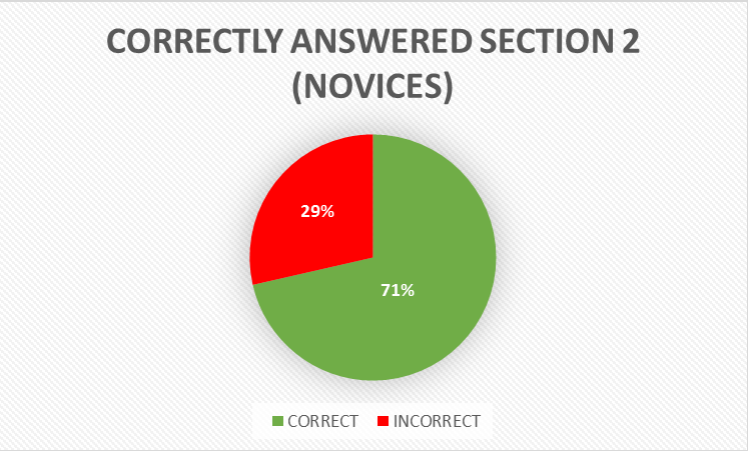




- ***Null hypothesis*: Interpretation of certainty represented by color value and texture is independent of a person´s previous experience with certainty visualization**
- **Fischer exact test p-value of 0.6670 > 0.05 alpha**
- **Difference statistically insignificant**

- **General reading and interpretation of flood risk and certainty (whole of section 2)**

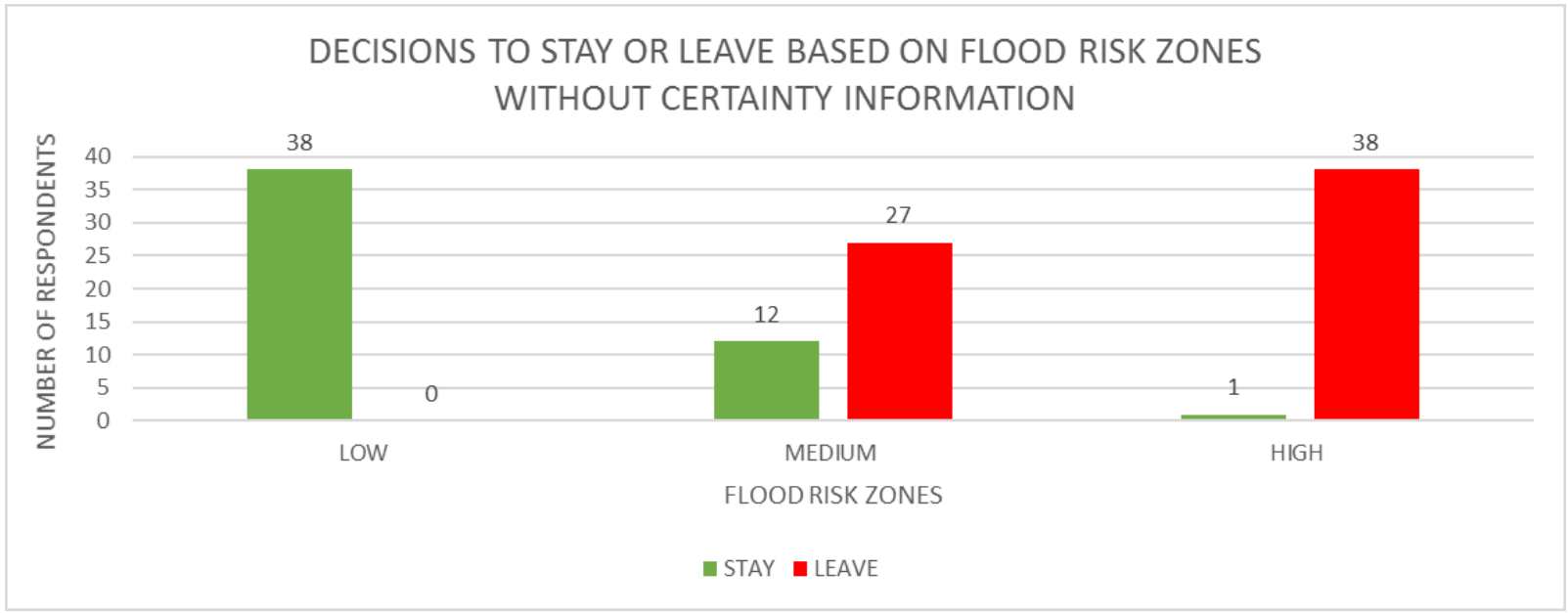




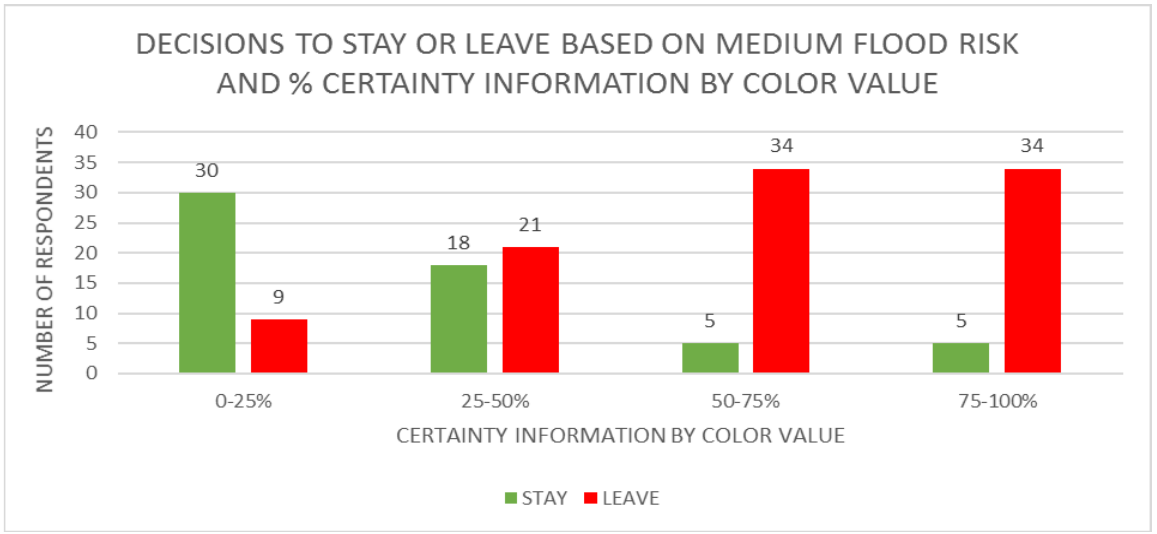
- ***Null hypothesis*: Reading and interpreting of flood risk maps and certainty information (represented by words, texture and color value) is independent of whether a person is a geography expert/novice.**
- **Pearson's Chi-square test p-value of 0.7062 > 0.05 alpha**
- **Difference statistically insignificant**

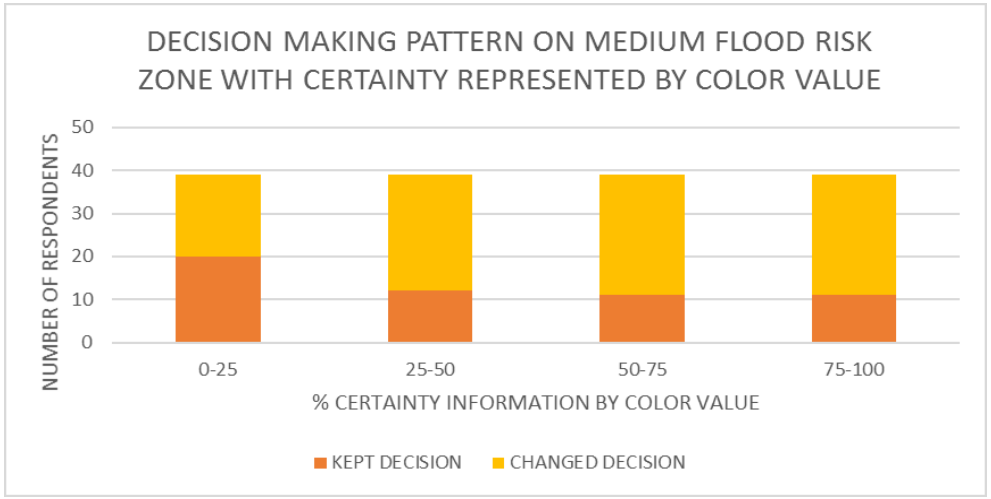
Section 3 – Decision making and confidence measures

- **Decision making without provision of certainty information**



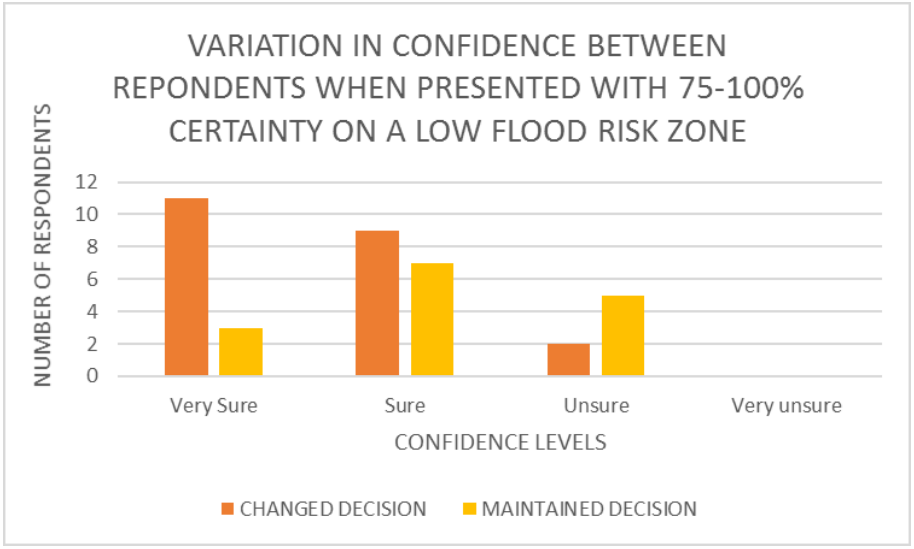
- **Decision making with provision of certainty information (medium risk zone)**





- **Inclusion of certainty caused changes in decisions in all the risk zones**

- **Confidence levels between respondents who changed versus those who maintained decisions given certainty information**
  - **Difference statistically insignificant except in low risk zone with 75-100% certainty**



  - **A Mann Whitney U test p-value of 0.0455 < 0.05 threshold**
  - **Respondents who changed decisions had higher confidence than those who maintained their decisions.**

- **Decision making by respondents with and without floods encounter**
  - **Fischer exact tests p-values > 0.05 in all zones**
  - **Differences in decisions between the two groups was statistically insignificant**

- **Respondents opinion on inclusion of certainty information in flood risk maps**
  - **96% recommended**
    - **"It allows for a wider range of grading for the flooding risk"**
    - **"It gives more confidence on the results after interpretation"**
    - **"So that an individual is sure to what extent the information presented is accurate"**
  - **4% discouraged**
    - **"It can be confusing at times"**

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CONCLUSIONS

Research findings

- **Which uncertainty visualization methods recommended by previous research are applicable to flood risk maps?**
  - **Intrinsic color value and extrinsic texture overlay**
- **Are the novices and experts user groups from Kenya able to understand and interpret uncertainty correctly?**
  - **Experts user group interpreted both techniques appropriately**
  - **Novices user group was better at interpreting color value than texture but the difference was statistically insignificant**
  - **Inexperience in uncertainty visualization did not hinder uncertainty interpretation**
  - **There was no difference in the decision making patterns between users with and without previous flood encounter**

- **Do the study users change decisions when presented with uncertainty?**
  - **Yes**
- **How does user confidence in decisions vary when presented with uncertainty?**
  - **There is potential for increased confidence in users whose decisions are influenced by the uncertainty**
- **The users recommended inclusion of uncertainty information on flood risk maps for better and informed decisions**

Limitations and recommendations

- **Limitations**
  - **The categorization of users into geography experts and novices is debatable**
  - **Decision to stay or leave was solely based on flood risk and uncertainty**
  - **Survey was rendered online, the colors may have appeared differently to users**

- **Recommendations for future research**
  - **Inclusion of additional base map information to the fictional maps**
  - **Test alternative uncertainty visualization techniques**
  - **Use of performance-based incentives to control user response**
  - **Involve a bigger user group**

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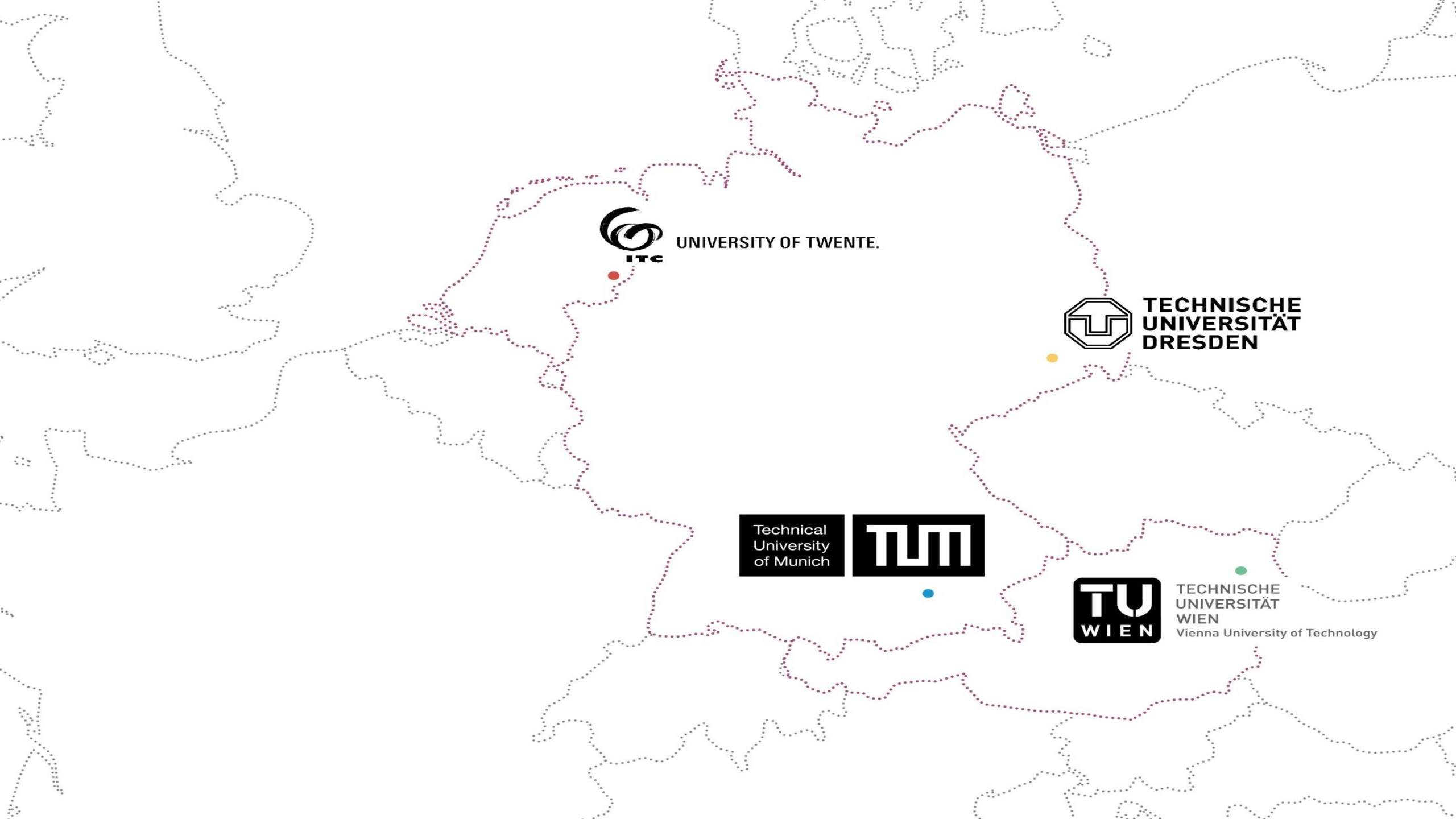
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